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Modeling Climate Change Effects on Hydrology and Water Resources using WEAP and SWAT Models – A Review

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Abstract
With growing evidence in the vulnerability of river basins to water availability due to the potential effects of climate change, managers of natural resources need tools with which can be used to predict and therefore respond to changes in those resources. Hydrologic models are the simplified conceptual representation of a part of the hydrologic cycle, and are primarily used for hydrologic prediction and understanding of the water resources systems processes. A review of some current studies that assess the impacts of climate change using Water Evaluation And Planning (WEAP) and Soil and Water Assessment Tool (SWAT) was undertaken. There is less agreement on the magnitude of change of climatic variables. Still, several studies have shown that climate change will impact the availability and demand for water resources and is likely to affect nearly every aspect of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply to wetlands and wildlife management. Challenges associated with earth observation and in-situ climatic data certainly represent existing research and knowledge gaps in climate change impact analysis.

Keywords: *Climate change, Impact, Vulnerability, Models, Prediction, Demand*

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1. Introduction

IPCC (2013) distinguished weather from climate by defining the former as the description of the conditions of the atmosphere at a certain place and time concerning meteorological elements (precipitation, temperature, pressure, humidity, wind, etc.); and the occurrence of special phenomena, such as thunderstorms, dust storms, tornados and others. On the other hand, climate refers to the average weather and associated statistics (frequency, magnitude, trends, etc.) of relevant quantities over a period ranging from months to thousands or millions of years, but usually 30 years (Flato *et al.*, 2013). Thus, climate change is that change in the state of the climate or deviations from a regional climatology identified by analysis of long-term measurement (using statistical tests, for example) or the changes in the mean and the variability of its properties, and that persists for an extended period, typically decades or longer (UNFCCC, 2007; IPCC, 2013). The drivers of climate change are natural and anthropogenic substances and processes that alter the Earth's energy budget (Flato *et al.*, 2013).

Climate models are an extension of weather forecasting. They analyze long time spans and predict how average a condition will change in a region over time (decades). The models are typically generated from mathematical equations that use thousands of data points to stimulate the transfer of energy and water in the climate system. They also provide a useful framework within which enhanced understanding of climate processes, alongside improved observations, are merged into clear projections of future climate change (Bader *et al.*, 2008; Green, 2016). The three most common types of climate models are: Energy Balance Models (EBM's), Intermediate Complexity Models (ICM's), and General Circulation Models (GCMs). Energy Balance Models help to forecast climate changes as a result of Earth's energy budget; Intermediate Complexity Models describe the climate with less spatial and time-specific detail; and General Circulation Models are the most complex and precise models for understanding climate systems and predicting future climate scenarios (Green, 2016). GCMs are widely in use today and include information regarding the atmospheric chemistry, land type, carbon cycle, ocean circulation and glacial makeup (Ramirez-Villegas *et al.,* 2013).

GCMs data reflect four greenhouse gas concentration trajectories, referred to as Representative Concentration Pathways (RCPs), adopted by the IPCC for its Fifth Assessment Report (AR5) in 2013. These are RCPs 2.6, 4.5, 6.0 and 8.5. However, the four RCPs differ in terms of radioactive forcing, global mean temperature anomaly and global mean CO_2 and reflect underlying assumptions that vary in global population change, economic growth, energy consumption patterns, land use and other environmental parameters (Van-Vuuren *et al.*, 2011). Currently, more than a dozen centres around the world developed climate models as part of the Coupled Model Intercomparison Projects Phase 3 (CMIP3) and Phase 5 (CMIP5) to enhance our understanding of climate and climate change and to support the IPCC activities (IPCC, 2001, 2007, 2013). As a result of the coarse resolution of GCMs, downscaling techniques emerged as a means of relating macro-scale atmospheric variables to grid and sub-grid scale surface variables or, from large-scale atmospheric variables to watershed and sub-watershed scale surface variables (Christensen *et al.,* 2007; Green, 2016). Thus, hydrologic models are the simplified conceptual representation of a part of the hydrologic cycle, and are primarily used for hydrologic prediction and understanding of the hydrologic and water resources systems processes (Gayathri *et al.,* 2015).

So many literatures exist containing a large number of reports detailing the application of hydrologic models to the assessment of the potential effects of climate change on a variety of water resource issues. The purpose of this paper is to review some of the studies on hydrology and water resources modeling for use in simulating the effects of climate change and identify additional research needs.

2. Hydrologic models

The objective of hydrologic models is to study the hydrologic system operation and accurately predict the distribution of water among its various pathways (Leavesley, 1994). Thus, the distribution of water is expressed by the principle of mass conservation or continuity equation.

$$Q = P - ET \pm \Delta S \qquad (1)$$

where Q is a runoff, P is precipitation, ET is evapotranspiration, and ΔS is the change in system storage. Equation (1) is common to all hydrologic models. Thus, hydrologic models for different purposes were developed to solve the continuity equation (Leavesley, 1994). Chow *et al.* (1988) classified hydrological models as; physical and abstract or mathematical models according to description of the physical processes and spatial description of catchment processes respectively (Fig. 1). The classification criteria was based on the purpose of model application, model structure, spatial discretization, temporal and spatial scale (Xu, 2002). Quite a number of hydrological models were applied to assess the effects of climate change on hydrology and water resources of a watershed. Reviewing some of these modeling approaches explores the newest and most advanced ideas in hydrological modeling. Thus, some studies on climate change analysis using Water Planning And Evaluation (WEAP) and Soil and Water Analysis Tools (SWAT) models have been reviewed.

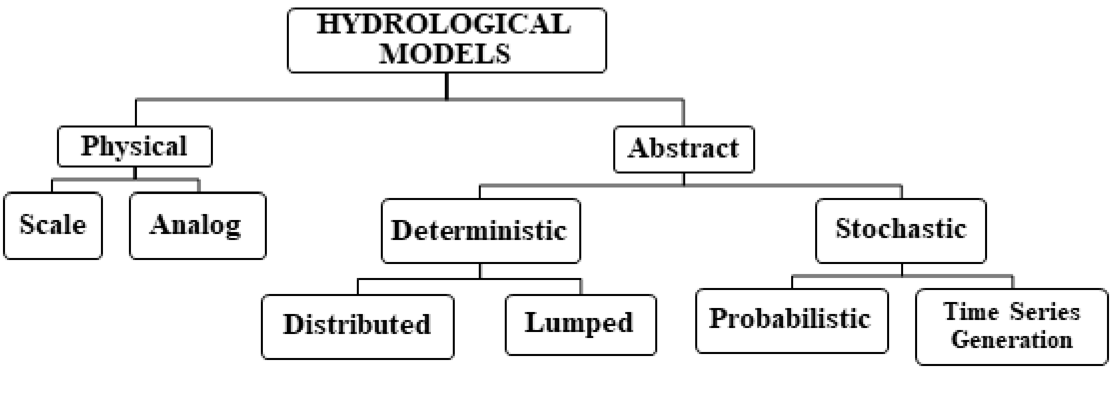

Fig. 1: Classification of hydrological models (Chow *et al.,* 1988)

