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Editors

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Editors
Godfrey A. Uzochukwu
North Carolina A&T State University
Greensboro, NC, USA

Keith Schimmel
North Carolina A&T State University
Greensboro, NC, USA

Vinayak Kabadi
North Carolina A&T State University
Greensboro, NC, USA

Shoou-Yuh Chang
North Carolina A&T State University
Greensboro, NC, USA

Tanya Pinder
North Carolina A&T State University
Greensboro, NC, USA

Salam A. Ibrahim
North Carolina A&T State University
Greensboro, NC, USA

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Preface

This book contains peer-reviewed chapters accepted for presentation at the National Conference on Advances in Environmental Science and Technology. The chapters are arranged by topics with names of authors and affliations.

Several conversations about environmental regulations, groundwater remediation technologies and waste to energy, climate change, economics and environmental justice, fate and transport of contaminants, food bio-processing, innovative environmental technologies, sustainable energy and water resources and waste management among federal agencies, private agencies, and university professors set the stage for the September 12, 2013 National Conference on Advances in Environmental Science and Technology. The purpose of the National Conference on Advances in Environmental Science and Technology which was held in Greensboro, North Carolina, was to provide a forum for agencies to address advances in environmental science and technology including problems, solutions, and research needs. Our goal was to foster relationships that could result in partnerships needed to protect, sustain the environment and improve the quality of life.

The National Conference on Advances in Environmental Science and Technology was sponsored by Sullivan International Group, Waste Industries, CDM Smith, United States Department of Energy, United States Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, and North Carolina Agricultural and Technical State University. These agencies are thanked for their financial and logistics support. The hard work of Tarcy Keyes, Stephen Johnson, Angela Smith, and Pat O'Connor is gratefully acknowledged. Special thanks to Johnsely S. Cyrus, Stephanie Luster Teasley, and Heather Stewart for their assistance. The following keynote speakers are thanked for their contributions: Michael Maloy, Vice President, Sullivan International Group, San Diego; Greg Green, Director of Outreach and Information, United States Environmental Protection Agency; Barry Edwards, Director of Utilities and Engineering, Catawba County Government, NC; Joe B. Whitehead, Jr., Provost and Vice Chancellor for Academic Affairs at North Carolina Agricultural and Technical State University; and Barry Burks, Vice Chancellor for Research and Economic Development at North Carolina Agricultural and Technical State University.

Greensboro, NC

Godfrey A. Uzochukwu
Vinayak Kabadi
Shoou Yuh Chang
Keith Schimmel
Tanya Pinder
Salam A. Ibrahim

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Contributors

Elvis B. Addai Department of Civil Engineering, North Carolina Agricultural &Technical State University, Greensboro, NC, USA

Emmanuel Ansah Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Godwin Appiah Assumaning Department of Civil and Environmental Engineering, NC A&T State University, Greensboro, NC, USA

Saddam S. Awaisheh Department of Nutrition and Food Processing, Al-Balqa Applied University, Salt, Jordan

Uma Bhatt Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA

Nana Abayie Boakye-Boaten Department of Natural Resources and Environmental Design, North Carolina A and T State University, Greensboro, NC, USA

Shoou-Yuh Chang Department of Civil, Architectural, and Environmental Engineering, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Somsubhra Chattopadhyay Department of Computational Science and Engineering and Civil, Architectural and Environmental Engineering, North Carolina A&T State University, Greensboro, NC, USA

Junming Chen International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA

William W. Edmonson Department of Electrical and Computer Engineering, North Carolina A&T State University, Greensboro, NC, USA

John Eshun Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Jenberu Feyyisa Department of Civil, Architectural, and Environmental Engineering, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Dante' Freeland Department of CAAE Engineering, North Carolina A&T State University, Greensboro, NC, USA

Torupallab Ghoshal Department of Civil Engineering, North Carolina A&T State University, Greensboro, NC, USA

Rabin Gyawali Department of Energy and Environmental Systems, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Christopher L. Hall Department of Civil and Architectural Engineering, North Carolina A&T State University, Greensboro, NC, USA

Saeed A. Hayek Department of Energy and Environmental Systems, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Regine Hock Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA

Salam A. Ibrahim Department of Family and Consumer Sciences, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Manoj K. Jha Department of Civil, Architectural and Environmental Engineering, North Carolina A&T State University, Greensboro, NC, USA

