INTERNATIONAL JOURNAL OF ENGINEERING AND MANAGEMENT SCIENCES
© 2004 -18 Society For Science and Nature (SFSN). All Rights Reserved
www.scienceandnature.org

IMPACT OF CLIMATE CHANGE AND VARIABILITY IN THE HYDROLOGY OF CHOKIE MOUNTAIN BASIN, ETHIOPIA

[2*]Megbar. W. Birhan & [1]Fentahun. A. Worku
[1]Department of Hydraulic and water resources Engineering, Institute of Technology College, Debre Markos University; Debre Markos, Ethiopia
[2]Department of physics, Science College, Debre Markos University; Debre Markos, Ethiopia
[*]Corresponding Author Email: megbar.radiation05@gmail.com

ABSTRACT
In this study to characterize the impact of climate change and variability in the hydrology of Chokie Mountain basin, Ethiopia. The increment of temperature affects the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, frequency and intensity rates are not well known over Chokie Mountain basin. This study is justified the negative impact of climate parameters on hydrology. It is also helps us to know the correlation between climate change and hydrological phenomena. The main negative cause of climate variability that affects the hydrology of Chokie mountain basin is the increment of the temperature. But, the decrement of precipitation has insignificance causes. After the period of 2010, positive anomaly of temperature and negative anomaly of precipitation and runoff are observed. In the summer season, the range of precipitation varied from 1 to 8 mm/day with an average of 5 mm/day. The range of runoff varied from 1 to 7 mm/day with an average of 3.5 mm/day. Annual precipitation of Chokie mountain basin, increased from Northeast to Southwest with estimated average value of 0.3 mm/day. The maximum evaporation is extracted from the Northwest parts of the study area and it is contributed rainfall to Southwest parts. Annual average of runoff varied from 0.1 to 0.8 mm/day with an average of 0.25 mm/day. The annual average temperature varied from 11 to 18 degree centigrade with an average of 14.5 degree centigrade.

KEYWORDS: climate change; precipitation; temperature; hydrology

INTRODUCTION
Chokie mountain basin is a water tower of East and West Gojjam Zone in Amhara region, Ethiopia. The availability of freshwater over the region, the population density is high (Bewket, 2010). The Chokie mountain basin has variable topographical area and it has aired and semiarid climates. Due to its topography variability, it is highly affected by climate change. Weather and climate affects human presence and activities on earth in very complex ways. One direct influence is due to the greenhouse effect, which can be resumed to an increase in air temperature when the concentrations of some atmospheric gases appear high. Climate change poses uncertainties to the supply and management of water resources. The annual periodicity in weather patterns, which helps us the prediction of climate change. Intergovernmental Panel on Climate Change (IPCC, 2007 and Kumar, 2012) estimate that, the global mean surface temperature has increased through time. Climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation and evapotranspiration.

Precipitation and temperature is the main components of climate variability in the atmosphere. The increment of temperature affects the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence magnitude, frequency and intensity of precipitation that leads drought (Megbar and Tadese, 2016). The relationship between the changing climate variables and hydrology is more complicated and not clearly understood for pervious researchers but other countries suggested the impact of climate change on hydrology e.g in UK, by Boko MI et al., (2007), in Dinder National Park, at Sudan by Amir and Basheer, (2016). In upper Blue Nile basin the climate change on hydrology suggested by different scholars (e.g. Elshamy et al., 2009; Beyene et al., 2010; Rizwan, 2010; Setegn et al., 2011; Taye et al., 2011; Enyew et al., 2014; Gebre et al., 2015 and Dagnenet, 2016). In Chokie mountain basins that studies the effects of land use Change on hydrological responses by Friedrich, (2012) but the combined between climate change and hydrology was not clearly understood. Therefore, this paper is aimed to attempt the effect of climate change on the hydrological process by using observational data and reanalysis model European Centre for Medium-range Weather Forecast (ECMWF) data for the first time on Chokie mountain basin. We also analyzed climate variables that associated with the hydrology and to correlate the climate parameters with hydrological parameters.

The paper is organized as follows: Section 2 describes the data, method and site description of the study area. Section-3 emphases the result and the discussions of climate change and hydrology. Conclusion and recommendations are stated in section 4.

METHODS AND DESCRIPTION OF THE STUDY AREA

Description of the study area

The study site, Choke Mountain basin, is located approximately between coordinates 9.33 to 11.50 North latitude and 36.42 to 38.58 East longitudes. Topographically, the basin lies at an altitude ranging from 2100 to 4413 meter. Because of these altitudinal variations, about 27%, of the basin is found in Woyina Dega (Midland), 82% of the basin is Dega (Highland) and 9.7% is Wurch (Hail) traditional agro ecological zones respectively. The Chokie mountain basin is found entirely in East Gojjam Zone of six Woredas such as; Bibugne, DebayTilatgin, Gozamen, Hulet Eju Enssie, Machakel, and Senan (Bewket, 2010) and west Gojjam it reaches around Jigga. Due to different topography features, Chokie mountain basins highly variable in the case of rainfall and temperature due to climate change refer in **Fig. 1**.

