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Evaluation of Climate Change Impact on Stream Inflow of Mai-Nefhi Catchment

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Abstract - *This study was conducted on Mai-Nefhi catchment area, Eritrea, to model the hydrology, water balance and monthly stream inflow for projected climate change parameters. Meteorological, hydrological and temporal data was collected from various stations available in the catchment area for period of 15 years (1972-1986). First nine years (1972-1980) data was used to simulate the watershed with SWAT interface in ArcGIS and calibrated with SWAT-CUP. Next six years (1981-1986) data was used for model validation. The impact of climate change on streamflow in the Mai-Nefhi watershed was analysed with projected rainfall and temperature changes for the periods 2011-2040 (20's), 2041-2070 (50's) and 2071- 2100(80's). Five global climate models (GCM) under three greenhouse gas emission scenarios, A1B, A2 and B1 were used for analysis. Although these models predicted an increase in monthly precipitation, the hydrological simulation show less changes in annual streamflow volume. Main reason for this is short rainy months and temperature rise. The predicted monthly stream flow for future periods present decreasing and increasing tendencies ranging between -19% and +300% respectively. All scenarios during 20's, 50's and 80's period present increasing tendencies in annual average stream flow, ranging between 11% and 34%. This is because the percentage increase in precipitation during dry months will have less effect on streamflow, as base line precipitation shows little or no rainfall. These study findings can be used by Asmara water supply authority to manage water resources in Mai-Nefhi catchment efficiently.*

Key words: *Hydrologic Modelling, SWAT, Climate change impact, Mai-Nefhi Watershed, water balance, Eritrea*

1. INTRODUCTION

Global advances in economies and living standards have resulted in a growing dependency on water resources [1]. Changes in many components of the hydrological cycle such as precipitation, air temperature, evapotranspiration, and stream flow are direct effects of climate change. The magnitude of such changes and their variability both in time and space has great impact on the water resources of a region especially in developing countries, because of their poor capacity to cope up with the climate change[2]. Africa's population depends to a large extent on natural resources. This dependency, coupled with fragile governance capacities could result in severe problems in addressing the challenges of climate change. This will need effective and sustainable water resources management and adaptation strategies in short , medium and long term [3]. Climate change is characterized not only by rises in surface temperatures and sea-level, but also changes in precipitation and decreases in snow cover [4]. Such change in climate will have a negative impact on the socio-economic development of society. Climate variability and change are expected to alter regional hydrologic conditions and result in variety of impacts on water resource systems throughout the world [2] . Eritrea is not endowed with water resources and it normally characterised as a water-stressed country. The report, UNDP-country Profile for Eritrea, stated that mean annual temperature has increased by 1.7°C since 1960, an average rate of 0.37°C per decade with the most rapid in July, August and September at a rate of 0.55°C . Further, the report indicates that rainfall has been declining for central and southern highlands on average by 0.4 mm/year[5]. Given the vital role of water resources in socio-economic development, the potential hydrological impacts of climate change pose a significant challenge for water resource planning and management. Consequently, impacts of climate change have been widely studied, mainly using water balance models coupled with General Circulation Models, GCMs [6]. Though There is a high degree of uncertainty in predicting the impact of climate change on precipitation with GCMs [7], [8] due to coarse resolution (1-4 degree equivalent to 100-400 km), The [4] Emissions Scenario Special Report states that the GHG scenarios are alternative images of how the future might unfold and that they are important tools in climate change analysis, including climate modelling and the assessment of impacts, adaptation, and mitigation. Many studies conducted on availability of water in future reviled that there is high stress on accessibility of water for future generations due to hydrological changes caused by climate variations [7], [9]–[13]. The projection [4] report shows that by 2020, between 75 and 250 million of people in Africa will be exposed to increased water stress due to climate change.

Simulations of the water balance dynamics of catchments are needed for addressing a number of engineering and environmental problems such as assessing anthropogenic effects on water quantity and quality, estimating design values and streamflow forecasting [14]. The selection of a model to adequately simulate stream flows in the watersheds depends mostly on the availability of field data, model input requirements, ease of applying the model, and the capability of the model to be properly calibrated. In water resources, simulation models can be statistical or process oriented, or a mixture of bot. Since the advent of highly powerful computers most simulation models combine features of both of these extremes [15]. The hydrologic simulation model, Soil and Water Assessment Tool (SWAT) was chosen for this study as it includes many useful components and functions for simulating the water balance and the other watershed processes such as water quality, climate change, crop growth, and land management practices. Furthermore, the SWAT model was adopted in this study because the efficiency and reliability of the model has already been tested in several studies carried out on catchments areas around East Africa such as Ethiopia and Kenya with very good and encouraging outcomes [16]–[18]. The calibrated SWAT model was used to simulate the impact of climate change on the stream flow of Mai-Nefhi river using five climate change models and three greenhouse emission scenarios up to the end of this century.

One of the main objectives of this study is to evaluate the climate change impacts on the future water balance components of the Mai-Nefhi river watershed, which is one of the most important sources of water for Asmara City. In order to accomplish this objective, SWAT, a distributed hydrologic model has been used. Modelling of the effect of climate change on river discharge is usually achieved either by direct use of climate model data in hydrological models or by changing existing climate data series with expected changes [19]. In this study, future climate projections simulated by the regional Climate Model PRECIS under A1B, A2 and B1 scenario were used as input to SWAT to project future stream flow changes. The purpose of the research is to provide insight into the magnitude of stream flow changes that might occur in the Mai-Nefhi river watershed as a result of future projected climatic change in temperature and precipitation. The information is also critical for the development of water resources management strategies and policies as well as possible adaptation strategies.