Bernice D. Karlton-Senaye North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Jeremy Krieger Arctic Region Supercomputing Center, University of Alaska Fairbanks, Fairbanks, AK, USA

Chuhan Lu International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA

Gwendolyn McFadden North Carolina A&T State University, Greensboro, NC, USA

Nabil Nassif Department of Civil and Architectural Engineering, North Carolina A&T State University, Greensboro, NC, USA

Tony Nguyen Department of Civil, Architectural and Environmental Engineering, North Carolina A&T State University, Greensboro, NC, USA

Temitayo O. Obanla North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Guidgopuram B. Reddy Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Anup Saha Department of Civil Engineering, North Carolina A&T State University, Greensboro, NC, USA

Mohammad Sayemuzzaman Department of Energy and Environmental System, North Carolina A&T State University, Greensboro, NC, USA

Abolghasem Shahbazi Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Harmohindar Singh Department of Civil and Architectural Engineering, North Carolina A&T State University, Greensboro, NC, USA

Reza Tahergorabi North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Wei Tao Department of Physics and EES, North Carolina A&T State University, Greensboro, NC, USA

Raymond Tesiero Department of Computational Science and Engineering, North Carolina A&T State University, Greensboro, NC, USA

Godfrey A. Uzochukwu Waste Management Institute, North Carolina A&T State University, Greensboro, NC, USA

Lijun Wang Department of Natural Resources and Environmental Design, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

Jean Wells Howard University, Washington, DC, USA

Vereda Johnson Williams North Carolina A&T State University, Greensboro, NC, USA

Shuangning Xiu Department of Natural Resources and Environmental Design, North Carolina A and T State University, Greensboro, NC, USA

Rawfin Zaman Department of Electrical and Computer Engineering, North Carolina A&T State University, Greensboro, NC, USA

Jing Zhang Department of Physics, North Carolina A&T State University, Greensboro, NC, USA

Department of Energy and Environmental Systems, North Carolina A&T State University, Greensboro, NC, USA

Xiangdong Zhang International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA

Part I
Climate Change

Assessment of Climate Change Impact on Watershed Hydrology

Somsubhra Chattopadhyay and Manoj K. Jha

Abstract Evidence of pronounced fluctuation in climate variability has caused numerous impact assessment studies of climate variability and change on watershed hydrology. Several methods of impact assessment have been used over the last decade which basically incorporates atmospheric-ocean circulation-based climate models' projection of changes in meteorological variable into the simulation of land surface hydrological processes. In this study, we have evaluated two methods, frequency perturbation and direct use of data, through forcing of a simulation model with data from a suite of global climate models. Hydrologic response of a typical watershed in Midwest was evaluated for the change in climatic condition. Frequency perturbation method found precipitation decrease by 17 % and reduction in temperature by 0.43 °C on an average annual basis. The changes when applied through the watershed simulation model resulted in 13 % reduction in evapotranspiration (ET) and 25 % reduction in water yield. In contrast, direct method with 1.25 % decrease in precipitation and 0.2 °C decrease in temperature on annual basin found an increase of 1.8 % for ET and 5 % reduction in water yield. Changes in ET and water yield on temporal and spatial scale due to changes in future climate are likely to have severe implications for the water availability. However, more research is needed to evaluate several impact assessment methods for more accurate analysis.

Introduction

Hydrological cycle has been found to be significantly impacted by global warming caused by the climate change in recent times. Intergovernmental Panel for Climate Change (IPCC) reported evidences of strong correlations between the increasing amount and concentration of greenhouse gases and aerosols into the atmosphere and the rising global temperature. The impact of climate change on hydrological processes have been investigated across the globe during the last decades in several

S. Chattopadhyay • M.K. Jha (✉)
Computational Science and Engineering and Civil, Architectural and Environmental Engineering Department, North Carolina A&T State University, Greensboro, NC, USA
e-mail: schattop@aggies.ncat.edu; mkjha@ncat.edu

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studies which clearly emphasizes the consequence of climatic change and variability on water resources (Jha et al. 2004, 2006, 2010a, b; Jha and Gassman 2013; Jin and Sridhar 2012; Mango et al. 2011). Global climate models (GCMs) are considered as the most important tool to conduct climate change impact assessment studies. Wilby et al. (2004) pointed out that variations in local climate are mainly governed by the regional physiographic conditions which often are not accurately represented by the coarse resolutions of GCM outputs and this further puts into question the process of forcing these information into hydrologic models.