3. Scenario-based simulations using WEAP and SWAT models

Water and its distribution is greatly influenced by climate change via its effects on supply and demand situations, agricultural sustainability, reservoir management and decision support systems (Ashofteh *et al.*, 2017; Duan *et al.*, 2017; Ahmadaali *et al.*, 2018; Aryal *et al.*, 2018; Bajracharya *et al.*, 2018; Bhave *et al.*, 2018; Khalil *et al.*, 2018; Shiferaw *et al.*, 2018). It is of interest to simulate the effect of possible changes in climate variables alongside population growth that may occur in the near future through scenario-based approaches. Scenarios were created based on the Special Report on Emission Scenarios (SRES), and RCPs of the Intergovernmental Panel on Climate Change (IPPC) coupled with some national policy measures to assess discrepancies in hydrologic components (Blanco-Gutiérrez *et al.*, 2011; Hamlat *et al.*, 2012; Pervez and Henebry, 2015; Abbas *et al.*, 2016a; Adhikari and Nejadhashemi, 2016; Johannsen *et al.*, 2016; Chattopadhyay *et al.*, 2017; Islam *et al.*, 2017; Pham *et al.*, 2017; Spalding-Fecher *et al.*, 2017; Stefanidis *et al.*, 2018; Tiwari *et al.*, 2018). Simulating a catchment's hydrologic response through different scenarios involves calibration and validation of the hydrologic model. Calibration is a process of tuning the model parameters either manually or automatically to compare observed and predicted values based on an objective function. On the other hand, validation is the process of appraising the capabilities of the model to simulate the hydrological components after calibration of the parameters.

3.1 WEAP model

WEAP is a data-driven system that is used in simulating watersheds through a graphical user interface. Its platform provides an integrated assessment of climate, hydrology, land use, irrigation facilities, water allocation, and water management priorities of the watershed. The WEAP model offers a choice of three methods to simulate watershed hydrological processes, namely Soil Moisture, Rainfall-Runoff, and Simplified Coefficient Approach method (Sieber and Purkey, 2007). The conceptual framework of the WEAP model is presented in Fig. 2.

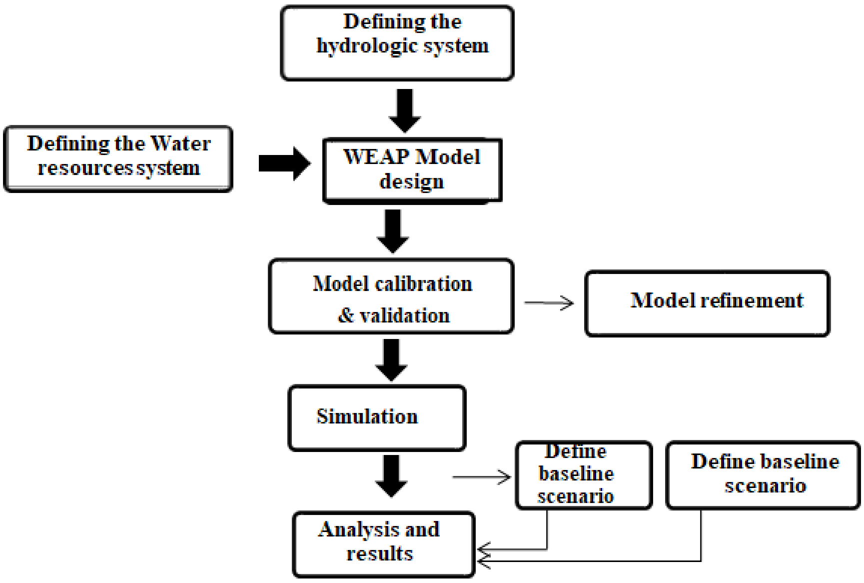

Fig. 2: Conceptual framework of the WEAP model and its setup (Leong and Lai, 2017)