STUDY AREA DESCRIPTION

The study area is located in central region and capital city of Asmara, Eritrea, lies between Longitude of 38.7oE to 39.0oE and Latitude of 15.2^{o}N to 15.6^{o}N (Fig.1). This region has five surface water reservoirs namely Mai-Nefhi, Toker, Adi-Sheka, Stretta-Vaudetto and Mai-Sirwa, (Fig.2). The overall surface area of whatershed covers around 770 km2 and catchment area, capacity of each reservoir, given in (Table 1). Elevation of the catchment range from 1780 m to 2600 m above Mean Sea Level. The mean annual temperature in this region is 15-18^{o}C while the mean annual rainfall is around 500 mm. The central region of Eritrea experiences one main wet season from end of June to mid-September (up to 250 mm per month in the wettest regions), but also a 'short' rain season of lighter rainfall in the preceding months of April and May. While the northern most and eastern most parts of Eritrea receive little rainfall [5]. In most parts of the country, rainfall is available for few months of the year and displays strong seasonality and spatial variability making the country prone to recurrent droughts and climate change.

Table 1 Catchment areas and reservoirs developed for Asmara water supply

Reservoir Name	Catchment Area (Km^2)	Maximum Storage Capacity (MCM)	Depth (m)
Adi-Sheka	37.5	5.4	33
Mai-Sirwa	8	2.2	13
Stretta-Vaudetto	15.8	1.8	12
Toker	69.8	13.5	38
Mai-Nefhi	94.5	26	35

The remaining months are characterized as dry season. Although the rainy season extends from June to September, more than 70% of the total annual rainfall is received during the months of July and August. In this study, Mai-Nefhi watershed was taken for hydrological modelling and it covers areas mostly to the south east of the Central Region. The water from this catchment area is collected at Mai-Nefhi dam located at a distance of about 25 km south east of Asmara. Mai-Nefhi dam reservoir has a capacity of 26 MCM and in operation since 1972. The Mai-Nefhi catchment area is estimated around 95 km^2 and covers the area to the south and south-west of Asmara. It has the largest capacity and acts as major source of water supply to the Asmara city. The dominant land use categories (Fig. 3) in this basin are agricultural land (49%), grazing land (36%) and built-up (12%) while plantation and water body account for about 3%. Updated and processed spatial soil data layers were also collected from Water Resources Department of MoLWE. Combosols and vertisols (Fig.4) are the most predominant soil classes in the study area.