There are several methods available that are used to create future variations in local scale climate from the GCM outputs. Delta change method involves altering the observed temperature and precipitation series according to the "expected" future change signal from the GCMs (Hay et al. 2000; Prudhomme et al. 2002). While temperature has shown good agreement across GCMs according to this method, there has not been the corresponding response for precipitation. In addition, keeping the number of wet days unchanged along with discarding potential changes in correlation among different variables might result into neglecting climate variability. Frequency perturbation change method essentially implies transferring the extracted climate change signals to the observed series which accounts for the changes in extreme rainfall events (Taye et al. 2011; Mora et al. 2013). This approach also provides predictions consistent with the occurrence of wet days and wet day rainfall amounts. Rainfall series is perturbed in relation to their frequency of occurrence. Thus, daily rainfall amounts are perturbed with a unique factor dependent on return period. Direct method (Takle et al. 2005, 2010) uses direct output of GCM runs into the hydrologic simulation and thus takes into account more complex changes in the probability functions of the input weather variables into hydrological models. Bias could be perpetuated in some occasions which accounts as a disadvantage of direct method.

In this chapter, we examined a range of methods and attempted to devise a strategy while clarifying some of the issues with the impact assessment studies. Frequency perturbation method and direct method were applied to obtain watershed-scale future climatic information from a suite of 10 GCMs which were then forced to the hydrologic simulation model Soil and Water Assessment Tool (SWAT). Temporal variations of the major hydrological variables such as evapotranspiration, water yield, surface runoff, and baseflow were evaluated for impact assessment. A modeling framework for a typical Midwestern watershed, developed by Jha et al. (2010a, b), was used to test these two methods.

Materials and Methods

Study area: Raccoon River Watershed covers an area of 9400 km^2 in west-central Iowa before finally draining to larger Des Moines River Watershed. Landuse pattern have been dominated by agricultural crop production mainly corn and soybean (70 %) followed by grassland (16.3 %), woodland (4.4 %), and urban

(4 %) areas. Raccoon River also is of chief importance for the central Iowa region as it serves as a potable water source for nearly 500,000 people.

Hydrological modeling with SWAT: SWAT is a long-term, continuous, watershed-scale simulation model that operates on a daily time step and is designed to assess the impact of different management practices on water, sediment, and agricultural chemical yields. The model is distributed, computationally efficient, and capable of simulating a detailed level of spatial detail (Arnold et al. 1998). It simulates the hydrological cycle based on the water balance equation. Major model components are hydrology, weather, soil temperature, crop growth, nutrient, bacteria, and land management. SWAT divides a watershed into several subwatersheds which then are further delineated according to unique combination of landuse, soil type, and soil class called Hydrologic Response Units (HRUs). HRUs are the smallest possible division of a watershed and the model accounts for the water balance of each subwatershed over the individual HRUs. Each HRU has four distinct components, i.e., snow, soil profile, shallow, and deep aquifer contributing towards total water balance.

Climate change impact assessment methods: The projection simulation was based on A1B Special Report Emission Scenario (SRES) which basically puts a balanced emphasis on all energy sources in future. In this study, we have chosen to compare the frequency perturbation approach with the direct method. Expected changes in rainfall was determined as the ratio of the value in the scenario period to the value of the control period, known as perturbation factor while temperature was changed according to difference between control and scenario period. For rainfall, frequency analysis of quantiles method was applied where perturbation factors were obtained by comparing quantiles for given empirical return periods (or values of the same rank) in both the control and scenario series (Chiew 2006; Harrold et al. 2005; Olsson et al. 2009; Willems 2011; Mora et al. 2013). This perturbation calculation was performed considering only wet days where a wet day was defined as a day receiving a minimum rainfall amount of 0.1 mm. We selected 0.1 mm as a standard wet-day threshold based on previous studies such as in Elshamy et al. (2009). Changes in the wet-day frequencies were also calculated following quantile perturbation calculation for the wet-day rainfall intensities. The day-to-day variability was addressed through the adjustment of the length of wet and dry spells. We have used a random approach that kept altering the wet and dry spells. Wet spell was defined as any span of time longer than two consecutive days receiving more than 0.1 mm rainfall. The change in mean wet spell length was then calculated from the wet spells in the control and scenario GCM runs on a monthly basis and was adjusted in the observed rainfall series through adding or removing wet days to the beginning or end of the wet spells in the series. Thus, we have perturbed observed rainfall series in two steps first by removing or adding wet days in the series using the random approach described earlier and secondly by applying intensity perturbation to each wet day dependent on the empirical return period of the rainfall intensity. Direct method implied running the hydrologic simulation with the BIAS corrected GCM data for both current and future conditions. Contemporary GCM data was used as the baseline scenario while future GCM data was used for the mid-century scenario.