3.1.1 Predicting climate change effects on water resources management using WEAP model

To better understand the hydrology of a river basin and associated water distribution to meet its targeted demand, Mounir *et al.* (2011) used the WEAP model to optimize and allocate present and future Niger River resources between competing water demands. The Niger River Basin, in the Niger Republic, encompasses biosphere reserves, parks with a variety of wildlife, an important livestock activity, very fertile land for agriculture, and a growing industrial sector. Management of water in the basin is very complicated due to socio-cultural, ecological, and economic issues. On the other hand, Blanco-Gtiérrez *et al.* (2011) used the WEAP model to replicate catchment-scale hydrologic processes and represent basin-scale water system operations of the Middle Guadiana basin in Spain. Farmers' behaviour was simulated using a multi-scale economic optimization model to evaluate the potential implications of different water policies under normal and dry climate conditions on the large-scale irrigation systems. The integration of the hydrology and economic models was made empirically by replicating the different irrigation demand nodes and simulating the same scenarios in both models, and technically by an automated wrapper interface to facilitate the exchange of data between the two models. The study proves that the accuracy of the models in predicting farmers' and water systems' behaviour improves when the economic and hydrology models are coupled together, evidencing the potential of integrated tools in replicating the reality of complex water systems. More so, Comair *et al.* (2012) studied water resources management of Jordan River Basin. The study analyses the results of WEAP by reviewing the vulnerability of water resources in the Lower Jordan River under a changing climate pattern and growing water demands. The model shows that all aquifers supplying the city of Amman will be depleted within the next few decades. Hamlat *et al.* (2013) used WEAP to simulate water resources management scenarios in western Algeria watersheds. The results of the study confirmed that WEAP software offers a solid basis to assist planners in developing recommendations for future water resource management by revealing hot spots of action. Bhave *et al.* (2014) assessed the potential effects of climate change on water resources and evaluated stakeholders prioritized adaptation options to address adaptation requirements using the WEAP model. The model highlights the merits of a comparative assessment of adaptation options. In conclusion, a combined approach involving stakeholders, scenario analysis, modeling techniques, and multi-model projections may support climate change adaptation decision-making in the face of uncertainty. Esteve *et al.* (2015) used WEAP in developing a hydro-economic model to assess climate change impacts and adaptation in irrigated agriculture. WEAP provides a representation of the physical and spatial dimensions of water resources and climate, which is essential for assessing climate change and, specifically, for the representation of the supply side of water management. Johannsen *et al.* (2016) applied WEAP to Middle Draâ valley in Morocco to determine water demand and supply, including several socioeconomic and land-use scenarios under one basic climate change scenario. The climate scenario shows a significant decrease in available water resources up to 2029 while all socioeconomic scenarios show an increase in water demand. Spalding-Fecher *et al.* (2017) uses the WEAP model to study and develop integrated water and power scenarios for the Zambezi River Basin. This is to engage stakeholders and inform decision-makers to assess potential climate change impacts on water availability and energy security in the basin and the southern African Power Pool. The results indicated that for the expansion of existing hydropower stations and construction of new ones (both reservoir and runoff-river), there is a critical need to integrate both climate change and upstream development demands into the feasibility studies before investment decisions are made, and to consider possible adaptations in design and operation. Leong and Lai (2017) employed a simple integrated water resources management model developed based on WEAP to demonstrate how efficient the complexity of a water system can be managed by this methodology. The models illustrate the application of the suggested method to a specific catchment area (Langat River basin, Malaysia). The model was able to simulate various possible future scenarios to evaluate the current and future water management system of Langat River Basin and acts as an integrated management planning network for decision makers to resolve conflicts over water allocation. WEAP was applied to evaluate the impact of climate change and population growth on groundwater resources of the Klela basin in Kenya (Toure *et al.*, 2017). The results showed that groundwater storage is decreasing mainly due to climate change effect and human activities. Gao *et al.* (2017) applied the WEAP model for Strategic Environmental Assessment (SEA) in measuring the impact of the implementation of a proposed plan on the local water resource system in arid and semi-arid areas of China. The model made it easy to simulate and compare the results of different water utilization scenarios. With this first experience in China, the WEAP model appeared to be a useful tool for the rapid assessment of water utilization as part of the SEA conclusion. Duque and Vázquez (2017) worked on monthly water balance modeling to plan an irrigation project located in a semi-arid zone of southern-central Chile, using historical data and predictions of climate change conditions. The researchers use WEAP21 as a modeling tool. However, concerning historical records, the mean annual climate forecasts suggest a maximum temperature increment of about +1.1ºC and a maximum reduction in precipitation of 20.7%. The hydrological modeling suggests a maximum reduction in the mean annual streamflow of 49.7% and a reduction in the magnitude and frequency of streamflow peaks. They concluded that with the potential uncertainties attached to climate change projections, the irrigation project would most probably be significantly affected in terms of water availability and crop water consumption. This is because rainfall is expected to decrease, while temperature and evapotranspiration may likely increase. Khalil *et al.* (2018) used the WEAP model to assess the current water supply and demand situations in Mae Klong Basin, Thailand. The researchers established six different scenarios to evaluate the response of the basin to increasing demands under two Special Report on Emissions Scenarios (SRES); scenarios A2 and B2. The results revealed that the water resources in the basin is sufficient to meet the existing needs in the wet season. The results further showed that more water shortages occurred under the A2 scenario as compared to the B2 scenario. Thus, for the six developed scenarios, there are indications of water shortages causing the basin to face water scarcity, particularly in scenario five, where transferring water to the adjoining area is difficult to possibly be implemented. Thus, the implemented WEAP model for the basin can be a useful tool for decision-makers in terms of the effective management of water resources. Ahmadaali *et al.* (2018) evaluated the indices of environmental and agricultural sustainability using performance criteria influenced by climate change and water management strategies for the Zarrinehrud and Siminehrud River basins using the WEAP21 model. Three future emission scenarios (A2, A1B, and B1), for the period of 2015-2040 were adopted for the model. Subsequently, five water management scenarios were incorporated to evaluate the basin's response to future emission scenarios. The results showed that the highest values indices of environmental and agricultural sustainability were related to the scenario of combining the crop pattern change with improving the total irrigation efficiency under the B1 emission scenario (B1S4). Bhave *et al.* (2018) developed an iterative Multi-Decision-Making under Uncertainty (M-DMUU) approach, including scenario generation, a coproduction with stakeholders, and water resources modeling. The researchers further applied this approach to explore the robustness of adaptation options and pathways against future climate and socioeconomic uncertainties in the Cauvery River Basin in Karnataka, India. In the study, WEAP model was adopted and was calibrated and validated satisfactorily using observed streamflow. The calibration and validation focused on the simulation of monthly and annual flows at the most downstream gauging stations in the basin. Reasonable future changes in Indian Summer Monsoon (ISM) precipitation and water demand were used to drive simulations of water resources from 2021 to 2055. The results revealed how changes in both climatic and socioeconomic factors strongly influence future water resource system performance. It further found an iterative approach to DMUU valuable because it enabled the analysis evolve to suit the decision context and stakeholder requirements. Consequently, it facilitated stronger stakeholder engagement and feedback, which is an important constituent of knowledge coproduction. In contrast to the previous studies, Al-Zubari *et al.* (2018) worked on assessment of the vulnerability of municipal water management systems to the impacts of climate change in the Kingdom of Bahrain. The model was developed using WEAP software and was calibrated and validated by historical data for 2000–2012. The model was used to evaluate the municipal water sector performance in terms of municipal water demands, and their associated cost without and with climate change impacts scenarios for 2012–2030. The impact of climate change on the municipal water system was quantified as the difference between the two scenarios in three selected cost indicators: financial (production, conveyance and distribution costs), economic (natural gas asset consumption by desalination plants), and environmental (CO_2 emissions by desalination plants). The results revealed that the current municipal water management system in the study area was generally inefficient and associated with relatively high costs, which are expected to increase with time under the current policies and management approach, focusing on supply-side management. The increase in temperature will increase these already high costs, and would exacerbate the water management challenges. The results further indicated a large potential for reducing the municipal water demand and its associated cost by the year 2030.

3.1.2 Predicting climate change effects on surface water resources using WEAP model

The projected impacts of climate change on basin hydrology depend on so many factors that include precipitation, air temperature, and evapotranspiration. Several studies revealed that an increase in evapotranspiration value leads to a decrease in storage volume in surface waters. Recently, Ashofteh *et al.* (2017) studied the effects of climate change on water resources and water uses in a multipurpose reservoir, East Azerbaijan, in Iran. The researchers tried to minimize the effects of shortages resulting from climate change in sections of water resources, and water uses with proper management, utilizing HadCM3 GCM (under the emission scenarios A2). Simulation results from the WEAP model showed that inflow to the reservoir is decreased in climate change interval compared to the baseline interval (1971–2000) so that comparison of long-term average monthly inflow to the reservoir in climate change interval is reduced to about 25% compared to the baseline. Pham *et al.* (2017) offered a simple process for investigating climate change impacts on streamflow and subsequent water shortage at downstream of the Thac Mo reservoir in Vietnam. By integrating GCMs output and the WEAP model, the streamflow and subsequent water shortage for the baseline (1994–2003) and future scenario (2046–2064) were simulated. The results indicate that mean streamflow tends to increase around 10.1% in the wet season due to an increase in rainfall but also tends to decrease in December (-4.4%), January (-1.0%), and February (-0.85%) of the dry season relative to the baseline scenario. Consequently, the downstream of the Thac Mo reservoir may face a big challenge in the dry season in terms of water use. On the other hand, Faiz *et al.* (2017) investigated the influence of climate on the streamflow in Songhua River Basin (SRB), Northeast China, utilizing the Integrated WEAP tool coupled with observed precipitation data, as well as the Asian Precipitation-Highly-Resolved Observational Data Integration (APHRODITE). The results indicated that WEAP could be used effectively in the SRB. Thus, the application of the model suggested a maximum decline in streamflow, reaching 24% until the end of the 21st century under future climate change scenarios. The drought indices (standardized drought index and percent of the normal index) revealed that chances of severe to extreme drought events are highest in 2059, 2060 and 2085, while in the remaining period, mild to moderate drought events may occur in the entire study area.

3.2 SWAT model

The SWAT model is semi-distributed physically-based simulation model to predict the impacts of land-use change, and management practices on hydrological regimes in watersheds with varying soils, land-use and management conditions over long periods and primarily as a strategic planning tool (Arnold *et al.*, 1998; Neitsch *et al.*, 2005). SWAT possesses the ability to model a particular watershed or a network of several watersheds that are hydrologically linked in a location (Neitsch *et al.*, 2011). The conceptual framework of the SWAT model is presented in Fig. 3.