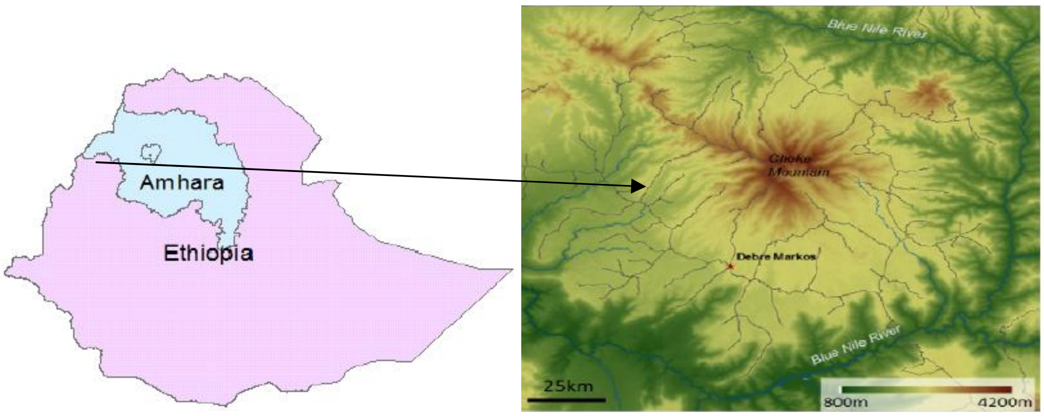

Fig. 1: Location map of Chokie mountain basin from Amhara region, Ethiopia

Data sources

Daily-monthly precipitation, river discharge and temperature data obtained from situ measurements (land only) from National Meteorology Agency the time period available is 1982-2014. The second daily and daily mean monthly precipitation, evaporation, zonal u wind, mieridional v wind velocity data at 10 m altitude, temperature at 2 meter and runoff data obtained from ECMWF reanalysis dataset (ERA-Interim) (Kallberg et al., 2004; Berrisford et al., 2011a; Dee et al. 2011). This data covers the time period from 1979-2017. The present updating grid horizontal resolution is 0.125 × 0.125 degree and temporal resolution 00:00:00, 06:00:00, 12:00:00 and 18:00:00 six hour difference. ERA-Interim is based on an atmospheric model and reanalysis system with 60 levels in the vertical with a top level at 0.1mb (Berrisford et al., 2011a).

Methodology

Hydrodynamic river model ECMWF is selected for river basins and atmospheric climate data. The statistical trend analysis on the river flow, precipitation and temperature series for the present and past climate is analyzed. Weather parameters for which the climatic average values is calculated for; temperature, precipitation, U and V wind velocity are determined. Analyze the temporal and spatial variability of hydrology runoff data with temperature and precipitation data. Then, identify the parameters that affect hydrology due to climate change. We achieve our objectives the procedure follows as; first to validate the model data with situ observational data; second identifying these hydro meteorological parameters that are significantly affected by climate change. Third we find out the cause of this hydro meteorological parameter variability and give the solution on it. Finally, we correlate hydrological parameter and climate parameter data. The correlation coefficient of climate variability and hydrology calculated by:

$$r = \frac{\sum[(X-\bar{X})(Y-\bar{Y})]}{\sqrt{[\sum(X-\bar{X})^2(Y-\bar{Y})^2]}} \qquad [1]$$

Where, r is correlation coefficient, X is climate parameters, Y is hydrology parameters and, X and Y bar were the mean value of the data.

To characterize the future climate and hydrological phenomena trend analysis is calculated

$$tr = \left(\frac{(Z-\bar{Z})}{std}\right) \qquad [2]$$

where, tr is trend analysis, Z is number of data points, Z bar is the mean of the data and std is standard deviation of the data. In trend analysis we have three cases. If tr is negative value the two determined parameter values one is decrease and the other is increased with time. If tr is zero the two determined parameter values were independent and tr is positive the two determined parameter values both are increase or decrease with time.

RESULT AND DISCUSSION

In this section we were present the validation of the model data with in situ measurements. The temporal validation of precipitation, runoff in situ measurement and model reanalysis data is too valid.

Validation of climate reanalysis model data with in situ measurements and time series analysis