Results and Discussions

Projected climate change in the Raccoon River Watershed in mid-century: Changes in climate occurring over both North and South RRW were analyzed using an ensemble of 10 GCM simulations driven by the A1B of the SRES scenario. Raccoon River Watershed was found to have an average 17 % decrease in monthly precipitation while average temperature is expected to decline by 0.43 °C in the mid-century according to the mean projection of all the GCMs.

Monthly analysis for the watershed (Fig. 1) also suggested that climate could have some interesting variations in future. It was found that for RRW precipitation was mostly decreasing on a monthly basis. Summer months comprising May, June, July, and August showed an average of 16 % decrease while winter months of December, January, and February displayed an 18 % decline. This trend of precipitation over the watershed in mid-century clearly suggests that water scarcity could hamper the agricultural practices during the summer months as crops in the growing season needs more water. This trend in precipitation could also impact the hydrological behavior of the watershed as the water input to the system is substantially reduced in a consistent basis. Projected monthly patterns of temperature for RRW in mid-century were found to have different trend than precipitation. While the climate models suggest mostly an increasing pattern for average daily temperature for winter months of November, December, and January, it is predicted that average daily temperature would be decreasing for the other months of the year (Fig. 2) Winter months evidenced an increase of 0.22 °C in average temperature while summer months showed a decrease of 1.06 °C. On an average, monthly average temperature was found to reduce by 0.42 °C.

Impact on hydrological response: After the future scenarios were developed for rainfall and temperature, original and perturbed series were then used to drive the hydrological model to assess the influence of climate change. Hydrological simulation results were statistically processed to study the impact of climate change.

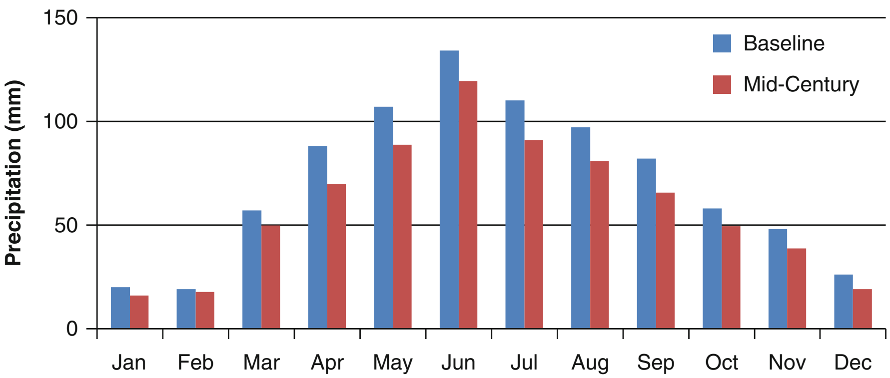


Fig. 1 Comparison of precipitation for baseline (1983–2000) and perturbed baseline according to the frequency perturbation method for the mid-century (2046–2063)

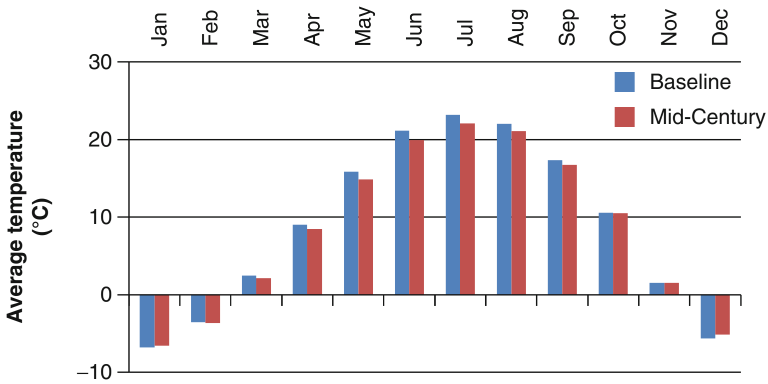


Fig. 2 Comparison of average temperature for baseline (1983–2000) and perturbed baseline according to absolute change method for the mid-century (2046–2063)