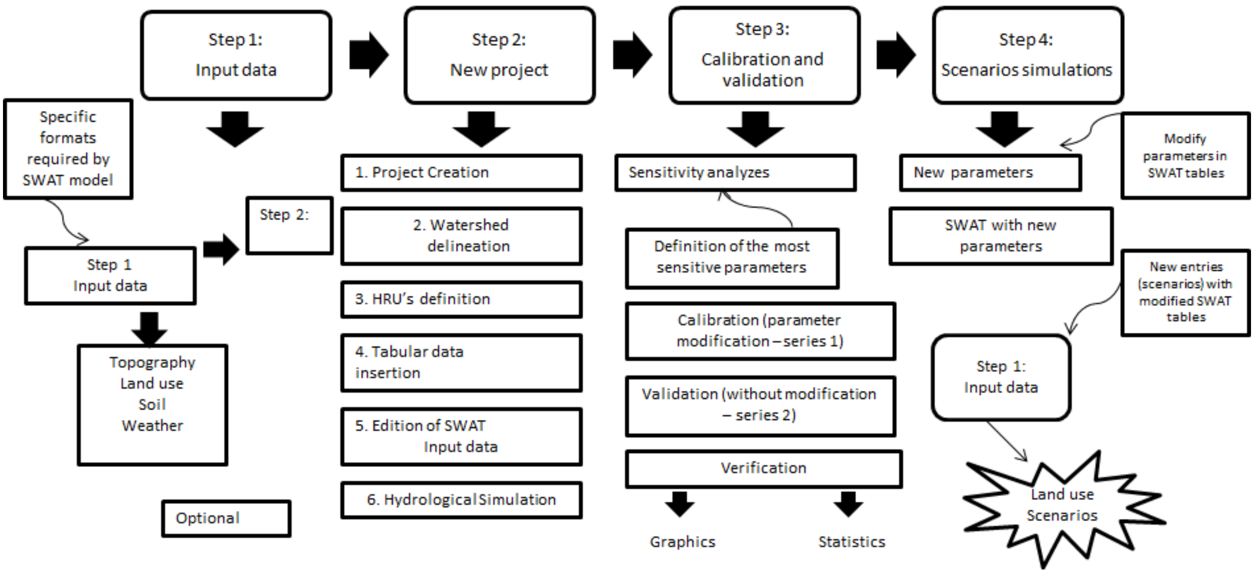

Fig. 3: Conceptual framework of the SWAT model (Andrade *et al.*, 2020)

3.2.1 Predicting climate change effects on water resources management using SWAT model

In recent times, GCMs are being used to forecast changes in future climate. The outputs of different GCMs were used by several studies in modeling water resources management alongside socio-economic aspects. Jin and Sridhar (2011) simulated the Boise and Spokane River Basins for a basin-scale hydrology by coupling the downscaled precipitation and temperature outputs from a suite of global climate models and the SWAT model between 2010 and 2060 and assessed the impacts of climate change on water resources in the region. The results of their study indicated that precipitation and temperature projections between 2010 and 2060 exhibited a wide range. For the Boise River Basin, changes in precipitation ranged between -3.8% and 36%, and changes in temperature were expected to be between 0.02 and 3.9 °C. In the Spokane River region, changes in precipitation were expected to be between -6.7% and 17.9 % and changes in temperature appeared ranging between 0.1 and 3.5 °C throughout next five decades between 2010 and 2060. In the Boise River basin, change in peak flows (March through June) was projected to range between -58 to +106m^3/s, and for the Spokane River basin the range was expected to be between -198 m^3/s and +88m^3/s. Consequently, both basins exhibited substantial variability in precipitation, evapotranspiration, and recharge estimates. Thus, these range of possible hydrologic impacts at a local scale were expected to enable the stakeholders with possible options in their decision-making process. SWAT model was applied to the Khabour Basin in Kurdistan, Iraq at monthly time steps by Abbas *et al.* (2016a). Weather data, including daily precipitation, 0.5 hourly precipitation, maximum and minimum temperatures alongside streamflow data were utilized for the study. The model was calibrated and validated at the Solo Zakho discharge station to simulate the streamflow. The calibrated model was used for identifying the trends of water components in the last three decades. The findings were matched with observations, and the model was applied for assessing the impacts of climate change in the near future (2046-2064) and distant future (2080-2100) under three emission scenarios (A2, A1B, B1) using six GCMs. All models run under three emission scenarios predicted that the catchment would be drier in the near and distant futures. Precipitation, blue water, and green water flows were found to significantly decrease from 1980 to 2010. The results of the study, therefore, could be advantageous in detecting appropriate water resources management strategies and cultivation practices for the future. Adhikari and Nejadhashemi (2016) did a similar work by examining climate change impacts on water resources in the African country of Malawi. The researchers used downscaled outputs from six GCMs, for the most extreme Representative Concentration Pathway (RCP 8.5) as inputs to the SWAT model. The findings of the study revealed that a -5.4% to +24.6% change in annual rainfall, a -5.0% to +3.1% change in annual evapotranspiration, and an increase from –7.5% to over +50% change in annual surface runoff and water yield, and up to an 11.5% increase in annual soil moisture were predicted at the country level. Meanwhile, at the watershed level, an increase in annual rainfall and evapotranspiration in the north and a gradual decline towards the south were predicted. Sub basin-level analysis showed a large probability of an increase in the annual precipitation, surface runoff, water yield, and soil moisture, especially in the north. Conclusively, the northern region was found to be more prone to floods, while the southern region was found to be more prone to droughts. Abbas *et al.* (2016b) used the SWAT model to evaluate the impacts of climate change on water resources in Al-Adhaim Basin, North East of Iraq. Six GCMs (CGCM3.1/T47, CNRM-CM3, GFDLCM2.1, IPSLCM4, MIROC3.2 (medres) and MRI CGCM2.3.2) were used under a very high emission scenario (A2), a medium emission scenario (A1B), and a low emission scenario (B1) for two future periods (2046-2064) and (2080-2100). The projected temperatures and precipitation were then inputted into the SWAT model to compare water resources in the basin with the baseline period (1980-2010). The researchers tested the model for its suitability in capturing the basin characteristics. They used the aforementioned six GCMs output to evaluate the impacts of climate change on water resources under three emission scenarios: A2, A1B, and B1. The calibration and validation results showed good performance of the model in simulating hydrological processes. The results revealed that all models showed good agreement with the observed data. It further predicted that the whole basin might be extremely dry in the near and far future. Thus, this might enable decision-makers to find suitable water resources management and crop production for the future. Huyen *et al.* (2017) predicted and evaluated changes of water resources in the Srepok watershed, central highland of Vietnam, under the impact of climate change scenarios using the SWAT model. The study used observed weather data (temperature and precipitation) and climate change data based on dynamic downscaling of global change scenarios generated by ECHAM4 GMC and the use of the PRECIS regional climate model (RCM). Calibration and validation were achieved for a baseline period of (1990–2010) scenario. However, for investigating the impacts of climate changes scenarios on the streamflow, the future prediction separated the A1B and A2 emission scenarios into two future periods (2011–2039 and 2040–2069). Thus, the validated model parameters were run for the scenarios. After comparing the model output of climate scenarios to the baseline period scenario, the following conclusions were made: future minimum and maximum daily average temperature would rise in all climate change scenarios, and the amount of annual precipitation would fall in scenario A1B and goes up in scenario A2. Thus, the annual water discharge in scenario A1B decreased by 11.1% and 1.2% during the second and third periods, respectively, compared with the first. In scenario A2, annual water discharge increased by 2.4% during the second period but decreased by 1.8% during the third period. Aryal *et al.* (2018) sought to quantify the various sources of uncertainty in assessing climate change impact on hydrology in the Tamakoshi River Basin, located in the north-eastern part of Nepal. The researchers utilize four Regional Climate Models (RCMs), namely ACCESS 1, CNRM, MPI, and REMO, to project the future climate in the study area. The spatial resolution (0.44° × 0.44°), emission scenarios (RCP 4.5 and RCP 8.5), and future climate period (2006–2099) were the same for all climate models applied in the research. Multiple climate and hydrological models were used to simulate future climate conditions and discharge in the basin. The simulated results of future climate and river discharge were analyzed for the quantification of sources of uncertainty using two-way and three-way ANOVA. The results showed that temperature and precipitation in the study area were projected to change in near- (2010–2039), mid- (2040–2069) and far-future (2070–2099) periods. The maximum temperature was likely to rise by 1.75°C under Representative Concentration Pathway (RCP) 4.5 and by 3.52°C under RCP 8.5. Similarly, the minimum temperature was expected to rise by 2.10°C under RCP 4.5 and by 3.73°C under RCP 8.5 by the end of the twenty-first century. More so, the precipitation in the study area was expected to change by − 2.15% under RCP 4.5 and − 2.44% under RCP 8.5 scenarios. Both minimum and maximum temperatures were expected to rise in each of the three-time periods (near-future, mid-future, and far-future), whereas precipitation was expected to decrease. Thus, the study concluded that future climate variables and river hydrology contain uncertainty due to the choice of climate models, RCP scenarios, bias correction methods, and hydrological models. Bajracharya *et al.* (2018) did a similar study on climate change impact assessment on the hydrological regime of Kaligandaki Basin, Nepal using the SWAT model. The researchers utilize the RCP 4.5 and RCP 8.5 of ensemble downscaled CMIP5 GCM outputs (precipitation and temperature). The findings revealed that extreme projection of an RCP 8.5 scenario would result in the average annual temperature of the basin to increase by >4°C. Likewise, the average annual precipitation in the basin might increase by as much as 26% during the late century. The synergetic effect of an increase in temperature and precipitation shows the aggravated effect on the discharge and water yield with an increase of more than 50% at basin's outlet. Snowmelt, on the other hand, largely contributes to the increase in discharge, as snowmelt was anticipated to increase by as much as 90% during the 2090s. Conclusively, there does not seem to be a problem of water availability in the Kaligandaki basin in this century considering a projected increase in precipitation, snowmelt, water yield, and discharge. Stefanidis *et al.* (2018) examined the response of a multi-stressed Mediterranean river to future climate and socio-economic scenarios in Europe by analyzing projected surface air temperature and precipitation produced by two climate models, GFDL-ESM2M and IPSL-CM5ALR, after applying bias correction with linear scaling from 1975-2010. Scenarios in the study were based on combinations of RCPs and Shared Socioeconomic Pathways and referred to the early century (2030) and mid-century (2060) representing future climate worlds with particular socioeconomic characteristics. The study revealed that the techno world scenario driven by fast economic growth and intensive exploitation of energy resources had the largest impact on both the abiotic status (nutrient loads and concentrations in water) and the biotic indicators. The predicted changes under the other two future worlds, consensus and fragmented, were more diverse and were mostly dictated by the projected climate.