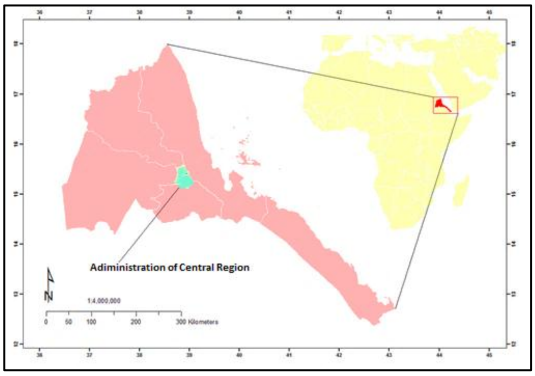

Fig. 1. Eritrea and Central Regional Administration

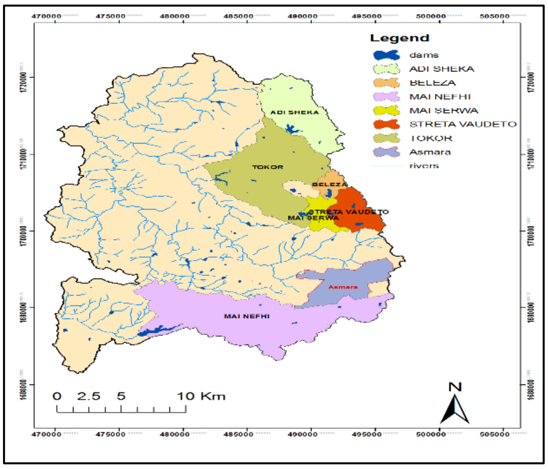

Fig. 2. Catchment areas developed for Asmara water supply

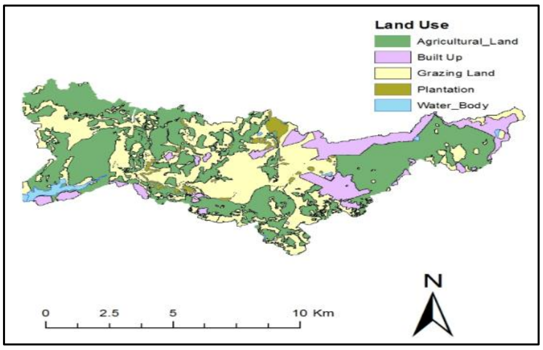

Fig. 3. Land use classification (FOA) for Mai_Nefhi watershed

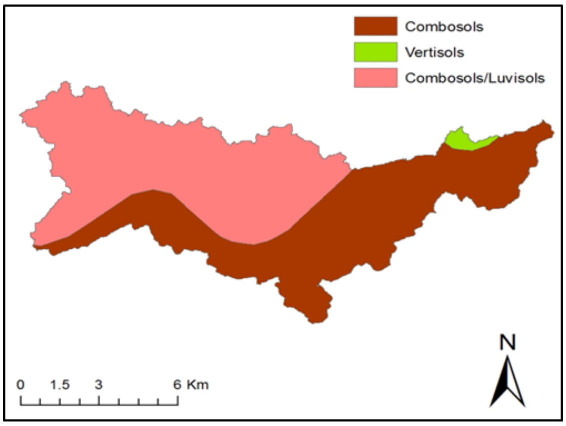

Fig. 4 Soil Classification of study area

MATERIALS AND METHODS

Data Collection

In this study, hydro-metrological, spatial and temporal data were obtained from Asmara International Airport Meteorological Station, to setup the model for Mai-Nefhi basin. This is the only station within this watershed with daily weather data of precipitation, temperature (maximum and minimum), relative humidity, wind speed and sunshine hours. The Mai-Nefhi river basin is ungagged and measured stream flow data was not available and the stream flow values were measured from daily water level (volume) changes of the Mai-Nefhi reservoir located at the outlet of the river.

The climatic data is fundamental model input of SWAT but in many areas of the world the measuring station network is not very dense and the time periods with measured data are short and/or have many missing and sometimes even erroneous data [20]. Lack of reliable measured data is one of the most common problems hydrologists face in developing countries especially in Africa.

Records for the period of 15 years observed for the study, out of which data of first nine years (1972-1980) was used for model simulation and next six years' (1981-1984) data was used for model validation. Spatial data includes Digital elevation model (DEM) with spatial resolution of 30 m. The topographic parameters such as terrain slope, channel slope or reach length were also generated from the DEM (Fig. 5).

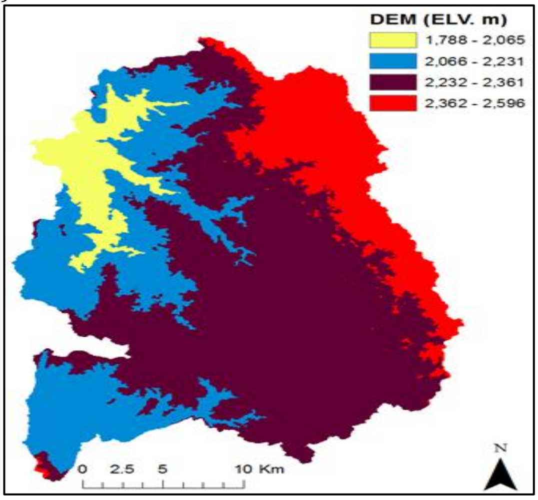

Fig. 5. Digital Elevation Model (DEM) of Central Regional Administration

Soil and land use maps were also obtained from Department of Water Resources, Ministry of Land, Water and Environment (MoLWE) of Eritrea. Digital soil map was developed by Food and Agriculture Organization, United Nations (FAO-UN) soil and terrain database for East Africa (FAO, 2006). Besides the observed weather data, rainfall data was extracted from remotely sensed satellite data provided by Famine Early Warning System (FEWS) and Daily Rainfall Estimate (RFE). The RFE rainfall data was obtained from 1st January, 2001 to 31st December, 2012. To check the accuracy of this data, a comparison against observed rainfall records with original data for same period. The result showed acceptable correlation ($R^2 \approx 0.80$) between two data sources. Long term monthly and annual climatic parameters (Table 3) were collected at Asmara International Airport meteorological station. The total mean annual rainfall is around 480 mm. Unlike precipitation, the mean monthly temperature in Asmara does not show substantial variability and the daily mean is rarely higher than 16^{o}C. (Fig. 6), shows the average monthly depth of rainfall in mm and mean monthly temperature in Asmara. As far as water resources is concerned the only months with excess rainfall producing exploitable runoff are the wet months of July and August. The small precipitation amounts recorded in the other months are mostly lost by evaporation without creating any significant runoff.

Table 2 Best parameters ranked from sensitivity analysis

Rank	Parameter	Description
1	SOL_Z	Soil depth (mm)
2	CN2	initial SCS runoff curve number for moisture condition II
3	GWQMN	Threshold water depth in the shallow aquifer for flow (mm)
4	ESCO	soil evaporation compensation factor
5	SOL_AWC	Available water capacity (mm H_2O)
6	BLAI	Maximum potential leaf area index
7	CANMX	Maximum canopy storage (mm)
8	ALPHA_BF	Base flow alpha factor (days)
9	REVAPMN	Threshold water depth in the shallow aquifer for 'revap' (mm)
10	GW_REVAP	Groundwater 'revap' coefficient

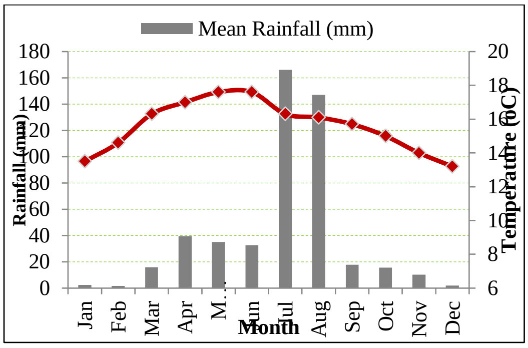

Fig. 6. Mean monthly rainfall and temperature values of Asmara

Sensitivity Analysis

The parameter sensitivity analysis was done using the Arc SWAT interface for the whole catchment area. The sensitivity analysis method used in Arc SWAT interface combines the Latin Hypercube simulation and the One-factor-At-a-Time sampling. Twenty-six hydrological parameters were tested for sensitivity analysis for the simulation of the stream flow in the study area. Here, we used the default lower and upper bound parameter values. (Table 2) represent ten most sensitive parameters resulted from the sensitivity analysis.

