Climate Change Impact Assessment on Water Resources of Gumara Watershed, Upper Blue Nile Basin

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Abstract

Recently, there is growing scientific evidence that the global climate has changed, is changing and will continue to change. Climate change is also expected to aggravate current stresses on water resources availability due to rapid population growth and economic development. The major uncertainty in water resources management is the variability of water supply and demand pertaining to changes in climatic variables and in dynamics of river basins. Therefore, the water supply potential of a river basin is sensitive to land use and climate change. Hence, in many river basins steady climatic (stationary) conditions are no longer considered a valid assumption for sustainable water resources management. The case study was carried out on Gumara River where the government has proposed to construct a dam and diversion weir to irrigate 14100ha of land. The aim of this study was to assess the potential impact of climate change on the water resources of Gumara watershed using reliability, resilience and vulnerability indices. Generally, projected maximum and minimum temperature shows an increasing trend for the next century for all scenarios studied. However, the precipitation shows decreasing trend in case of the A2a and B2a scenarios and an increasing trend for the RegCM3-A1b scenario. It is also observed that the reliability index for all climate scenarios reveal above 91%, resilience index of above 96% and vulnerability of less than 30%. Hence, it is concluded that the proposed Gumara irrigation project has high capability to meet the required target demand in 2030s and 2090s, and also it recovers quickly from a failure to meet the demands and satisfying them. Based on the result of performance indices, the decision makers, concerned persons or any water users in the area can be assured that the proposed irrigation project has very good potential to irrigate the required area under 2030s and 2090s climatic condition.

Key words: Climate change, Water demand, Downscaling, HEC-HMS, Gumara watershed

Introduction

Recently, there is growing scientific evidence that the global climate has changed, is changing and will continue to change (NRC, 1998). The latest Assessment Report

(AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) projected that global average temperatures in 2100 will be 1.4-5.8°C higher than the 1980-2000 average. Sea levels are projected to rise 0.18-0.59m by 2100. In Ethiopia, the trend analysis of annual rainfall over the last 50 years shows that a declining trend has been observed over the Northern half and South-Western Ethiopia. It also reveals that there has been a warming trend in temperature. The average annual minimum temperature over the country has been increasing by about 0.25^{o}C every ten years while average annual maximum temperature has been increasing by about 0.1^{o}C every decade. It is interesting to note that the average annual minimum temperature is increasing faster than the average annual maximum temperature (MoWR and NMSA, 2001).

A major uncertainty in water resources management is the variability of water supply and demand pertaining to changes in climatic variables and in dynamics of river basins. The water supply potential of a river basin is therefore sensitive to land use and climate changes. Rapid population growth and economic development are also expected to put extra pressure on demand for water (Solomon, 2002). Hence, in many river basins, steady climatic (stationary) conditions are no longer considered a valid assumption for sustainable water resources management. Therefore, despite its significant computational effort, water resources studies at the river basin level are increasingly linked to regional climate studies. In addition to natural variability, which is incorporated in existing water planning methods, new water projects will have to deal with uncertainty associated with population growth and trends in climate change (Mohamed *et al*, 2005).

Despite its economic importance to the national economy and for the survival of the people around, the design study of the Gumara irrigation project does not consider the future climate impact on the proposed irrigation scheme. Although climate change is expected to have adverse impacts on socio-economic development globally, the degree of the impact will vary across nations. It is expected that climate change impacts are going to be most severe in the developing world like Ethiopia, because of their poor capacity to adapt to climate variability (Gosain *et al*, 2006). Besides, a large part of Ethiopia is arid and semiarid, and is highly prone to desertification and drought; climate change and its impacts are a cause for concern (MoWR and NMSA, 2001). In addition, both observed and Global Climate Models (GCMs) future scenarios suggest a recent amplification of climate contrasts across the globe (IPCC, 2007). Furthermore, most (Conway, 2005; Kim *et al* ,2008; Mohamed *et al*, 2005; Soliman *et al*, 2009 and Soliman *et al*,2008) of the studies made so far are mainly at the basin level. It is advisable to study the impact of climate change in sub-basin level (Yihun, 2009). Moreover, previous climate change impact studies in the Nile Basin have mostly focused on the effect on runoff and the consequences for downstream countries. However, climate change can affect multiple features of water resources, e.g., quantity and quality, high- and low-flow extremes, timing of events, etc (Kim *et al*, 2008).