Thus, it showed that the future scenarios, especially the mid-century ones, had a significant impact on both abiotic status and biotic responses, underpinning the need for implementing catchment management practices able to mitigate the ecological threat on waters in the long-term. Tiwari *et al.* (2018) examined the mid-21st century climate projections over Satluj, western Himalayas from the CMIP5 global climate models under RCP scenarios (RCP4.5 and RCP8.5). Seven GCM models were chosen to analyze the present-day (historical) and projected climate from RCP 4.5 and 8.5 for temperature and precipitation. The highest emission scenario RCP8.5 was the first priority and the scenario with stabilization without overshoot, i.e., RCP4.5, was the second priority for the study. All the global climate models used in the analysis indicated that the study region would be warmer by mid-century. The temperature trends from all the models studied were statistically significant at 95% confidence interval. Thus, from the study, multi-model ensemble spreads showed that there were large differences among the models in their projections of future climate with spread in temperature ranging from about 1.5°C to 5°C over various areas of western Himalayas in all the seasons. Spread in precipitation projections lies between 0.3 and 1 mm/day in all the seasons. The reduction of precipitation from June to September was expected to be greater than 3–6 mm/day in RCP8.5 as compared to the present climate. It was expected that precipitation amount should increase over the basin in the future (mid-21st century). Conclusively, the SWAT model with downscaled output indicates that during winter and spring, more discharge shall occur in future (RCP8.5).

3.2.2 Predicting climate change effects on surface water resources using SWAT model

It is well known that changes in climate accompanied by land-use significantly alters hydrological responses, in particular runoff patterns. To demonstrate such effects, Pervez and Henebry (2015) assessed the impacts of climate and land-use and land cover change on the freshwater availability in the Brahmaputra River basin, Bangladesh. The researchers utilize daily observed precipitation data of 23 gauging stations, daily observed maximum and minimum temperatures, and daily observed discharge data at Bahadurabad gauge station obtained from the National Oceanic and Atmospheric Administration (NOAA) Global Surface Summary of Day (GSOD) data set and Climate Forecast System Reanalysis (CFSR) weather data over 16 years (1988–2004) as input to SWAT model. The observed precipitation and weather data (temperature, relative humidity, and wind speed) were processed for 1988–2004. The period 1988–1997 was used to calibrate the model, and 1998–2004 (excluding 2002) was used to validate the model. Model spin-up time was achieved using the first two years for each simulation, excluding the missing data year of 2002. The researchers calibrated the SWAT model at the basin level using observed river discharge at the Bahadurabad gauging station. The calibrated model was then run for the period 1998–2004 for validation by keeping the optimized parameters constant and allowing only the observed precipitation to vary. The calibrated and validated model was run for the entire period 1988–2004 under an average atmospheric CO_2 concentration of 330 ppm and subjected to uncertainty analysis with a sequential uncertainty fitting algorithm. The sensitivities and impacts of projected climate and land-use changes on basin hydrological components were simulated for the A1B and A2 scenarios and analyzed relative to a baseline scenario of 1988–2004. The results revealed that basin average annual evapotranspiration was found to be sensitive to changes in CO_2 concentration and temperature. At the same time, total water yield, streamflow, and groundwater recharge were sensitive to changes in precipitation. The basin hydrological components were predicted to increase with seasonal variability in response to climate and land-use change scenarios. Strong increasing trends were predicted for total water yield, streamflow, and groundwater recharge, indicating exacerbation of flooding potential during August – October, but strong decreasing trends were predicted, indicating exacerbation of drought potential during May – July of the 21st century. Thus, the model was observed to have the potential to facilitate strategic decision-making through scenario generation integrating climate change adaptation and hazard mitigation policies to ensure an optimized allocation of water resources under variable and changing climate. Ahiablame *et al.* (2017) did similar work, evaluating the streamflow response to potential land-use, and climate changes in the James River watershed, Upper Midwest, United States. The study adopted three projected climate change scenarios (A1B, A2 and B1) of three GCM (CGCM3.1, GFDL-CM2.1, and HADCM3) and was developed for mid (2046–