Analysis of the changes in terms of both magnitude and percentage suggest that chief hydrological components were significantly affected by the climatic conditions of mid-century. Annual average decrease of 17 % precipitation along with a decrease of 0.43 °C average temperature produced significant changes on projected ET, water yield, and thus overall hydrologic balance. Changes in surface runoff and water yield were found to be 48 % and 25 %, respectively, while baseflow was found to be reduced by 8 %. ET was found to decline by 13 % in mid-century with a magnitude of 79 mm on an annual average basis. A decrease in ET is primarily caused by both reductions in temperature and precipitation. Due to highly nonlinear and complex interactions between the different components of water movement, changes in surface runoff and water yield are not proportional. Water yield which is the total amount of water available at any time was found to decrease by 60 mm while surface runoff and baseflow reduced by 42 and 11 mm, respectively. Monthly variations of water yield (Fig. 3a) showed a wide range of reduction varying from 8 % in August to 62 % in April. April was the highest impact month in terms of reduction in water yield. Winter months are expected to be more affected in terms of water yield reduction with 34 % decline from baseline than summer months when the reduction was found to be 19 %. On an average, 30 % reduction was noticed in water yield on a monthly basis which clearly implies RRW might suffer from water scarcity in the mid-century. ET showed (Fig. 3b) almost a clear decreasing trend for all the months except April when it increased by 34 %. Maximum reduction of water yield was found in the month of April and the increase in ET could be attributed as a reason. A 16 % decrease in precipitation in the summer months almost produced proportional results in ET and water yield as they declined by 19 % and 20 %, respectively. Reason behind decreasing trend of ET is most likely due to the decreasing pattern of the two main variables governing it, i.e., precipitation and temperature. On an average, ET was found to be decreasing from baseline conditions by 15 % on a monthly basis.

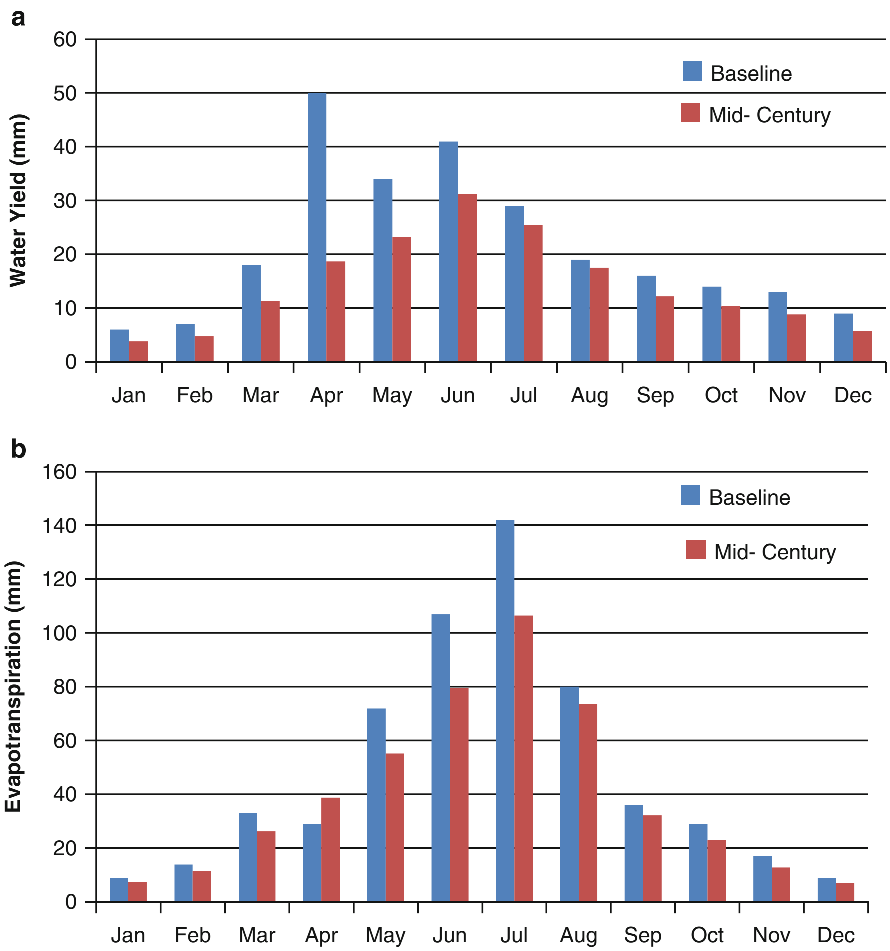
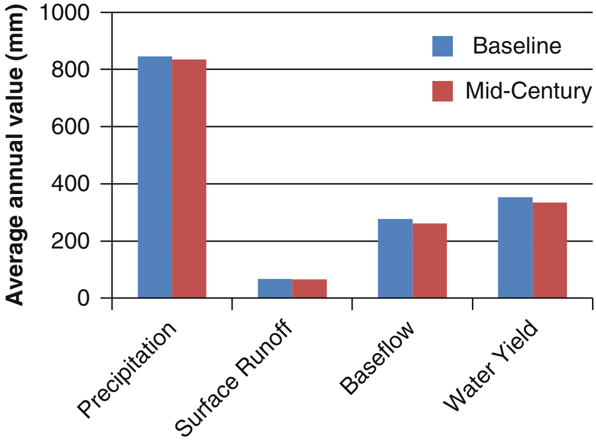