Hence, assessing vulnerability of water resources to climate change at a watershed level is crucial, which gives an opportunity to plan appropriate adaptation measures that must be taken ahead of time and also to consider possible future risks in all phases of water resource development projects. The main objective of this study is to evaluate the impacts of future climate change on both hydrologic regime and water resources of the Gumara watershed. This study has used a statistical downscaling technique to downscale HadCM3, Dynamical downscaled RegCM3 outputs and a HEC-HMS hydrological model to simulate the possible impacts of climate change on the Gumara watershed. This technique may provide a valuable tool for future water resources management if climate trends, both observed and modelled, can be translated into hydrological impact.

Materials and Methods

Description of the Study Area

The Gumara River is located to the east of Lake Tana and has a total drainage area of about 1893km^2 and 1394km^2 above the gauging station at Gumara. After flowing for a length of 132.5 km, the river joins Lake Tana. It falls between latitude 11^{o}56 ! boe! 11^{o}66 ! O! boe! mpohjuvef! 48^{o}41 ! boe! 48^{o}61 ! F/! Ui f! x bufsti fe! dpot jtut! pg! svhhfe! boe! undulating topographies with different ridges, valleys and steep slopes which vary from 1790 up to 3700 m asl. The land-use of the study area is categorized as agricultural, agro-pastoral, pastoral and urban which constitutes 59%, 36%, 3.4% and 0.1% respectively. With regard to soil type, Vertisols and soils with vertic characteristics are the dominant soil groups. Chromic Luvisols, Orthic Luvisols, Chromic vertisols and Lithosols covers 56%, 26%, 14% and 2.2% respectively. The annual rainfall is relatively high in the watershed, ranging between 1145 mm and 1523 mm. The maximum and minimum monthly temperature varies between 23^{o}C-29.9^{o}C and 7^{o}C-14^{o}C respectively. Total population of the sub-catchment is 1.1 million (MoWR, 2008).

An earthen dam and a diversion weir will be built on the main tRibbutary of the Gumara river, the Sendega River before its confluence with the main stream for irrigation. The dam has a total catchment area of 385 sq. km at the proposed dam site and a capacity of $24Mm^3$. The proposed diversion will be located about 28km below the proposed dam and has an area of $1166km^2$. The diversion weir consists of 16.5 m long scouring sluice bays and 75m long ogee shaped weir, with a 2m wide divide wall in between. The full supply discharge is $19.7m^3/s$. The cultivable command area is 8940 ha on the left bank and 5160 ha on the right bank, total being 14,100 ha, which is 84% of the gross command area that can be irrigated by the proposed irrigation project.