3.3 SWAT Model setup

SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying land use and management conditions over a long periods of time [21]. It is physically based and semi-distributed model developed for continuous simulation on a daily time step. SWAT allows simulating the major watershed processes and has the capacity to simulate physical processes such as stream flow, sediment transport and agrochemical yields.

Digital elevation model (DEM), weather data, soil data and land use/land cover data are the most important data input for the setup of the SWAT model and for the simulation of the hydrological components [22]. One of the main goals of SWAT model is to predict the impact of land management practices on water quantity and quality over long periods of time for large complex watersheds that have varying soils, land use and management practices [21].

SWAT can be broken into two major components: a land phase, and a routing phase. The land phase of the model distributes the incoming precipitation between the possible hydrologic pathways (all units are mm per unit area) through the water balance equation. No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed (Netsch, Arnold and Kiniry). The hydrologic cycle is simulated by SWAT model based on the following water balance equation.

$$SW_t = SW_o + \sum_{i=1}^{t} R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}$$

where: t is the time in days, SWt the final soil water content (mm), SWo the initial soil water content (mm), Rday is amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), Qgw is the amount of return flow on day i (mm).

The first step in using SWAT model is to generate stream network and sub-basins within the study area and then to delineate the watershed based upon the Digital Elevation Model (DEM), which is the topographic characteristic of the area, and the outlet selected by the user.

The next step is the creation of homogeneous areas called hydrologic response units (HRUs) that GIS derives from the overlaying of slope, land use and soil layers. This is basically dividing the basins into smaller pieces each of which has a particular soil/land-use/slope range combination.

The model parameterisation for Mai-Nefhi catchment area was derived using the ArcMap GIS interface for SWAT2009, which provides a graphical support for the disaggregation scheme and thus facilitates the data handling. First, the whole watershed was delineated using the DEM and with an outlet at the location of the dam. In the next step, land uses and soils were characterized and overlaid to the watershed. This resulted in subdivision of the watershed into 21 sub-basins (Fig. 7). Finally, the weather input files were created, after defining the sub-basins based on dominant land use, soil, and slope.

Table 3 Mean monthly climatic parameters for Asmara city

Month	Mean Rainfall (mm)	Temperature (°C)			Mean RH (%)	Mean WR (Km/Day)	Mean SH (hours/Day)
		Mean Max	Mean Min	Mean			
January	2.4	22.3	4.3	13.5	53.8	257.0	9.4
February	1.7	23.8	5.1	14.6	47.6	284.0	9.3
March	15.8	25.1	7.5	16.3	46.0	285.0	8.9
April	39.5	25.1	8.7	17.0	49.3	310.0	8.8
May	35.0	25.0	10.2	17.6	48.1	302.0	8.3
June	32.6	24.9	10.5	17.6	47.5	269.0	7.3
July	166.0	21.6	10.8	16.3	76.4	289.0	4.9
August	147.0	21.5	10.7	16.1	79.7	250.0	5.2
September	17.8	22.9	8.6	15.7	59.4	242.0	7.1
October	15.6	21.7	8.1	15.0	63.1	336.0	8.8
November	10.2	21.5	6.6	14.0	66.3	292.0	9.2
December	1.9	21.5	4.8	13.2	61.1	272.0	9.1
Total	483	*23.1*	*8.0*	*15.6*	*58.2*	*282.3*	*8.0*

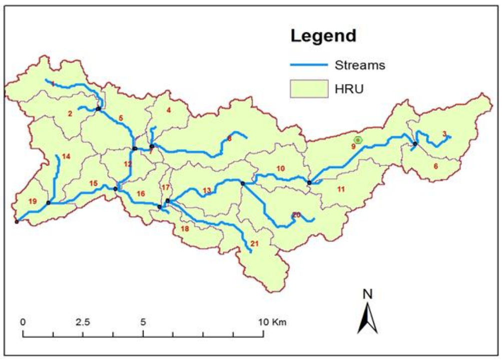

Fig. 7. Delineation of sub-basins

Model calibration and validation

The hydrological model efficiency mainly depends on quality of calibration [23]. The SWAT model can be calibrated in two ways either manually and automatically or combination of both [24], [25]. For present work, the estimated average monthly observed volume inflow to the Mai-Nefhi reservoir during the period 1972-1980, has been used for calibration of the model. This was carried out using SWAT-CUP SUFI-2 (Sequential Uncertainty Fitting version 2) program for a combined optimization-uncertainty analysis. SUFI-2 is a multi-site, semi-automated global search procedure and quick calibration can be done [26]. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data (Abbaspour). The validation has been done thereafter to evaluate the performance of the model with calibrated parameters to simulate the model. The temporal daily data used to set up the SWAT model in Mai-Nefhi covers 15 years (1972- 1986). The first nine years (1972-1980) were used to simulate the watershed with SWAT and calibrate with SWAT-CUP. The next four years (1981-1984) for model validation. Statistical measures such as the Nat-Sutcliffe Efficiency (NSE) and the Correlation Coefficient (R^2) were used to describe and compare the observed and simulated data sets.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2} \right] \qquad R^2 = \frac{\sqrt{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}}{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2}$$

Where, Y_i^{obs} is the ***ith*** observed streamflow, Y_i^{sim} the ***ith*** simulated value, Y^{mean} the mean of observed data and n is the total number of observations.