2065) and end (2080–2099) of the 21st century for analysis using SWAT model. Corresponding land-use maps for years 2055 and 2090 were obtained from the FOREcasting SCEnarios of Land-Cover (FORE-SCE) model. The scenarios were designed so that land-use be changed while climate conditions remain constant, land-use was then held constant under a changing climate, and finally, both land-use and climate were changed simultaneously to reflect possible future land use and climate conditions. The results from the study revealed that potential land-use and climate changes would result in 12–18% and 17–41% increases in annual streamflow, respectively, by the end of the century. The combined effects of land use and climate changes would intensify future streamflow responses with 13–60% increases in the region. Thus, the study provides a broad perspective on plausible hydrologic alterations in the region, prompting individual and collective opportunities to engage with the topic for sustainable planning and management of watersheds. Acharya (2017) quantified the impacts of climate change on water availability over the Flint River sub-watershed (FRW) located in the Wheeler Lake Watershed (WLW) in northern Alabama, USA. The researcher utilizes observed climate data from the Alabama Mesonet stations and modeled climate projections (GCMs) obtained from four emission scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) of the World Climate Research Program's database and CMIP5. The researcher used the SWAT model and was calibrated and validated for the period of 2004 to 2013, based on daily meteorological forcing and monthly streamflow data. Various climate scenarios were developed concerning the anticipated future climate until 2100, based on representative concentration pathways (RCPs). They were forced into the calibrated SWAT model to quantify future water availability. The GCM-modeled climate data for precipitation and average temperature were compared for future periods: the 2030s (2025–2035), the 2050s (2045–2055), the 2070s (2065–2075), and the 2090s (2085–2095), with respect to the base period, the 2010s (2004–2014). A change factor/percent was calculated between the present and future average monthly precipitation and applied proportionally to the daily precipitation to perturb it to the future climate. Thus, in a comparison of climate data for future periods (the 2030s/2050s/2070s/2090s) with respect to the base period (2010s), monthly temperatures showed an increasing pattern for all scenarios until the end of the century, except for RCP 2.6, which showed comparatively larger temperature changes during the 2050s and 2070s. RCP 8.5 showed the highest increase in temperatures among all scenarios. The overall outcome of the study showed that the simulated average change in monthly streamflow varied from +23 to −46%, +29 to −48%, +40 to −48%, and +38 to −48% for scenarios RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 respectively, and the simulated total annual streamflow varied from +18 to −28%. However, the average change in total annual stream flow based on all scenarios showed a decreasing pattern from −0.3 to −1.2% for future periods, except for a slight increase of +0.17% at the end of this century. Consequently, the simulated results that quantified water availability under changing future climate conditions could be used by water managers, stakeholders, and decision-makers in planning and managing available water resources and their allocations based on users and water demands, and in considering alternatives for monitoring and mitigating long-term impacts. Chattopadhyay *et al.* (2017) evaluated the potential impacts of climate change on hydrologic processes in the Kentucky River basin using the SWAT model. The SWAT model was forced with downscaled and bias-corrected forecasted precipitation and temperature outputs from a suite of eight CMIP5 GCMs, corresponding to two different representative concentration pathways (RCP4.5 and 8.5) for two distinct periods (2036 – 2065 and 2070 – 2099) referred to as midcentury and late-century, respectively. The results revealed that relative to the baseline period, corrected GCM projections indicated a modest basin-wide increase in precipitation (2.5 – 5%, with relatively consistent increases in the winter) with a more substantial basin-wide increase in average annual temperature (2 – 4.7 °C, with greatest increases during the summer months), depending on timeframe (mid-century or late-century) and RCP scenario (4.5 or 8.5). Similar basin-wide increase (3 – 5% relative to baseline) was projected for Evapotranspiration (ET), with the greatest increase during the winter and decrease in the summer. Basin wide water yield was projected to increase by 2 – 5%, though the pattern of increasing and decreasing months appears more related to the RCP scenario than for other variables. Thus, basin-wide, there was very little projected change in the proportion of time in a drought condition or the average length of drought conditions. Duan *et al.*

(2017) used the SWAT model to evaluate the impacts of possible future climate change scenarios on the hydro-climatology of the upper Ishikari River basin, Hokkaido, Japan. The researchers used the Statistical Downscaling Model (SDSM) version 4.2 to downscale the large-scale Hadley Centre Climate Model 3 GCM A2 and B2 scenarios data into finer scale resolution. After model calibration and testing of the downscaling procedure, the SDSM-downscaled climate outputs (temperature and precipitation) were used as an input to run the calibrated SWAT model for three future periods: 2030s (2020–2039), 2060s (2050–2069), and 2090s (2080–2099). The period 1981–2000 was considered as the baseline period against which comparison were made. In the study's assertion, the average annual maximum temperature might increase by 1.80 and 2.01, 3.41 and 3.12, and 5.69 and 3.76 ^{0}C, the average annual minimum temperature might increase by 1.41 and 1.49, 2.60 and 2.34, and 4.20 and 2.93 ^{0}C, and the average annual precipitation might decrease by 5.78 and 8.08, 10.18 and 12.89, and 17.92 and 11.23% in 2030s, 2060s, and 2090s for the A2a and B2a emission scenarios, respectively. Furthermore, the annual mean streamflow might increase for all the three future periods except the 2090s under the A2a scenario. Comparing the results obtained, the largest increase was observed in the 2030s for A2a scenario, up to approximately 7.56%. Conclusively, uncertainties were found within the GCM because only one single GCM (HaDCM3) was used in the study. Islam *et al.* (2017) set up a SWAT model over ungauged Braha-Putra river basin in Bangladesh to evaluate the hydrological response of the basin to climate change using CMIP5 GCM ensemble. The study used long-term observed records of stream flow and climate data (temperature and precipitation) integrated with a weather generator model called WGEN, which is an Excel macro designed to generate climatic data or fills missing data using monthly statistics, which are calculated from existing daily data. Regional Climate Models (RCMs) were simulated for the historical period from 1980 to 2009 which were considered as the baseline for historical simulations. Future river discharge for the river basin was estimated for three-time windows, i.e., 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099), and the model was simulated and forced by the RCP8.5 scenarios of 11 RCMs. Thus, the results indicated that there was an increasing tendency of discharge of the River at Bahadurabad station during monsoon; when flood usually occurs in Bangladesh. In a similar study by Reshmidevi *et al.* (2017) to evaluate the impact of climate change on the water balance of a catchment in India, the researchers simulated rainfall and hydro-meteorological variables for current GCM scenario (1981-2000) and two future periods: mid of the 21st century (2046-2065), and end of the century (2081-2100) using Modified Markov Model-Kernel Density Estimation (MMMKDE) and k-nearest neighbour downscaling models. The study used climate projections from an ensemble of 5 GCMs (MPI-ECHAM5, BCCR-BCM2.0, CSIRO-mk3.5, IPSL-CM4, and MRI-CGCM2). SWAT model was adopted in hydrologic simulations of the current as well as future climate scenarios. The results showed a marginal reduction in runoff ratio, annual streamflow and groundwater recharge towards the end of the century. Increased temperature and evapotranspiration suggested that there will be an increase in irrigation demands towards the end of the century. Rainfall projections for the future showed marginal increase in the annual average rainfall. Short and moderate wet spells were projected to decrease, whereas short and moderate dry spells were projected to increase in the future. The projected reduction in streamflow and groundwater recharge, along with the increase in irrigation demand, are likely to aggravate the water stress in the region under the future scenario. Shiferaw *et al.* (2018) evaluated surface runoff generation under climate change scenarios for Ilala watershed in the Northern highlands of Ethiopia using the SWAT model. The researchers analyze climate change scenarios using delta based statistical downscaling approach of two representative concentration pathways (RCPs), 4.5 and 8.5, in R software package. The study used the Soil Water Analysis Calibration and Uncertainty Program of Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm to compute the uncertainty analysis, calibration and validation process. The results showed that the minimum and maximum temperature increases for the future by 1.7 and 4.7°C, respectively. The rainfall doesn't show any significant change in the study area. The 95% prediction uncertainty brackets the average values of observation by 71 and 74% during the calibration and validation processes, respectively. Thus, the researchers concluded that there would be a considerable effect of climate change on surface runoff. Therefore, it called for water managers' decisions and policymakers to follow a direction mechanism for adaptation and mitigation measures. Swain and Patra (2018) assessed the impact of land-use/land cover (LULC) and climate change on streamflow regionalization in ungauged catchment of India. The researchers sought out to quantify the effect of land-use/land cover, and climate on the streamflow in some selected 32 catchments spread over Jharkhand, West Bengal, Chhattisgarh, Odisha, Telangana, Andhra Pradesh, Tamil Nadu, Karnataka, and Maharashtra. SWAT, in combination with two regionalization techniques, i.e., Inverse Distance Weighted and Kriging were applied. Analysis of temperature, precipitation, and streamflow data were made using two time periods: the first period (1990–2000) was considered as the calibration period, while the second period (2001–2011) was treated as the validation period. Impact assessment of land cover change on streamflow regionalization was analyzed using land-use decadal data of India for the years 1995 and 2005. The trend analysis was carried out for annual rainfall and mean annual temperature to analyze the change in pattern using the Mann–Kendall test, a non-parametric method. The study revealed that the climate factor overshadowed the effect of LULC. Thus, there might be a correlation between the increase in temperature and the decrease in rainfall volume, which was distinctive in a monsoon-dominated country like India.