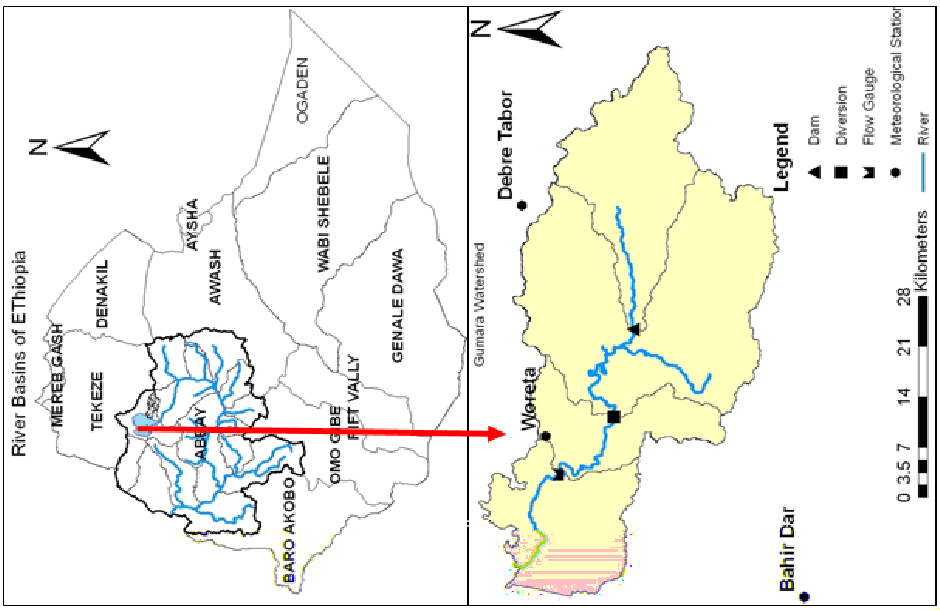

Figure 10-Location of the study area

Methods

The general steps followed in the study of climate change impact on the water resources of the study area are described below:

First, analysis was made of the observed data for the reference-period (1971-2000), checking the absence of trends and the stability of the mean using TREND-program (Simple and reliable time series analysis program to evaluate homogeneity, consistency and independence of data); filling in missed data using Autoregressive (AR) model and generate data using Long Ashton Research Station Weather Generator (LARS-WG) to extending records for stations that have a limited length of data. LARS-WG is a stochastic weather generator which can be used for the simulation of weather data at a single site (Semenov and Brooks, 1999; Semenov *et al*, 2002), under both current and future climate conditions. These data are in the form of daily time-series for a suite of climate variables, namely, precipitation (mm), maximum and minimum temperature (°C) and solar radiation ($MJm^{-2}day^{-1}$).

Then temporal climate change scenarios of precipitation, temperature, and Potential Evapotranspiration (PET) were developed using Downscaling Model from large-scale predictor variable information of GCMs. Based on the availability of public domain GCMs and time, the study used GCM scenarios of HadCM3 from UK Hadley Center and Regional Climate Model (RegCM). HadCM3, running under A2a and B2a emission scenarios (where A2a is referred as the medium-high emissions scenario and B2a as the medium-low emissions scenario), represent rainfall patterns in East Africa relatively well (McHugh, 2005). The main reason for the selection of this model for impact study is that the GCM output is available together with the downscaling tools called Statistical Downscaling Model (SDSM). Among the widely applied statistical downscaling techniques, the multiple linear regressions based model called Statistical Downscaling Model (SDSM) is used in this study. Statistical downscaling is based on the view that the regional climate is conditioned by two factors: the large scale climate state, and regional/local physiographic features (e.g. topography, land-use). From this perspective, regional or local climate information is derived by first determining a statistical model which relates large-tdbmf! dmjnbuf! wbsjbcmft!)ps! qsfejdupst‘ ! up! sfhjpobm boe! mpdbm wbsjbcmft!)ps! qsfejdubo et‘ /! Uifo! mbshf-scale output of a GCM simulation is fed into this statistical model to estimate the corresponding local and regional climate characteristics. One of the primary advantages of these techniques is that they are computationally inexpensive, and thus can be easily applied to output from different GCM experiments. Another advantage is that they can be used to provide site-specific information, which can be critical for many climate change impact studies. The major theoretical weakness of statistical downscaling methods is that their basic assumption is not verifiable, i.e. the statistical relationship developed for the present day climate also holds the different forcing conditions of possible future climates (Wilby *et al*, 2004)

Besides, the RegCM3 model nested with the ECHAM5 GCM were applied. The RegCM3 predictor variables are available for the A1b experiment. Soliman *et al* (2009) and Soliman *et al* (2008) calibrated and validated RegCM3 over the Blue Nile basin domain. While comparing the model results with different observational data sets, they found that the model was able to accurately simulate the climatology of the Blue Nile. The observed spatial and temporal pattern of temperature and the seasonality and spatial pattern of precipitation were well represented by the model outputs.