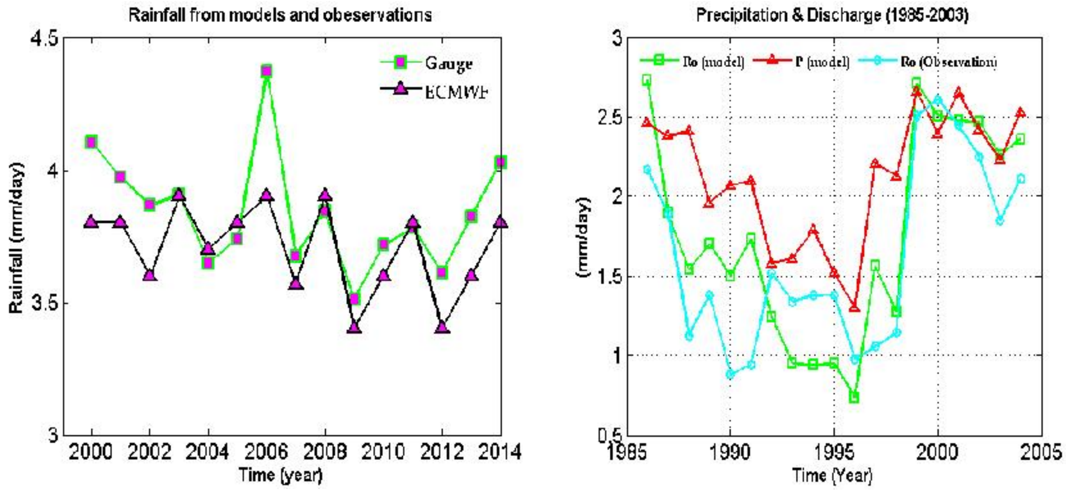

Fig. 2: Validation between in situ observation and model reanalysis runoff and precipitation data

In the study area and throughout Ethiopia the distribution of situ measurements is spares and irregular. Therefore, the scarcity of the data is occurred as addressed by Wuletawu et al. (2016). Hence, to resolve this challenge, ECMWF data is used, since it has 0.125 degree spatial resolution and daily temporal resolution as mentioned in section 2. From the left panels of Fig. 2 indicated that the gauge precipitation and ECMWF reanalysis precipitation outputs; showed as well validation. So, we preferred the reanalysis model output due to the quality of the data and good spatial coverage. Runoff from the ECMWF and from in situ average value of different rivers has strong correlation with the correlation coefficient of 0.72. Runoff and precipitation have positive correlations refer the right panels of Fig. 2.

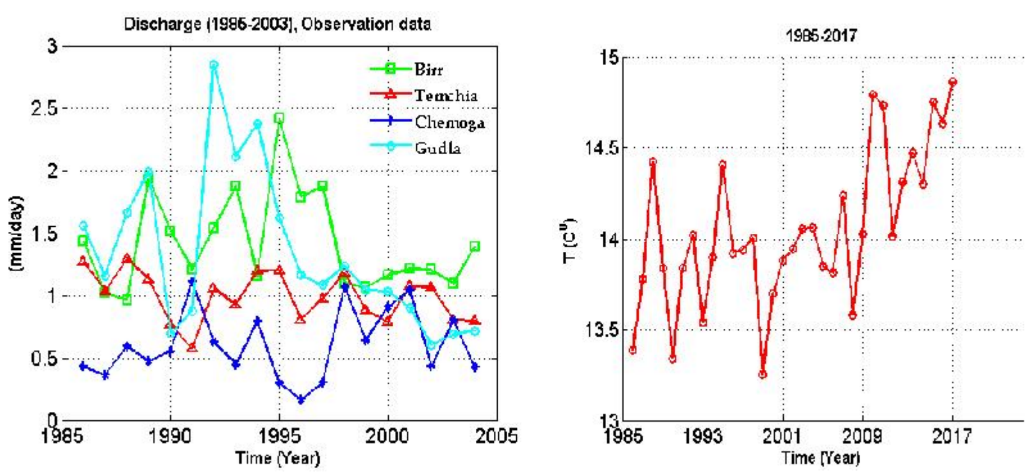

Fig. 3: Temporal variability of river discharges and temperature in Chokie mountain basin

After the year in 1998 the river discharges were decrease because of the positive anomaly of temperature (Fig. 3). After 1998 the temporal variability of temperature is increased (Fig.3) but runoff and precipitation are decreased from 1998 to 2005 as shown the right panels of Fig. 2. Therefore, precipitation is decreased with the increment of temperature due to greenhouse gases. The temporal correlation between runoff and precipitation was 0.87 and temperature with precipitation was -0.65 over the study period. Hence, the increment of temperature as a result of greenhouse gases that leads the decrement of the hydrological process in Chokie mountain basin. Precipitation and hydrological event has positive implications.