Fig. 3 Comparison of (**a**) water yield and (**b**) evapotranspiration as simulated by SWAT for the baseline and mid-century according to frequency perturbation method

Hydrologic balance of water movement is controlled by precipitation, and evapotranspiration, which finally results in water yield. Directions of water yield changes are following the same trend as precipitation although the changes for water yield are greater in magnitude than the precipitation changes. These results proved to agree with GCM precipitation and temperature predictions used in the hydrologic simulation.

Direct method analysis: Climate change impact assessment was also done using the direct method which assumes that the GCMs are simulating the weather pattern well. It should be mentioned that for direct method "baseline" corresponded to the hydrologic simulation using climate model contemporary data while mid-century corresponded to hydrologic simulation using the future climatic data from the

Fig. 4 Comparison of precipitation over the baseline and mid-century scenario for the Raccoon River watershed according to the direct method



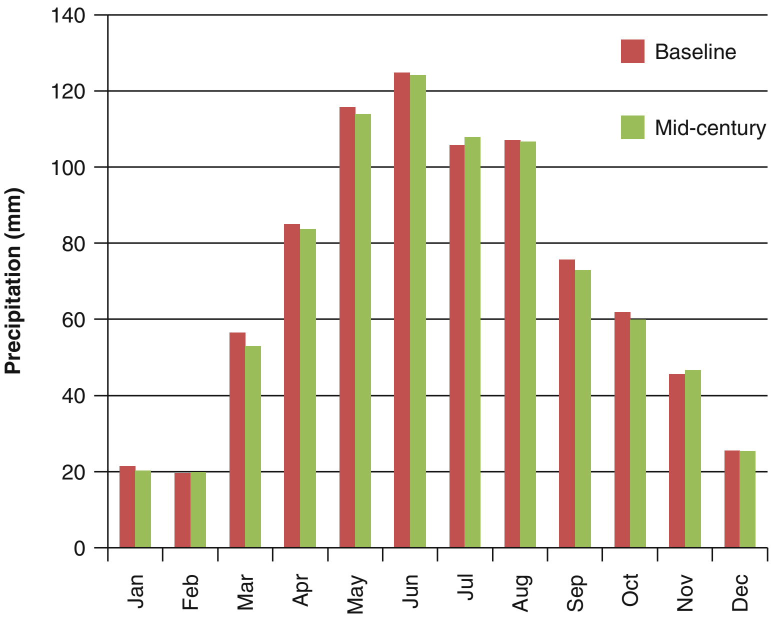


Fig. 5 Comparison of annual water balance components under the baseline and mid-century conditions according to the direct method

climate models. It was found that on an average annual basis, precipitation got reduced by 1.25 % in mid-century as compared to the baseline climatic conditions. Annual average temperature got reduced by 0.17 °C in future. Monthly variations of precipitation revealed mostly decreasing pattern with the exceptions of February, July, and November (Fig. 4). Figure 5 displays the annual water balance components for current and future conditions. ET displayed an increase of 1.8 % on an average annual basis while water yield got reduced by 5 %. Possible interpretation of decreasing water yield could be reducing surface runoff and baseflow by 1.87 % and 6 %, respectively, from the baseline scenario. Comparing the two methods of impact assessment shows an interesting pattern for monthly precipitation. While direct method displayed reductions in small range for winter (December, January, and February) and slight increase for summer months, frequency perturbation method showed steady decrease over all the seasons with the most in winter. However, the general trend appears to be that of a reducing nature.