The predictand for statistical downscaling using SDSM are mean areal precipitation and temperature derived from Bahir-Dar, Debre-Tabor and Woreta stations using Inverse Distance Weight (IDW) method for the base period from 1971-2000, and PET calculated from the temperature using FAO Penman Monteith method. However, dynamically downscaled RegCM3 outputs are available only for the period 1991-2000, 2031-2040 and 2091-2099 at daily time steps. These data have been collected from IWMI-Ethiopia.

After selecting the hydrological model using the criteria of Cunderlik and Simonovic (2007) and Beven (2000), the HEC-HMS hydrologic model has been set-up and calibrated with climate and stream flow data that represent the current climate. Then, simulation of stream flow corresponding to future climate change scenarios has been made. Moreover, the simulated stream flow corresponding to the different time periods are analyzed to see if there is a trend in flow.

The impact of climate change on water consumption for some of these water uses is not yet clearly known. It is projected however, that climate change will increase irrigation water requirements due to increased potential Evapotranspiration for the doubling of CO_2 scenario. The Gumara irrigation project has been planned for cultivation of cereals, pulses, oil seeds and other horticultural crops. Therefore, the Irrigation requirement has been calculated based on the proposed percentage of land allocated for the different crops using CROPWAT by assuming that the proposed cropping pattern is the same in its design period whereas environmental flow requirement of the area is adopted from MoWR (2008). Finally, the climate impact is assessed for the period 2030s (2031-2040) and 2090s (2091-2100) using indices, these are *Reliability*, *Resilience and Vulnerability indices.*

Climate Impact Assessment Indices

The analysis of potential climate change impact on the water supply system requires simulation of the water balance under different climate scenarios. There are different measures for assessing system performance. This study used three performance indices that will be used to evaluate the climate change impact on reservoir comparatively, these are; *Reliability*, *Resilience and Vulnerability indices.*

1. Reliability

Reliability is defined as the probability that a water supply system will be able to meet, within the simulation period, the target demand in any given interval of time (often a year or a month). There are several measures of reliability, which are defined by Thomas et al (2004) as follows.

Time-based Reliability considers the proportion of intervals during the simulation period that the reservoir can meet the target demand. A general expression for estimating this metric is:

$$Rt = \frac{Ns}{N}; 0 < Rt \le 1 \qquad (1)$$

where Rt is the time-based reliability, Ns is the number of intervals that the target demand was fully met and N is the total number of intervals covering the historical or simulation analysis period. When the time interval is monthly or annual, we speak about a monthly or an annual time-based reliability, respectively.

Volumetric Reliability is defined as the volume of water supplied to a demand divided by the total target demand during the entire simulation period, i.e.

$$Rv = 1 - \frac{\sum_{i=}^{n}(D_i - D_i')}{\sum_{i=}^{n} D_i} = 1 - \frac{\text{Total Shortfall}}{\text{Total Target Demand}}; \; 0<\text{Rv}<1 \qquad (2)$$

where Rv is the volumetric reliability, D_i is the target demand during ith period, D_t' is the volume actually supplied during the ith period and n is the number of time intervals in the simulation, so that Rv=1 if D_i is totally satisfied, i.e. $D_i' = D_i$ for all i. It should be noted that Rv will always be equal to or greater than Rt because during a time interval in which a failure is recorded some release, although lower than the target demand, may still be made.

2. Resilience

Resilience is a metric defining how quickly a reservoir will recover from a failure. The measure adopted in this study is:

$$\varphi = \frac{fs}{fd}, \; fd \neq 0 \qquad (3)$$

where φ is resilience, *fs* is the number of individual continuous sequences of failure periods and *fd* is the total duration of all the failures, in other words, φ is the inverse of the average failure duration. Resilience is the probability of a year of success following a year of failure.

3. Vulnerability

The metric known as vulnerability measures the average volumetric severity of failure during a failure period.

$$\eta' = \frac{\sum_{j=1}^{fs} \max(S_j)}{fs} \tag{4}$$

Where η' is the vulnerability, S_j is the volumetric shortfall during j^th continuous failure sequence and *fs* is the number of continuous failure sequences.