4. Conclusions

Researchers in the field of hydrology, water resources and other disciplines are progressively using hydrological models to study the potential impacts of future changes in climate and land use. While modeling is an uncertain and probabilistic process, it is a useful methodology for investigating and studying the hydrologic phenomena operating in a catchment and how changes in the catchment may affect these phenomena, thus, projecting possible ranges of impacts that may be faced by water resource managers over the next several decades. The present review is concerned with modeling approaches to assess the effect of climate change on hydrology and water resources and the importance of scenario-based studies using WEAP and SWAT models. Several studies attempted to simulate the impact of scenario-based changes in climate on the hydrologic system. The scenarios were developed, incorporating SRES and RCP's of IPCC and national policies. The results of the climate change scenarios were compared to select the appropriate and plausible scenario for effective water management strategies in the future. These scenario-based studies do not try to project the actual future changes but rather an attempt to assess the effects of potential future changes. While most of the studies reviewed above looked at the potential impacts of climate change on hydrology and water resources, it is argued here that the studies mostly rely on the use of GCM projections. As such, there is a need for developing climate change models that uses earth observation and in situ data to increase understanding and improve the reliability of prediction of climate change.

References

Abbas, N., Wasimia, S.A. and Al-Ansari, N. (2016a) Assessment of climate change impacts on water resources of Khabour in Kurdistan, Iraq using SWAT model. Journal of Environmental Hydrology, 24(10): 1–21.

Abbas, N., Wasimia, S.A. and Al-ansari, N. (2016b) Assessment of climate change impacts on water resources of Al-Adhaim, Iraq Using SWAT Model. Engineering, 8: 716–732.

Acharya, A. (2017) Quantification of modeled streamflows under climate change over the Flint River Watershed in Northern Alabama. Journal of Hydrological Engineering, 22(9): 1–10.

Adhikari, U. and Nejadhashemi, A.P. (2016) Impacts of climate change on water resources in Malawi. Journal of Hydrological Engineering, 5: 1–13.

Ahiablame, L., Sinha, T., Paul, M., Ji, J. and Rajib, A. (2017) Streamflow response to potential land use and climate changes in the James River watershed, Upper Midwest United States. Journal of Hydrology: Regional Studies, 14(11): 150–166.

Ahmadaali, J., Barani, G.A., Qaderi, K. and Hessari, B. (2018) Analysis of the effects of water management strategies and climate change on the environmental and agricultural sustainability of Urmia Lake Basin, Iran. Water, 10(160): 1-21.

Al-zubari, W.K., El-sadek, A.A., Al-aradi, M.J. and Al-mahal, H.A. (2018) Impacts of climate change on the municipal water management system in the Kingdom of Bahrain: vulnerability assessment and adaptation options. Climate Risk Management, 20: 95–110.

Andrade, C.W.L, Montenegro, S.M.G.L., Montenegro, A.A., Lima, J.R.S., Srinivasan, R., and Jones, C.A. (2020) Modelling runoff response to land-use changes using the SWAT model in the Mundau watershed, Brazil. Journal of Environmental Analysis and Progress, 5(2): 194-206.

Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R. (1998) Large area hydrologic modeling and assessment part I: model development. Journal of the American Water Resources Association, 34: 73-89.

Aryal, A., Shrestha, S. and Babel, M.S. (2018) Quantifying the sources of uncertainty in an ensemble of hydrological climate-impact projections. Theoretical and Applied Climatology, 135(1-2): 193-209.

Ashofteh, P.S., Rajaee, T. and Golfam, P. (2017) Assessment of water resources development projects under conditions of climate change using efficiency indexes (EIs). Water Resources Management, 31(12): 3723-3744.

Bader, D.C., Covey, C., Gutowski, W.J., Held, I.M., Kunkel, K.E., Miller, R.L., Tokmakian, R.T. and Zhang, M.H. (2008). Climate Models: An Assessment of Strengths and Limitations. U. S. Climate Change Science Program Synthesis and Assessment Product 3.1. Department of Energy, Office of Biological and Environmental Research, Washington DC, USA.

Bajracharya, A.R., Bajracharya, S.R Shrestha, A.B. and Maharjan, S.B. (2018) Climate change impact assessment on the hydrological regime of the Kaligandaki Basin, Nepal. Science of the Total Environment, 625: 837–848.

Bhave, A.G., Conway, D., Dessai, S. and Stainforth, D.A. (2018) Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River Basin in Karnataka, India. Water Resources Research, 54: 1–21.

Bhave, A.G., Mishra, A. and Raghuwanshi, N.S. (2014) Evaluation of hydrological effect of stakeholder prioritized climate change adaptation options based on multi-model regional climate projections. Climatic Change, 123: 225–239.

Blanco-Gutiérrez, I., Varela-Ortega, C. and Purkey, D.R. (2011) Integrated economic-hydrologic analysis of policy responses to promote sustainable water use under changing climatic conditions. International Congress European Association of Agricultural Economics, Faculty of ETSI Agronomos (UPM), Zurich, Dinamarca, Switzerland, pp. 1 – 15.

Chattopadhyay, S., Edwards, D.R., Yu, Y. and Hamidisepehr, A. (2017) An assessment of climate change impacts on future water availability and droughts in the Kentucky River Basin. Environmental Processes, 4(1): 477-507.

Chow, V.T, Maidment, D.R. and Mays, L.W. (1988). Applied Hydrology (2010 edn), Tata McGraw-Hill, New York, NY, USA: 572pp.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. and Whetton, P. (2007). Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by H.L. Solomon, S. Qin, D. Manning, M. Chen, M. Marquis, Z. Averyt, K.B. Tignor and M. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 847-940.

Comair, G.F., Gupta, P., Ingenloff, C., Shin, G. and Mckinney, D.C. (2012) Water resources management in the Jordan River Basin. Water and Environment Journal, 27(4): 495-504.

Duan, W., He, B., Takara, K., Luo, P. and Nover, D. (2017) Impacts of climate change on the hydro-climatology of the upper Ishikari river basin, Japan. Environmental Earth Sciences, 76(490): 1–16.

Duque, L.F. and Vazquez, R.F. (2017) WEAP21 based modelling under climate change considerations for a semiarid region in Sourthern-central Chile. Maskana, 8(2): 125-146.

Esteve, P., Varela-ortega, C., Blanco-gutiérrez, I. and Downing, T.E. (2015). A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture. Ecological Economics, 120: 49–58.