Conclusions

This study looked upon climate change impact assessment using frequency perturbation approach and direct method. Both methods agreed that watershed is expected to receive less rainfall and the temperature is also expected to reduce in mid-century. For frequency perturbation approach, precipitation declined by 17 % while average temperature reduced by 0.43 °C. Direct method produced 1.25 % decrease in precipitation in mid-century while average annual temperature got reduced by 0.17 °C. According to the frequency perturbation method, ET was found to reduce by 13 %, water yield decreased by 25 % while direct method showed an increase of 1.8 % for ET on an average annual basis while water yield got reduced by 5 %. It was inferred that water scarcity could be an alarming issue for this watershed. By performing the detailed analysis using these two methods, it can be concluded that water resources need to be managed in an efficient way in near future for this region particularly from the agricultural production perspective. Further research is also anticipated considering other downscaling methods of GCM projections on this watershed to have even broader range of climate change impact assessment.

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Trend of Climate Variability in North Carolina During the Past Decades

Mohammad Sayemuzzaman and Manoj K. Jha

Abstract Trend of climate variability in North Carolina for the period of 1950–2009 was investigated in this study with annual scale minimum temperature ($T_{\min}$), maximum temperature ($T_{\max}$), mean temperature (T_{mean}), and precipitation data series from 249 evenly distributed meteorological stations. The trends were tested using Mann–Kendall (MK) test. Theil–Sen approach (TSA) and Sequential Mann–Kendall (SQMK) test were also applied to detect the magnitude and abrupt change of trend, respectively. Lag-1 serial correlation and double mass curve analysis were adopted to check the independency and in homogeneity of the data sets, respectively. For most regions and over the period of past 60 years, trend of $T_{\min}$ was found increasing (on 73% of the stations) while for $T_{\max}$, it was found decreasing (on 74 % of the stations). Although the difference between $T_{\max}$ and $T_{\min}$ trends were decreasing, but increasing trend in T_{mean} represent the overall temperature increasing pattern in North Carolina. Magnitude of $T_{\max}$, $T_{\min}$, and T_{mean} were found to be −0.05 °C/decade, +0.08 °C/decade, and +0.02 °C/decade, respectively, as determined by the TSA method. The SQMK test identified a significant positive shift of T_{mean} during 1990s. For precipitation trends analysis, almost equal nos. of stations was showing statewide positive and negative trends in annual time series. Annually, positive (negative) significant trends, seven (three) nos. of stations were observed at the 95 and 99 % confidence levels. A magnitude of precipitation trend of +3.3 mm/decade was calculated by the TSA method. No abrupt shift was found in precipitation data series over the period by the SQMK test.

M. Sayemuzzaman
Energy and Environmental System Department, North Carolina A&T State University, Greensboro, NC, USA

M.K. Jha (✉)
Department of Civil, Architectural and Environmental Engineering, North Carolina A&T State University, Greensboro, NC, USA
e-mail: mkjha@ncat.edu

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Introduction

Historical trends in surface climate components (such as temperature and precipitation) have received considerable attention in recent years. To predict climate shift, floods, droughts, loss of biodiversity and agricultural productivity, changes in temperature and precipitation pattern needs to be analyzed.

In temperature trend analysis, Degaetano and Allen (2002) found a significant increase in high temperature (both maximum and minimum) across the United States from 1910 to 1996, particularly at urban sites. Trenberth et al. (2007) concluded that the south-eastern United States is one of the few regions on this planet showing cooling trend during the twentieth century. In precipitation analysis, Karl and Knight (1998) reported a 10 % increase in annual precipitation across the United States between 1910 and 1996. Total precipitation has increased across the United States over the last several decades as also found by recent research (Kunkel et al. 2002; Small et al. 2006).