Because Eq. (4) averages out the maximum shortfall over all the continuous failure periods, then a reduction in fs will cause η' to increase when the numerator in Eq. (4) remains unchanged. A practical situation where this may occur is when the reservoir capacity is increased, with all other factors remaining constant. One way to avoid this anomaly is to remove the averaging in Eq. (4). Another point to note about Eq. (5) is that η' is in volumetric units; a more useful expression of vulnerability is its dimensionless form given by:

$$\eta = \frac{\eta'}{Df}, \; 0 < \eta \leq 1 \tag{5}$$

Where η is the dimensionless vulnerability metric, known as the vulnerability ratio in this paper, and *Df* is the (constant) target demand during failure. (Note that *Df*=*D*, i.e. target demand is the same for drought and non-drought periods.)

Results and Discussion

Statistical Test and Weather Generation

Statistical tests were carried out for observed annual rainfall and temperature data (1971-3111 !gps!bc tfodf!pg!usfoe!x ju!Tqfbsn bo t!sbol -correlation method and by t-test for stability of mean using TREND-trend/change detection program. The result shows that minimum and maximum temperature shows an increasing trend whereas precipitation does not show any significant trend.

Because of the short record (1985-2000), data are generated for Woreta station using LARS-WG for the period 1971-1984 to fit the 30 years base period criteria. To evaluate the performance of LARS-WG model, the Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Percent Bias (PBIAS) indices are used as shown in Table 1. Singh *et al* (2004) state that RMSE and MAE values less than half the observed standard deviation (SDev) of the measured data may be considered low and that either is appropriate for model evaluation which is valid for this study. Moreover, Moriasi *et al* (2007) also indicates PBIAS less than or equal to ±15 is very good for model evaluation. Since all indices are within acceptable range, LARS-WG has shown a good performance that indicates representative weather data can be generated from limited data for the study area. Hence, precipitation, maximum temperature and minimum temperature for Woreta meteorological station are generated using LARS-WG for the period 1971 to 1984.

Table 5. Summary statistic and error indices for LARS-WG generated data

Error index	**Minimum Temperature**	**Maximum Temperature**	**Precipitation**
SDev	3.66	2.95	7.58
RMSE	1.65	1.29	3.13
MAE	1.80	1.38	3.42
PBIAS (%)	3.40	0.16	8.90

Future HadCM3 and RegCM3 Outputs

Once the downscaling model has been setup and validated, this model is used to downscale the future climate change scenario simulated by GCM. The statistically downscaled outputs from A2a and B2a scenario of HadCM3 and Dynamically downscaled outputs of RegCm3 are shown in Table 2. The study will not give any conclusion towards a preference for one or the other as the output comes from different GCMs with different downscaling techniques. Here, the 1990s observed scenario is used for comparing the GCMs and downscaling techniques performance whereas the 2030s and 2090s scenario are used to predict the future climate trend.

Table 6. HadCM3 versus RegCM3 future scenario

Scenario	Climate Variables	Changes in 2030s	Changes in 2090s
HadCM3-A2a	Precipitation	-6.3%	-10.6%
	Maximum Temperature	0.50^{o}C	0.98^{o}C
	Minimum Temperature	0.32^{o}C	1.17^{o}C
	PET	1.6%	2.8%
HadCM3-B2a	Precipitation	-5.1%	8.2%
	Maximum Temperature	0.27^{o}C	0.8^{o}C
	Minimum Temperature	0.31^{o}C	0.73^{o}C
	PET	1.6%	2%
RegCM-A1b	Precipitation	4.7%	3.0%
	Maximum Temperature	2.61^{o}C	5.89^{o}C
	Minimum Temperature	1.96^{o}C	5.11^{o}C
	PET	8.6%	17.8%

Note: the negative sign (-) shows that decrement

Hence, Table 2 shows that future precipitation may decrease at increasing rate in statistically downscaled HadCM3-A2a and HadCM3-B2a. However, it may increase at decreasing rate in RegCM3-A1b. Future Temperature and PET increase at increasing rate for all scenarios although the rate is higher for the RegCM3-A1b. It is also observed that precipitation is shifting towards October in the case of RegCM3.