Climate Change Models and Scenarios

Important components of water balance for the future periods were estimated by developing and testing distributed hydrologic model (SWAT) with downscaled IPCC climate information. The impact of climate change has been analysed with projected rainfall and temperature changes for the periods 2011-2040 (2020s), 2041-2070 (2050s) and 2071-2100 (2080s), in relation to the current and historical climatic conditions. The data for these periods were obtained from spatially downscaled climate projections derived from the Canadian Climate Change Scenarios Network (CCCSN). Five Global Circulation Models (GCM) (Table 4), carefully selected from those participating in the IPCC fourth assessment, have been used to simulate the future climatology for the study area. Global Circulation Models

(GCMs) are large-scale representations of the atmosphere and its processes (Julian Ramirez-Villegas and Andy Jarvis). These models have been selected on how well they represent the historical precipitation over the study area, and to encompass the range of model uncertainty inherent in the IPCC projections. Data for three GHG (greenhouse gas) emission scenarios A1B, A2, and B1 were then temporally downscaled using the delta-change method. The method assumes that changes in climates are only relevant at coarse scales and that relationships between variables are maintained towards the future [27].

Table 4 Global circulation models selected to generate climate scenarios

Global Climate Model (GCM)	Model Group	Scenario
CNRMCM3	Centre Natinal de Recherches Meteorologiques, France	A1B, A2, B1
ECHAM5OM	Max Planck Institute for Meteorology, Germany	A1B, A2, B1
GFDLCM2.1	NOAA Geophysical Fluid Dynamics Lab, United States	A1B, A2, B1
HADCM3	Hadely Centre for Climate Prediction and research, UK	A1B, A2, B1
MIROC3.2	Centre for Climate System Research (The University of Tokyo) Japan	A1B, A2, B1

RESULTS AND DISCUSSIONS

Hydrologic model calibration and validation

The calibration approach adopted for modelling the Mai-Nefhi River watershed involved systematic adjustment of parameters which were generally applied throughout the basin. The results of the hydrologic simulation showed that the most sensitive parameters for hydrological modelling of upstream watershed of Mai-Nefhi dam are SOL_Z, CN2, GWQMN, ESCO and SOL_AWC. This result is in agreement with those found by many similar studies, confirming that these five parameters are the crucial sensitive parameters for water balance and stream flow.

The statistical analysis shows that for the calibration period the model efficiency (NSE) was 0.78, while the R^2 was 0.96 for a monthly time interval. The monthly values of NSE and the R^2 for the validation period were 0.58 and 0.88 respectively (Table 5).

Table 5 Statistical evaluation of simulated versus observed streamflow data

Coefficient	Calibration Period	Validation Period
R^2	0.96	0.88
NSE	0.78	0.58

Therefore, according to model evaluation a criterion introduced by model calibration is satisfactory. Monthly average observed and simulated flows for the calibration period 1972-1980 and for the validation period 1981-1986 are presented in (Fig.8) and (Fig. 9) respectively.

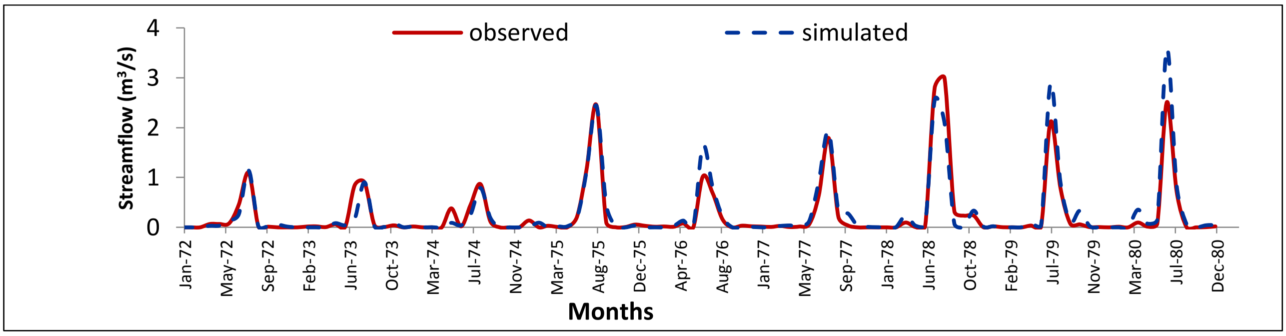

Fig. 8. Comparison of monthly observed and calibrated streamflow (1972-1980)