Trend analysis of precipitation, temperature and runoff

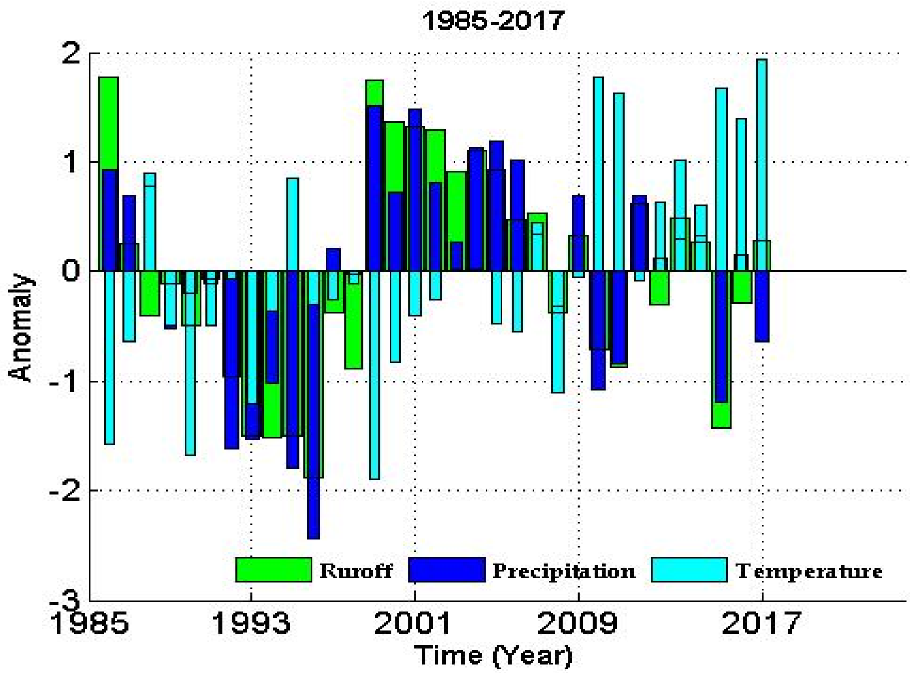

Fig. 4: Runoff, precipitation and temperature trend analysis in Chokie mountain basin

From 1988 to 1997 runoff, precipitation and temperature showed negative anomaly. The negative trend of precipitation and runoff may be associated with other factors, such as pacific decadal oscillations, north Atlantic oscillations and the sun activity (space weather). But 1998 to 2007 runoff and precipitation showed positive anomaly but not temperature. After the period of 2010, positive anomaly of temperature and negative anomaly of precipitation and runoff are observed (Fig. 4). From trend analysis indicated that, in the future the occurrence of drought may be occurred due to positive anomaly of temperature and precipitation deficiency.

Seasonal spatial variation of precipitation, temperature and runoff in Chokie mountain basin

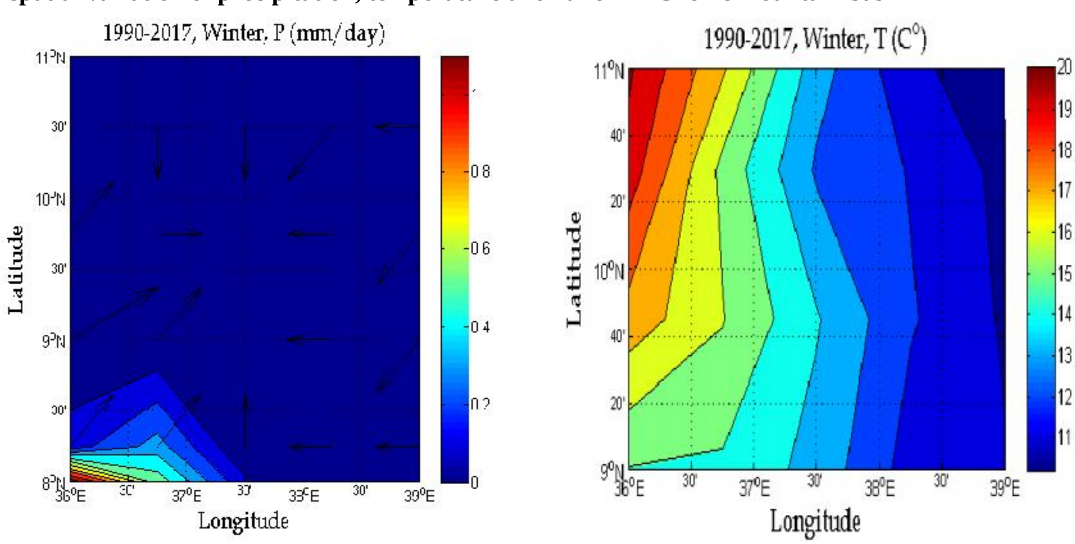

Fig. 5: Winter spatial variation of precipitation and temperature from 1990-2017

In winter different air masses came up to the study area, which was converging. But, from this different air masses the northern air masses were the dominate one. Because, during the winter season; the earth southern hemisphere tilts towards the sun. Inter tropical convergent zone (ITCZ) migrates to the southern hemisphere with the sun position. The southern hemisphere developed high temperature gradient force but in northern hemisphere developed high pressure gradient force. Therefore, wind that blows from high pressure gradient force to high temperature gradient force since at high temperature gradient force pressure gradient force is minimum. But the wind came to the northern hemisphere is dry due to the scarcity of Oceans in the northern hemisphere. Dry winds have less probability to give moisture for the study area. In the southwest parts of the study area got little precipitation because some moisture that blows from southern Atlantic Ocean and the locale moisture sources. At the winter, the range of precipitation varied from 0 to 1 mm/day with an average of 0.2 mm/day. At south west parts having 1 mm/day and the north east parts there is no precipitation observation. The range of temperature varied from 11 to 20 degree centigrade with an average of 13.8 degree centigrade (Fig. 5). The temperature distribution of the study area is increase from east to west parts.