Faiz, M.A., Liu, D., Fu, Q., Uzair, M., Khan, M.I., Baig, F., Li, T. and Cui, S. (2017) Stream flow variability and drought severity in the Songhua River Basin, Northeast China. Stochastic Environmental Research and Risk Assessment, 32: 1225-1242.

Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S.C., Collins, W., Cox, P., Driouech, F., Emori, S., Eyring, V., Forest, C., Gleckler, P., Guilyardi, E., Jakob, C., Kattsov, V. and Reason, M.R. (2013) Evaluation of climate models. in: climate change 2013: the physical science basis. contribution of working group i to the fifth assessment report of the Intergovernmental Panel on Climate Change. Edited by T.F. Stocker, D. Qin, G-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels and Y. Xia. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 741-882.

Gao, J., Christensen, P. and Li, W. (2017) Application of the WEAP model in strategic environmental assessment: Experiences from a case study in an arid/semi-arid area in China. Journal of Environmental Management, 198(1): 363–371.

Gayathri, K.D., Ganasri, B.P. and Dwarakish, G.S. (2015) A review on hydrological models. Aquatic Procedia, 4: 1001–1007.

Green, T.R. (2016). Linking climate change and groundwater. In: integrated groundwater management, Springer, Cham, Switzerlad, pp. 97–141.

Hamlat, A., Errih, M. and Azeddine, G. (2013) Simulation of water resources management scenarios in western Algeria watersheds using WEAP model. Arab Journal of Geosciences, 6: 2225–2236.

Huyen, N.T., Tu, L.H., Ngoc, V., Tram, Q., Minh, D.N., Liem, N.D. and Loi, N.K. (2017) Assessing the impacts of climate change on water resources in the Srepok watershed, Central Highland of Vietnam. Journal of Water and Climate Change, 8(3): 524-534.

IPCC. (2001) Climate Change 2001: The Scientific Basis. Contribution of Working Group I. In: Third Assessment Report of the Intergovernmental Panel on Climate Change. Edited by J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881pp.

IPCC. (2007) Climate Change 2007: The physical science basis. contribution of working group I. In: Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996pp.

IPCC. (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I. In: Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by T.F. Stocker, D. Qin, G-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1535pp.

Islam, A.K.M.S., Paul, S., Mohammed, K., Billah, M., Fahad, G.R., Hasan, A., Islam, G.M.T. and Bala, S.K. (2017) Hydrological response to climate change of the Brahmaputra basin using CMIP5 general circulation model ensemble. Journal of Water and Climate Change, 9(3): 434-448.

Jin, X. and Sridhar, V. (2011) Impacts of Climate Change on Hydrology and Water Resources in the Boise and Spokane River Basins. Journal of the American Water Resources Association, 48(2): 197-220.

Johannsen, I., Irene, M., Hengst, J.C., Goll, A., Höllermann, B. and Diekkrüger, B. (2016) Future of Water Supply and Demand in the Middle Drâa Valley, Morocco under Climate and Land Use Change. Water, 8(8): 313-330.

Khalil, A., Rittima, A. and Phankamolsil, Y. (2018) The projected changes in water status of the Mae Klong Basin, Thailand, using WEAP model. Paddy and Water Environment, 16(15): 1-17.

Leavesley, G.H. (1994). Modeling the effects of climate change on water resources - A Review. Climatic Change, 28: 159–177.

Leong, W.K. and Lai, S.H. (2017) Application of water evaluation and planning model for integrated water resources management: Case Study of Langat River Basin, Malaysia". International Technical Postgraduate Conference: Materials Science and Engineering, IOP Publishing, University of Malaya, Kuala Lumpur, Malaysia, pp. 1 – 14.

Mounir, M.Z., Ma, C.M. and Issoufou, A. (2011) Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands in the Niger River (In Niger Republic). Modern Applied Science, 5(1): 38–49.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. (2005) Soil and water assessment tool: theoretical documentation version 2005. Texas Water Resources Institute, Texas, USA, 541p.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. (2011). Soil and Water Assessment Tool: Theoretical Documentation

Version 2009, Technical Report No. 406. Texas Water Resources Institute, Texas, USA, 647p.

Pervez, S. and Henebry, G.M. (2015) Assessing the impacts of climate and land use and land cover change on the freshwater availability in the Brahmaputra River basin. Journal of Hydrology: Regional Studies, 3: 285–311.

Pham, B.Q., Yu, P.S., Yang, T.C., Kuo, C.M. and Tseng, H.W. (2017) Assessment of climate change impacts on hydrological processes and water resources by Water Evaluation And Planning (WEAP) Model: Case Study in Thac Mo Catchment, Vietnam". International Association of Hydro-Environment Engineering and Research, World Congress: Managing Water for Sustainable Development, Learning from the Past for the Future, Kuala Lumpur, Malaysia, pp. 4312–4321.

Ramirez-Villegas, J., Challinor, A.J., Thornton, P.K. and Jarvis, A. (2013) Implications of regional improvement in global climate models for agricultural impact research. Environmental Research Letters, 8(2): 1-12.

Reshmidevi, T.V, Kumar, D.N., Mehrotra, R. and Sharma, A. (2017) Estimation of the climate change impact on a catchment water balance using an ensemble of GCMs. Journal of Hydrology, 556: 1192-1204.

Sieber, J. and Purkey, D. (2007) WEAP: Water evaluation and planning system user guide for weap21. Somerville, MA, Stockholm Environment Institute, US Center. Available fromhttp://weap21.org/downloads/WEAP_User_Guide.pdf [accessed 18 September 2019].

Shiferaw, H., Gebremedhin, A., Gebretsadkan, T. and Zenebe, A. (2018). Modelling hydrological response under climate change scenarios using SWAT model: the case of Ilala watershed, Northern Ethiopia. Modeling Earth Systems and Environment, 4: 437-449.

Spalding-fecher, R., Joyce, B. and Winkler, H. (2017). Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin: System-wide impacts and policy implications.Energy Policy, 103: 84–97.

Stefanidis, K., Panagopoulos, Y. and Mimikou, M. (2018) Response of a multi-stressed Mediterranean river to future climate and socio-economic scenarios. Science of the Total Environment, 627: 756–769.

Swain, J.B. and Patra, K.C. (2018) Impact assessment of land use/land cover and climate change on streamflow regionalization in an ungauged catchment. Journal of Water and Climate Change, 10(3): 554-568.

Tiwari, S., Kar, S.C. and Bhatla, R. (2018) Mid-21st century projections of hydroclimate in Western Himalayas and Satluj River basin. Global and Planetary Change, 161: 10–27.

Toure, A., Diekkrüger, B., Mariko, A. and Cisse, A.S. (2017) Assessment of groundwater resources in the context of climate change and population growth: Case of the Klela Basin in Southern Mali. Climate, 5(3): 45-69.

United Nations Framework Convention on Climate Change. (2007) Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. United Nations Framework Convention on Climate Change, Bonn, Germany. Available from http://unfcc.int/ resource/docs/publications/ impacts. pdf [accessed 20 September 2019].

Van-Vuuren, D.P., Edmonds, J., Kainuma, M., Riabi, K., Thomson, A., Hibbard, K., Hurtt, G.C. and Rose, S.K. (2011) The representative concentration pathways: an overview. Climate Change, 109(5): 5–31.

Xu, C. (2002). Hydrologic Models (New edn, vol. 72). Uppsala University Department of Earth Sciences Hydrology, Uppsala, Sweden: 168pp.