Local climate variability is always more accurate/preferable than global or continental scales because of the finer resolution data (Trajkovic and Kolakovic 2009; Martinez et al. 2012). North Carolina has diverse topographic zone from west mountainous region to east coastal region. The nature of the topography makes complex weather pattern in North Carolina (Robinson 2005). There has been very few published works so far found on climatic variables pattern analysis in North Carolina. Boyles and Raman (2003) predicted precipitation and temperature trend in North Carolina on seasonal and annual time scales during the period of 1949–1998 utilizing 75 precipitation measuring stations. Linear time series slopes were analyzed to investigate the spatial and temporal trends of precipitation. They found that temperatures in North Carolina during the 1950s are the warmest in 50 years, but the last 10 years are warmer than average. They predicted that the precipitation of last 10 years in the study period was the wettest. They also found that precipitation has increased over the past 50 years during the fall and winter seasons, but decreased during the summer.

For the time series trend analysis and the shift of trend detection in hydrometeorological variables, various statistical methods have been developed over the years (Modarres and Sarhadi 2009; Tabari et al. 2011; Martinez et al. 2012; Sonali and Nagesh 2013). Nonparametric method has been favored over parametric methods (Sonali and Nagesh 2013). The chapter presents the trend analysis results for T_{max}, T_{min}, T_{mean}, and average precipitation on an annual scale utilizing the time series data from 249 weather stations across the state of North Carolina.

Materials and Methods

Study area and data. Total area of North Carolina is 52,664 mi^2 which is situated in the southeastern United States (34°–36° 21′ N and 75° 30′–84° 15′ W). Daily T_{max}, T_{min}, and precipitation data series of 249 stations were collected from the United

States Department of Agriculture-Agriculture Research Service (USDA-ARS 2012). The data sets facilitated and quality controlled by National Oceanic and Atmospheric Administration (NOAA) which includes the meteorological stations of both Cooperative Observer network (COOP) and Weather-Bureau-Army-Navy (WBAN). We consider the data sets of the stations based on record length, record completeness, spatial coverage, and historical stability over the period 1950–2009. The data sets are 99.99 % complete (USDA-ARS 2012). Though these data sets have been quality controlled, the double mass curve employed to detect the non-homogeneity/inconsistencies of the data sets, if any. Instrument changes, station shifts, changes of land cover/surrounding conditions may create the non-homogeneity/inconsistencies in hydro-meteorological data recording (Tabari et al. 2011). Tabari and Hosseinzadeh Talaee (2011) applied the double mass curve on their climate variables data sets to check the inconsistency. In our double mass curve analysis, we found almost a straight line with no obvious break points at all the stations of $T_{\max}$, $T_{\min}$, and precipitation data series within the study period. In this study, dense (1 per 548 sq. km.) observation station data indicate an important component of the analyses.

Seasonal and annual time series were obtained from the averaging of daily data for each of the 249 stations. Seasons as adopted from Boyles and Raman (2003) can be defined as follows: Winter (January, February, March); spring (April, May, June); summer (July, August, September); and fall (October, November, December).

Trend Analysis

Mann–Kendall test. The Mann–Kendall test is one of the widely used nonparametric tests to detect significant trends in hydro-meteorological time series. This test makes the comparison of the relative magnitudes of the sample data rather than the data values itself. The most salient features of the MK test are: (a) possess low sensitivity for the nonhomogeneous/inconsistent data sets (Modarres and Sarhadi 2009) and (b) doesn't require the data sets to follow any particular distribution (Gocic and Trajkovic 2013).

Theil–Sen approach (*TSA*). The MK test does not provide an estimate of the magnitude of the trend. For this purpose in this study, a nonparametric method referred to as the Theil–Sen approach (TSA) is used. TSA approach is originally described by Theil (1950) and Sen (1968). This approach provides a more robust slope estimate than the least-squares method because it is insensitive to outliers or extreme values and competes well against simple least squares even for normally distributed data in the time series (Jianqing and Qiwei 2003). TSA approach is also known as Sen's slope estimator. Sen's slope estimator has been widely used by researchers for the trend magnitude prediction in hydro-meteorological time series (Tabari et al. 2011; Martinez et al. 2012).

Sequential Mann–Kendall (*SQMK*) *test*. SQMK test is an extension of the MK method which is widely used to detect the time when trend has a shift (Modarres