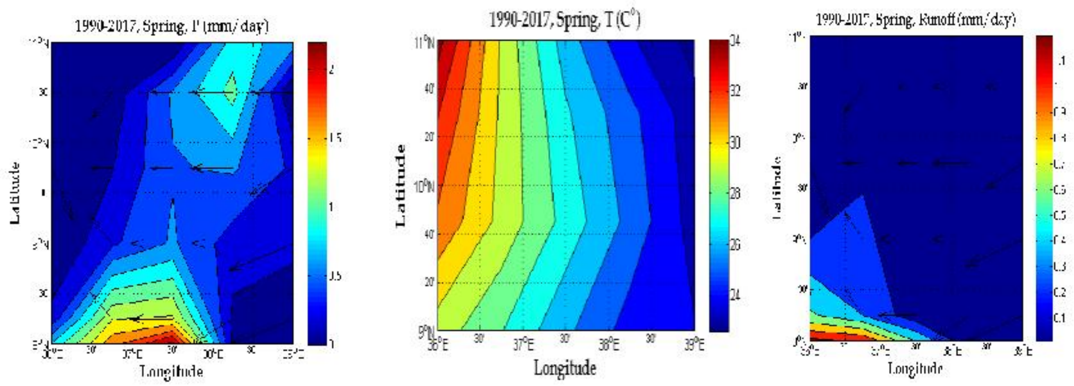

Fig. 6: Spring spatial variation of P, T and R

In spring, our study area got precipitation more than the winter season. Because, in this season; high pressure gradient force developed in Indian Ocean relative to Atlantic Ocean. Therefore, trend winds carry moisture from Indian Ocean to contribute eastern and southern parts of our study area as shown the left panel of Fig. 6. In this season, runoff is increased from north east to south west as shown the right panel of Fig. 6. This variation may be occurred due to vegetable coverage of the highland area in the northern parts of the study area. Other possibility, the increment of runoff from Northeast to Southwest because precipitation is increased from Northeast to Southwest. In spring, the range of precipitation, temperature and runoff varied from 0 to 2 mm/day with an average of 1 mm/day, 24 to 34 with an average of 28 degree centigrade and from 0.1 to 1.1 mm/day with an average of 0.4 mm/day respectively (Fig. 6).

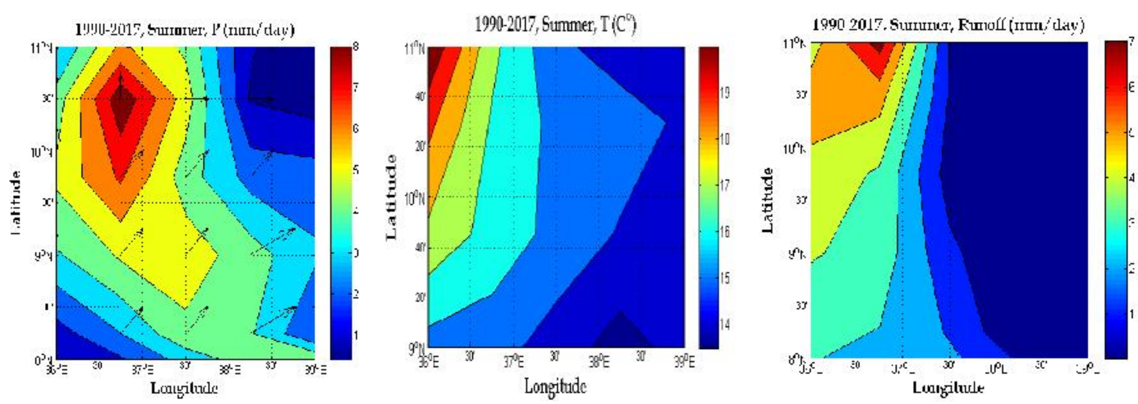

Fig. 7: Summer spatial variation of P, T and R

At normal phase summer season, the earth northern hemisphere tilts towards the sun. Therefore, the northern hemisphere receives maximum radiation than the southern hemisphere. High pressure gradient forces occurred in the southern hemisphere. Hence, moisture fluxes divergence to the northern hemisphere. These winds carry high amount of moisture from Atlantic Ocean that contributed to the different part of the African country and our study area. In this season, maximum amount of precipitation is recurred as shown the left panel of Fig. 7. The north central part of the study area contributed local rainfall to the same area. Runoff and precipitation have proportional spatial distribution refer the left and right panel of Fig. 7. At El Nino and La Nina phase the eastern part of Pacific Ocean sea surface temperature (SST) was increasing. Therefore, the temperature gradient force at eastern part of Pacific Ocean is greater than African continent. As a result the wind that blows from Atlantic Ocean to eastern part of Pacific Ocean. At eastern part of America affected by floods and African country such as Chokie basin affected by drought. Summer season, the range of precipitation varied from 1 to 8 mm/day with an average of 5 mm/day. The range of temperature varied from 14 to 19 with an average of 15.5 degree centigrade as we can the middle panel of Fig. 7. The range of runoff varied from 1 to 7 mm/day with an average of 3.5 mm/day refers the right panel of Fig. 7. In this season, western part of the study area gets maximum rainfall and runoff. Because, in summer season the sources of moisture is Atlantic Ocean as indicated the moisture flux vectors. Relatively Ethiopia has variety topography features, spatially Chokie mountain basins. Topography features of Chokie mountain basin, lies at an altitude ranging from 2100 to 4413 meter. Summer moisture transported from Atlantic Ocean to African continent and our research area through advection process. This moisture carrying winds reaches Chokie Mountain which is deflected upward due to higher elevations of the mountain and convective skims of the local moisture. Temperature is decreased with altitude due to lap's rat and the moisture becomes cool and reaches maximum thermodynamics points due to gravity failing to the earth. This wind passes through Chokie mountain is dried up and eastern parts didn`t get sufficient rainfall as shown the left panel of Fig. 7.