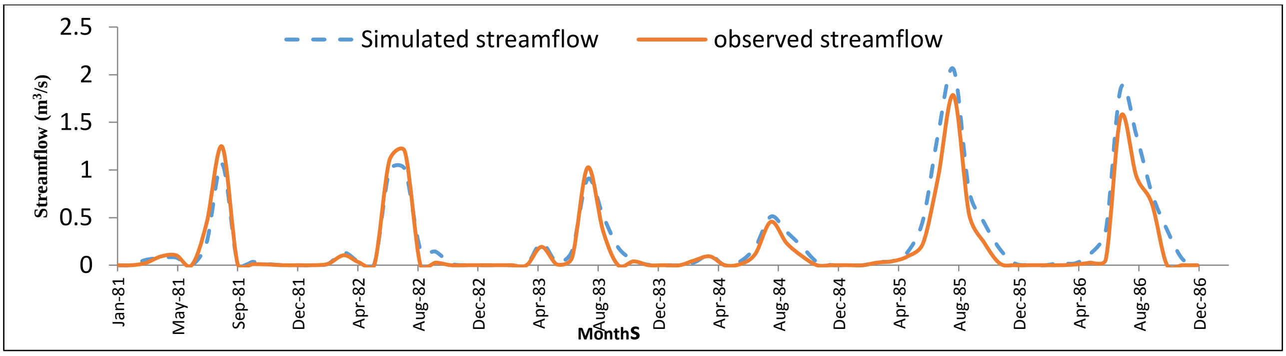

Fig. 9. Comparison of monthly observed and simulated streamflow for the validation period (1981-1986)

Forecast of future climate

(Fig. 10) and (Fig. 11) shows the predicted changes of mean monthly temperature in cº and percentage change in precipitation for future periods (20s, 50s and 80s) under various scenarios of A1B, A2, B1. All Scenarios show decreasing trends in precipitation and increase in temperature for early months of the year from January to July and great increase in rainfall amount from August to December. (Table 6**)** presents increased amount of annual average changes in precipitation and temperature. The Model A1B in all future periods shows decreasing values in the months between January to July with maximum of 26% in March for A1B_50s, and slight increase was observed in few months by up to 15.2% in February for A1B_20s.

The annual rainfall shows increase of 12.1, 10.2 and 8% for A1B_20s, A1B_50s and A1B_80s respectively. By the Model A2 in all the future stages, monthly mean rainfall shows medium decrease of up to 30.5% in April for A2_50s and maximum increase of 47.6 in January for A2_20s during early months from January to July. The average Annual rainfall by this model predicted to be 19.1%, 12.3% and 28.3% for A2_20s, A2_50s, A2_80s respectively. The other model B1 predict increase in rainfall for most of the months with maximum change of 39.1% and few months shows declining values up to 33.3% during early months. This model show increasing values of mean annual rain fall by 24.7%, 18.6 and 1.4 for B1_20s, B1_50s, B1_80s. For late months between August to September all models show great increase in monthly rainfall with the maximum of 120% for A2_80s in October month. while the mean monthly temperature shows positive changes in all months by Three GCM models with the maximum value of 6.6⁰C by. In early 20s, the average annual change in temperature predicted by the models to be near to 1ºC. whereas, for the period of 50s, estimated increase in temperature to be 2.5ºC, 3.4ºC and 1.75ºC for A1B_50s, A2_50s, and B1_50s respectively and the maximum value of 5.2ºC was observed in late parts of future periods by A2_80s. and that may have the less effect on stream flow. This predicted rise in temperature has little impact on water in the catchment to be evaporated in minor amount. As there is no reduction in annual rainfall amount and small raise in temperature will not have significant effects on stream flow of Mai-Nefhi catchment.

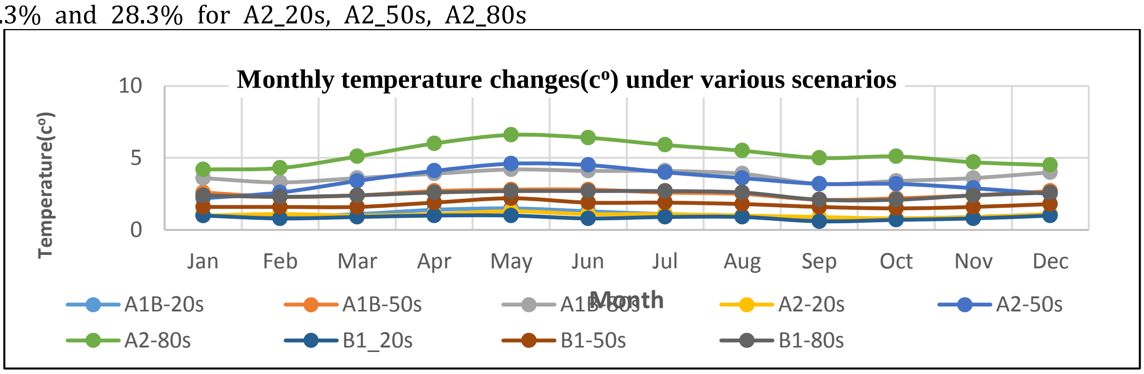

Fig. 10. predicted Monthly temperature changes (cº) under various scenarios for future periods (20s, 50s and 80s)

Table 6 Predicted average annual changes in temperature (cº) and precipitation (%)

Scenarios	Average Annual Changes	
	Temperature(cº)	precipitation(%)
A1B-20s	1.1	12.1
A1B-50s	2.5	10.2
A1B-80s	3.7	8.0