HEC-HMS Hydrological Model Development

HEC-HMS calibration performed from 1993-2004, and validation was carried out from 1985-1990 using both daily and monthly time step. The flow data at Gumara gauging station was collected from hydrological department of Ethiopian Ministry of Water Resources. Model validation is used to determine the effectiveness of the parameterization and calibration methodologies. Moreover, efficiency criteria such as Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2), percent difference (D) and RMSE-observations standard deviation ratio (RSR) were used for evaluation of the performance of the model. A summary of HEC-HMS hydrological model development using a combination of Deficit constant loss, Clasl t! vojlu i zesphsbqi! transformation, monthly constant baseflow and Muskingum routing method is shown in Table 3. In general the model performed reasonably in simulating flows for periods outside of the calibration period, based on adjusted parameters during calibration.

Table 7. The result of model performance criteria

	NSE	R^2	D (%)	RSR
Calibration (1993-2004**)**	0.70 (0.88)	0.72 (0.89)	0 (0)	0.55 (0.35)
Validation (1985-1990**)**	0.73 (0.91)	0.73 (0.92)	-3.4 (-3.42)	0.52 (0.29)

Note: The value outside the bracket is for daily time step and those in brackets is for monthly time step

Hydrological Model Simulation corresponding to Climate Scenarios

The inflow to the Gumara gauge-station is generated by using the downscaled climate variable as an input to the HEC-HMS hydrological model. For comparison purpose the generated flow is compared with the current (1991-2000) mean monthly observed flow.

Table 8. Changes in flow and climate variables

Period	Flow (%)	Precipitation (%)	Temperature (^{o}C)	PET (%)
	HadCM3-A2a Scenario			
2030s	-9.1	-6.3	0.31	1.6
2090s	-16.4	-10.6	0.97	2.8
	HadCM3-B2a Scenario			
2030s	-8.3	-5.1	0.29	1.6
2090s	-14.2	-5.7	0.63	2.0
	RegCM3-A1b			
2030s	4.1	4.7	2.3	8.6
2090s	3.2	3.0	5.5	17.8

Relative to the 1991-2000 (1990s) condition, the simulated future inflow to the gauge, based on the HadCm3-A2a scenario, shows an average annual decrease in volume by 9.1% in 2030s and 16.4% in 2090s. This may be due to the increment of future temperature, and reduction in future precipitation. In case of HadCM3-B2a scenario, the inflow projected to decrease by 8.3 % in 2030s which exhibits an average annual absolute temperature increase by 0.29^{o}C, PET increased by 1.6% and the precipitation decreased by 5.1% in the same time horizon, While in 2090s, the inflow volume decreases by 14.2% where the absolute annual average temperature increased by 0.63^{o}C, PET increased by 2% and the precipitation decreased by 5.7%. Considering RegCM3, the inflow projected to increase by 4.1% in 2030s which exhibits an average annual temperature increase by 2.3^{o}C, PET increased by 8.6% and the precipitation increased by 4.7% in the same time horizon, while in 2090s the inflow volume increases by 3.2% where the absolute annual average temperature increased by 5.5^{o}C, PET increased by 17.8% and the precipitation increased by 3% as shown in Table 4.

Climate Impact Evaluation: the Performance Indices

The values of the performance measures were computed after generating the inflow to the Gumara storage dam and Diversion weir. It is examined under the standard operation policy of the reservoir i.e.the target demand is fully supplied whenever sufficient water exists; otherwise all the available water is put into supply and the reservoir is left empty. Based on the availability of dynamically downscaled RCM outputs, both current (1990s) and future (2030s and 2090s) generated inflow are considered when quantifying the performance indices. The target demand consists of irrigation water demand and downstream release or environmental demand for the same period.