Annual spatial variation of atmospheric and hydrological parameters in Chokie mountain basin

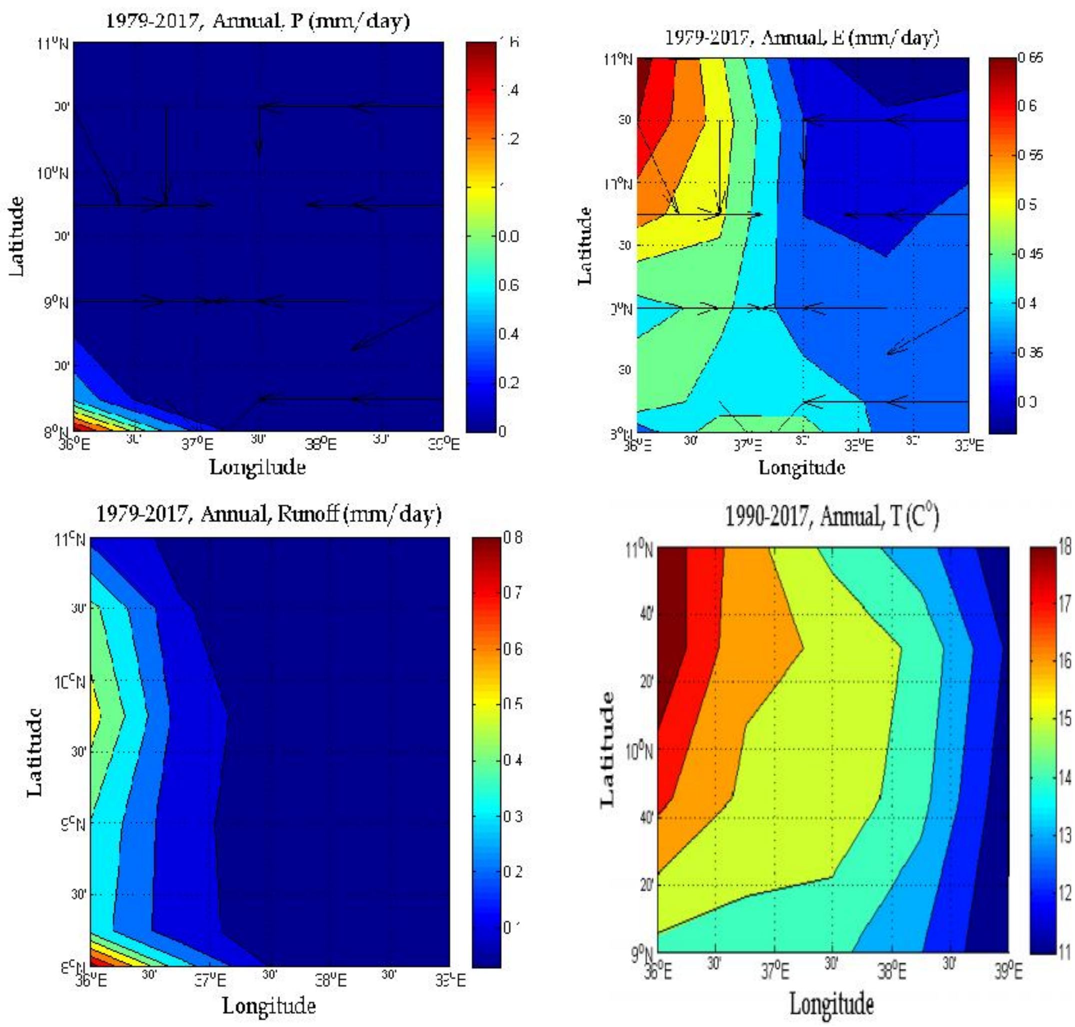

Fig. 8: Annual precipitation, temperature, evaporation and runoff spatial variation

Annual precipitation of Chokie mountain basin is increased from Northeast to Southwest with an average of 0.3 mm/day. The maximum evaporation was occurring in Northwest parts and that diverges to Southwest parts. As a result Southwest parts of the study area got maximum rainfall. Annual average of runoff varied from 0.1 to 0.8 mm/day with an average of 0.25 mm/day. The annual average values of temperature varied from 11 to 18 with an average of 15 degree centigrade (Fig. 8).