A2-20s	1	19.1
A2-50s	3.4	12.3
A2-80s	5.3	28.3
B1_20s	0.9	24.7
B1-50s	1.7	18.6
B1-80s	2.5	1.4

Impact of climate change on monthly and Annual Streamflow

The climate change models predicted quite substantial percentage changes of precipitation during the dry months and slight changes during the short rainfall months of July-September. Due to this condition the overall annual streamflow changes are not very high. As the increased precipitation amount is low towards starting and ending of the projected periods, models show same trend in stream flow changes. The maximum annual stream flow, shown by B1 scenario is 34% for the period 2011-2040 (Table 7). At the same time, the negative and positive changes of monthly mean rainfall amount predicted to be -68% and +300% for A1B_80s and A2_80s respectively. Projection of the monthly streamflow hydrographs from Mai-Nefhi catchment area obtained by the SWAT hydrologic model by the projection periods of 20's (2011-2040), 50's (2041-2070) and 80's (2071-2100), for each of the three emission scenarios A1B, A2 and B1 are shown in (Fig. 12), (Fig. 13), and (Fig. 14), respectively.

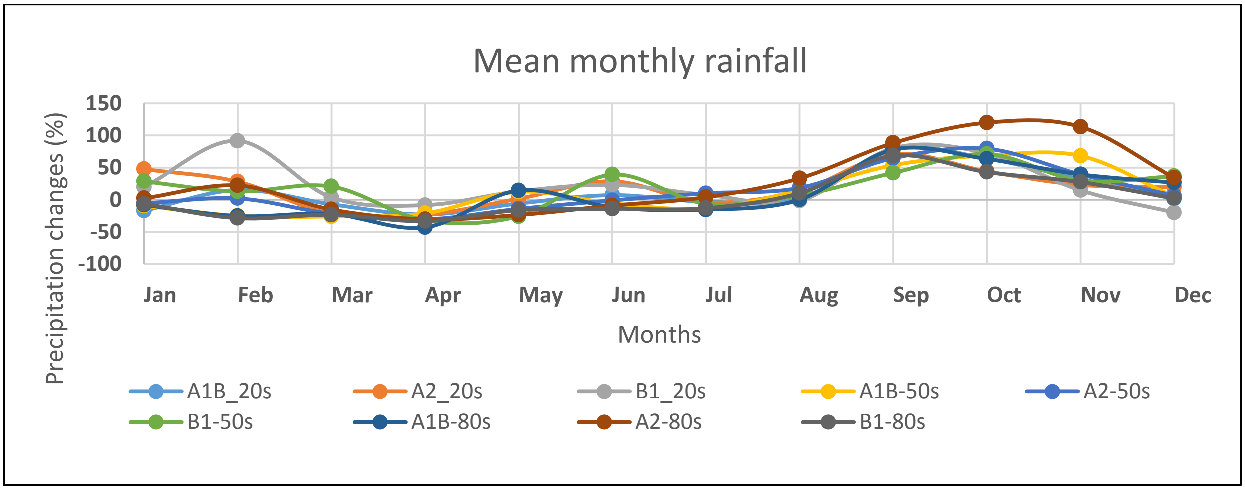

Fig. 11. predicted mean Monthly precipitation changes (%) under various scenarios for future periods (20s, 50s and 80s)

In each of the projection periods the streamflow hydrograph indicates no flow during the dry months of November – June. Although the climate change models predicted on the average an increase in monthly precipitation, the hydrological analysis in this study shows that the resulting effect on the annual streamflow volume is low. This is because the percentage increase predicted by the models during the dry months of the year will have less effect on streamflow as the base line precipitation data during the dry months shows little or no rainfall. At the same time, climate change tends to increase the rate of evapotranspiration which directly related to increase in temperature.