The averaged time-based reliability and volumetric reliability of the Gumara Irrigation Scheme reveals a value of about 90% and above 92% for all scenarios in both time periods respectively. The result value of above 80% tells that there exist very good potential at the site to meet the demand in terms of time as well as volume. Resilience indicates how quickly a system will recover from a failure. The resilience analysis result in Table 5, value about 100% for all scenarios and time periods, shows that the irrigation scheme recovers quickly for all scenarios in its design period. The volumetric vulnerability, which indicates the average of maximum volumes of shortages, reveals that the shortage is found within the ranges from 3.33Mm3 to 3.44Mm^3 for A2a and B2a scenarios, and 3.45 to 4.4Mm^{3}for the RegCM3 scenario. Comparing the scenarios, the maximum shortage occurred in RCM scenario where the temperature exhibits average increase.

Table 9. Results of performance indices

Scenario	**Period**	**Rt(%)**	**Rv(%)**	**φ(%)**	**η(Mm3)**	**$\acute{\eta}$**
Current	1991-2000	83.8	95.0	100	2.92	0.33
HadCM3 A2a	2030s	91.7	97.0	100	3.41	0.28
HadCM3 B2a	2030s	91.7	97.1	100	3.35	0.27
RegCM3-A1b	2030s	91.7	95.1	100	3.45	0.30
HadCM3-A2a	2090s	89.1	92.4	100	3.44	28.7
HadCM3-B2a	2090s	89.1	93.0	100	3.33	27.5
RegCM3-A1b	2090s	91.7	95.1	100	4.40	0.33

Conclusion

The performance of the Gumara reservoir and diversion weir under the climate change is quantified by using the reliability, resilience and vulnerability indices (RRV-criteria). Based on the study, the following conclusions are drawn as: LARS-WG has shown a good performance that indicates representative weather data can be generated from limited data for the study area. In addition, projected temperature shows an increasing trend for the next century. However, the precipitation shows decreasing trend for A2a and B2a outputs whereas it will increase in case of the ReCM3 output. It is also concluded that the HEC-HMS model is able to capture daily and monthly patterns that can be proven by NSE, R^2, D and RSR values. Hence, HEC-HMS is able to accurately explain the hydrological characteristics of the Gumara watershed. with regard to the inflow of the proposed dam. The average annual inflow volume will decrease for the A2a and B2a scenarios but increase for the RegCM3 scenario for both the 2030s and 2090s. Since a Reliability of about 90% and a Resilience of 100% is found, it is concluded that Gumara reservoir and weir has high capability to meet the required target demand in the 2030s and 2090s in terms of time as well as volume. Moreover, the supply system will recover quickly from a failure to meet the demand to satisfying the target draft. Hence, the proposed scheme has very good potential to irrigate the required area in its ljgf! qfsjpe t! dmjn bujd! dpoejujpo! x jui! uif! dpotjefsbujpo! pg! eftdsjcfe! limitations.

Based on the findings and limitations noted in this study, the following research gaps were drawn. The GCM outputs, the emission scenarios and the downscaling methods used have certain level of uncertainty. Therefore, further study should reduce the uncertainty by using additional GCMs, downscaling methods and emission scenarios for longer period (rather than only for 2030s and 2090s) to get better result. Besides, the study can be extended by considering change in land use, soil type and other climate variables in addition to temperature and precipitation. Future research should also include adaptation options to climate change. Finally, to make the evaluation of climate change impact more complete, it is appreciable to use addition of other performance indices, such as ratio of AET to PET, Drought Risk Index (DRI) and Sustainability Index (*K*).

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References

Beven, K.J., (2000). *Rainfall-Runoff Modelling*. The Primer, *John Willey and Sons, New York*

Conway, D. (2005). From *headwater tRibbutaries to international river*: *Observing and adapting to climate variability and change in the Nile Basin*. Global Environmental Change 15: 99-114.

Cunderlik, J. M. and. Simonovic, S. P, (2007): *Hydrologic Models for Inverse Climate Change Impact Modeling*, the 18th Canadian Hydrotechnical Conference on Challenges for Water Resources Engineering in a Changing World, Winnipeg, Manitoba, August 22-24, 2007.