Spatial correlations of climate and hydrological parameters

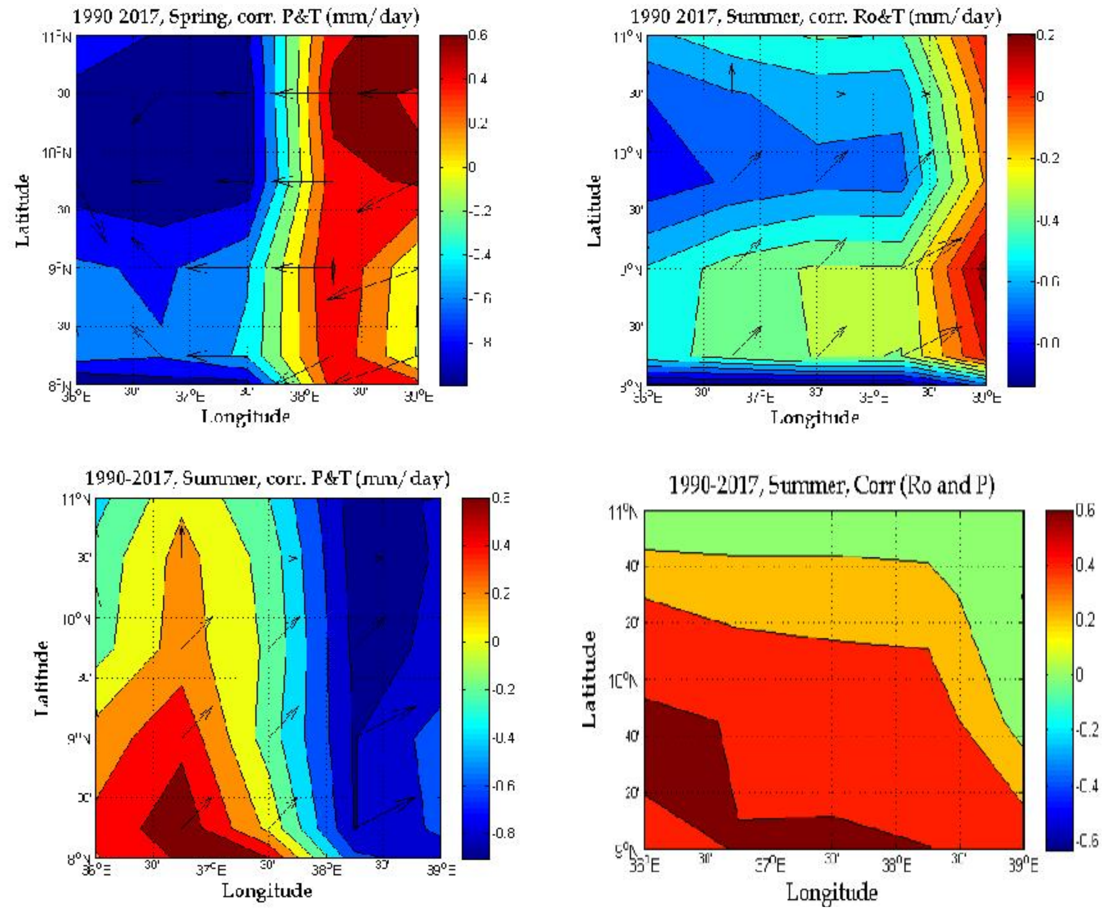

Fig. 9: The spatial correlation among atmospheric data over Chokie mountain basin

In spring the spatial correlation between precipitation and temperature in the Eastern part of the study area was positive; since the maximum pressure gradient force occurred in Indian Ocean. But, the highest evaporation due to maximum temperature was occurring in East African country such as Ethiopia relative to Indian Ocean with less pressure gradient force. Therefore, moisture carrying winds from Indian Ocean blows to our study area. It reaches the Chokie Mountain, the advection mass movement change to convectional movement due to higher altitude of the mountain. Altitude is increased the negative temperature lap`s rate is occurred. Hence, this moisture reaches the dew point it becomes rain due to gravity. As a result in Eastern part of the study area temperature and precipitation shows strong positive correlations. The wind that passes through Chokie Mountain becomes dried up and the temperature is increased in western part of Chokie mountain basin. The dry pressure gradient forces came to Western part but not supply rainfall. Therefore, temperature and precipitation showed negative correlations as shown in the top left panel of Fig. 9. During the summer, the correlation between precipitation and temperature in the Western parts was positive as we can see the bottom left panel of Fig. 9. Since, the summer moisture is coming from Atlantic Ocean. The Eastern parts show negative correlations because the wind passes through Chokie Mountain becomes dried. In the summer, the correlation between runoff and temperature for over the study area were negative as we can see the top right panel of Fig. 9. It indicated that, the temperature is evaporated the surface rainfall before to be runoff. Runoff and temperature shows negative correlation values in summer season. The correlation between precipitation and runoff throughout the study area is positive except Northeast parts as shown the bottom right panel of Fig. 9.