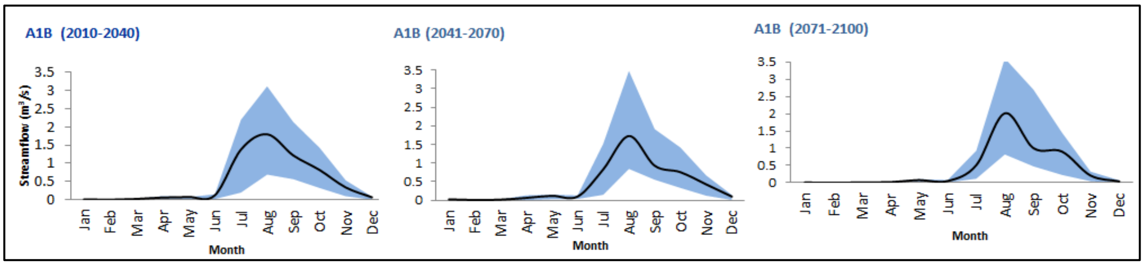

Fig. 12. Streamflow hydrographs (m^3/s) for Scenario A1B

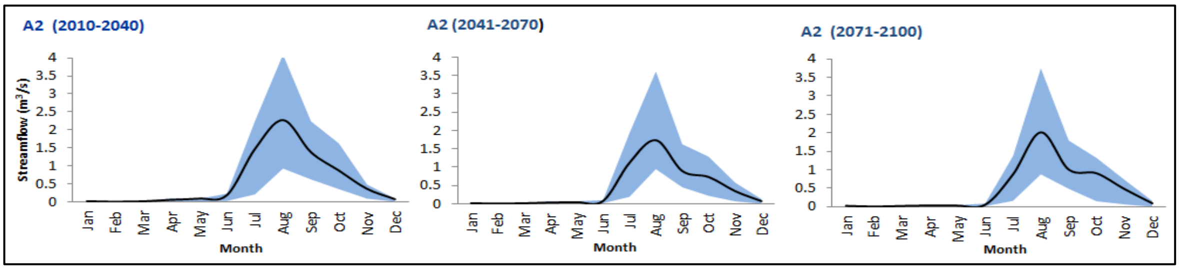

Fig. 13. Streamflow hydrograph (m³/s) for Scenario A2

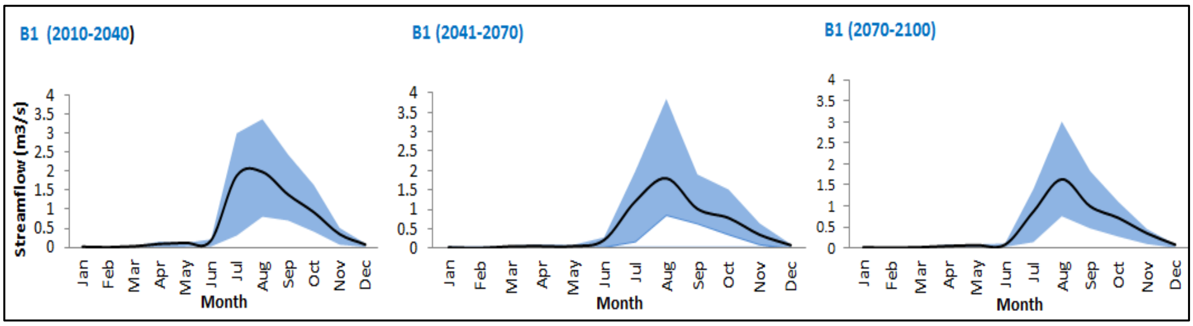

Fig. 14. Streamflow hydrograph (m³/s) for Scenario B1

Table 7 Estimated range of monthly and Annual streamflow changes for future periods (20s, 50s and 80s) for A1B, A2 and B1 scenarios

GHG Emission Scenario	Projection Period	Range of monthly Streamflow change	Annual change
A1B	2011-2040	[-19%,110%]	13%
	2041-2070	[-30%,292%]	16%
	2071-2100	[-68%,100%]	11%
A2	2011-2040	[-24%,240%]	29%
	2041-2070	[-45%,200%]	16%
	2071-2100	[-57%,300%]	26%
B1	2011-2040	[12%,179%]	34%
	2041-2070	[-27%,205%]	11%
	2071-2100	[-24%,248%]	28%

The A2 and B1 GHG emission scenarios show relatively higher streamflow as compared to A1B. This may be explained that in A2 the expected change in rainfall is the highest and the predicted increase in temperature is also a bit high, while for B1 the change in precipitation is moderate when the increase in temperature is low. In the study area, extreme climate change effects such as drought events have occurred with short recurrence intervals with higher peaks and levels of severity.

CONCLUSION

The impact of climate change on Mai-Nefhi water catchment was analyzed by SWAT and GHG scenarios A1B, A2 and B1, as a case study to predict the future water availability for Asmara City. The future changes in temperature and precipitation of the region by the GCM models were analyzed and used as input to the hydrological model SWAT to assess their effects on the streamflow of the basin. The following conclusions can be drawn from this study:

1) All the results of GCM model show decreasing trends in precipitation and increase in temperature for early months of the year from January to July and high increase in rainfall amount from August to December. On the other side, the amount of annual average changes in precipitation and temperature is projected to be increased for 20s, 50s and 80s compared to the observed periods.

2) The SWAT model was used with the help of ArcGIS for simulating observed data and predicted the stream flows for changed temperature and precipitation. Both observed and predicted stream flows are calibrated and validated with available data for the period 1972-1986. Statistical analysis of the model results is satisfactory. This SWAT model can be used to forecast the mean monthly stream flows for the target periods in future.

3) Comparing the fluctuations of stream flows predicted by all scenarios with past data, we can say that the hydrological behavior of Mai-Nefhi catchment area is not changed significantly except slight changes in July-September months. Mean annual amount of stream flow changes are not high as compared to the observed periods and Stream flow hydrograph shows no flow during the dry months of November-June.

4) The climate change driven alterations to the components of the hydrologic cycle, such as rainfall and evapotranspiration, will come on top of significant changes to catchments due to land-use, land-cover and temperature changes and this will affect water availability and water demand in the study area for particular months in a year.

5) Though there are certain changes in annual amount of stream flow in the catchment, there are less significant consequences in supplying water to meet

future demands if long term water resources management plans will be developed to store water and supply it in dry season.

6) Water resources availability and distribution are vital to the water supply of Asmara and its neighborhoods. Therefore, the method of analysis adopted in this study to evaluate the impacts of climate change on water resources across the region, is extremely beneficial tool for developing management strategies to deal with climate changes. The outcomes of this study can be utilized by Asmara water supply authorities to develop management plans for efficient use of water by future generations.

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