Gosain, A. K.; Sandhya Rao and Debajit Basuray (2006): *Climate change impact assessment on hydrology of Indian River basins*. CURRENT SCIENCE, VOL. 90, NO. 3, 10

IPCC (2007): *Climate Change 2007: Impacts, Adaptation and Vulnerability*. ContRibbution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson(Eds.), Cambridge University Press, Cambridge, United Kingdom, pp. 976.

Kim, U.; Kaluarachchi, J. J.; Smakhtin, V. U. (2008). *Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin, Ethiopia.* Colombo, Sri Lanka: International Water Management Institute. 27p (IWMI Research Report 126)

LARS-WG stochastic weather generators for diverse climates. *Climate Research* 10, 95-107.

McHugh M J (2005): *Multi-model trends in East African rainfall associated with increased CO2*. Geophysical Research Letters 32, L01707.

Moriasi, D. N.; J. G. Arnold, M. W.; Van Liew, R. L;. Bingner, R. D.; Harmel and T. L. Veith (2007): *Model Evaluation Guidelines For Systematic Quantification of Accuracy in Watershed Simulations*. American Society of Agricultural and Biological Engineers, Vol. 61)4 !996 : 11

Mohamed, Y. A.; Van den Hurk, B. J. J. M.; Savenije1, H. H. G.; and Bastiaanssen, W. G. M.(2005): *Hydroclimatology of the Nile: results from a regional climate model*. Hydrology and Earth System Sciences, 9, 263 278, 2005

MoWR (2008): *Gumara Irrigation Project Feasibility Study Report, Main Report, Ministry of Water Resources (MoWR)*, February 2008, Addis Ababa, MoWR and NMSA (2001): *Climate Change National Adaptation Programme of Action (Napa) Of Ethiopia*. Abebe Tadege (Edt), The Federal Democratic Republic Of Ethiopia Ministry Of Water Resources And National Meteorological Agency

Semenov M.A. and Barrow E.M.(2002): LARS-WG: A Stochastic Weather Generator for Use of Climate Impact Studies, User Manual, V3

Semenov, M. A., Brooks, R. J., Barrow, E. M., and Richardson, C. W. (1998): Comparison of the WGEN and

Singh, J., H. V. Knapp, and M. Demissie (2004): *Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT*. ISWS CR 2004-08. Champaign, Ill.: Illinois State Water Survey.

Soliman, E.S.A, M. A.A. Sayed, and Marc Jeuland (2009): *Impact Assessment of Future Climate Change for the Blue Nile Basin, Using a RCM Nested in a GCM*. Nile Basin Water Engineering Scientific Magazine, Vol.2

Soliman, E.S.A., M.A.A. Sayed, M.M. Nour El-Din, and G. Samy (2008): *Integration of NFS with Regional Climate Model to Simulate the Nile Basin Hydro-climatology*, Nile Water Science & Engineering Magazine 1.

Solomon Seyoum Demissie (2002): *Assessing the Reliability of Water Yield of a River Basin. National Hydrology Seminar 2002*: Water Resource Management: Sustainable Supply and Demand Programme and Papers, National University of Ireland, Galway

Thomas A. McMahon, Adebayo J. Adeloye and Sen-Lin Zhou (2004): *Understanding performance measures of reservoirs* Journal of Hydrology 324 (2006) 359 382

Wilby R.L, S.P. Charles, E. Zorita, B. Timbal, P. Whetteon and L.O. Mearns (2004): Gudelnes gps! Vtf! pg! Dm buf! Tdfobsjpt! Efwfmpqfe! gspn! Tubujtujdbm!Epxotdbmjoh! Nfuipet/! Tvqqpsting n bufsjbm! pg!uif! J DD

Yihun Dile (2009): *Hydrological Modeling to Assess Climate Change Impact at Gilgel Abay River, Lake Tana Basin ,Ethiopia*. MSc thesis done for the partial fulfillment of the requirements of the Master of Science degree at Lund University, Lund, Sweden