CONCLUSIONS AND RECOMMENDATIONS

The effect of climate change on the hydrological phenomena study is significantly important to predict future water availability on our local community. In spring the divergence of moisture is clearly visible that moves from East to West over the study area. This trend winds carry moisture from Indian Ocean. In Eastern part of the study area the temperature gradient is enhanced, but the pressure gradient force is diminished. Therefore, the wind strongly carries moisture from Indian Ocean to the study area. The wind blows from West to East in summer season. Precipitation and temperature shows positive with high magnitude correlation value in western parts of the study area during summer season. The Western winds contributed rainfall in Western part of our study area and the dry winds blows to Eastern part of the study area. Hence, the correlation between precipitation and temperature is negative over Eastern parts of the study area. Moisture airs coming to any direction it gives rainfall for the wind sides of Chokie Mountain and other locations fare away from the lee sides becomes dried. This study gives clear information for future further study in climate change and the hydrology. We wish, for future researchers to study the impact of climate change on hydrology phenomena by using other climate parameters such as carbon dioxide, ozone, and space weather and sea surface temperature data.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper

ACKNOWLEDGMENTS

The authors are thankful to Hydraulic Engineering, Institute of Technology, Debre Markos University; Debre Markos, Ethiopia

REFERENCES

Amir K. Basheer, (2016): Impacts of climate change under CMIP5 RCP scenarios on the streamflow in the Dinder River and ecosystem habitats in Dinder National Park, Sudan. Hydrol. Earth Syst. Sci., **20**, 1331–1353

Bewket Amede (2010): Local Level Analysis of Farmers Adaptation to Climate Change and variability: The case of Choke Mountain. East Gojjam: Unpublished MA Thesis in Addis Ababa University, Ethiopia

Beyene, T., Lettenmaier, D. P., and Kabat, P. (2010): Hydrologic impacts of climate change on the Nile River Basin: implications, Climatic change, **100**, 433–461

Boko MI, Niang A, Nyong C, *(2007)*: Climate Change: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, Cambridge UK: Cambridge University Press; pp. 433-67

Kumar, (2012): Climate Change and Its Impact on Groundwater Resources, *Vol. 1*, (October 2012), PP 43-60

Dagnenet Fenta, (2016): Analyzing the future climate change of Upper Blue Nile River Basin (UBNRB) using statistical down scaling techniques. Hydrol. Earth Syst.2016-543

Elshamy, M. E., Seierstad, I. A., and Sorteberg, A. (2009): Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios, Hydrol. Earth Syst. Sci., **13**, 551–565

Enyew, B., Van Lanen, H., and Van Loon, A. (2014): Assessment of the Impact of Climate Change on Hydrological Drought in Lake Tana Catchment, Blue Nile Basin, Ethiopia, J. Geol. Geosci., **3**, p. 174

Friedrich J. Koch, (2012): The Effects of Land use Change on Hydrological Responses in the Choke Mountain Range (Ethiopia) - A new Approach Addressing Land Use Dynamics in the Model SWAT, *nternational Environmental Modelling and Software Society (iEMSs)*

Gebre, S., Tadele, K., and Mariam, B. (2015): Potential Impacts of Climate Change on the Hydrology and Water resources Availability of Didessa Catchment, Blue Nile River Basin, Ethiopia, J. Geol. Geosci., **4**, p. 2329-6755

IPCC (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, 966 p

Megbar and Tadesse (2016): assessment of drought in Ethiopia using self-calibrated palmer drought severity index, international journal of management and technology volume **2**(7)

Rizwan, (2010): Blue Nile Runoff Sensitivity to Climate Change; *Open Hydrology Journal, **4**,* 137-151

Setegn, S. G., Rayner, D., Melesse, A. M., Dargahi, B., and Srinivasan, R. (2011): Impact of climate change on the hydro climatology of Lake Tana Basin, Ethiopia, Water Resour. Res., **47**, W04511

Taye, M. T., Ntegeka, V., Ogiramoi, N. P., Willems, P., (2011): Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin, Hydrol. Earth Syst. Sci., **15**, 209–222.

Kallberg P, Simmons A, Uppala S, Fuentes M. (2004): The ERA-40 Archive, ERA-40 Project Report Series No. 17 , European Centre for Medium-range Weather Forecast, Reading: UK; 31

Berrisford, P., P. Kallberg, S. Kobayashi, D. Dee, S. Uppala, A. J.Simmons, P. Poli, and H. Sato, (2011a): Atmospheric conservation properties in ERA-Interim. Quart. J. Roy. Meteor. Soc.,137, 1381–1399.

Wuletawu Abera, Giuseppe Formetta, Luca Brocca and Riccardo Rigon, (2016): Water budget modelling of the Upper Blue Nile basin using the JGrass-NewAge model system and satellite data, Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-290