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Climate change impact assessment on hydropower generation using multi-model climate ensemble

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ABSTRACT

Hydropower is the primary renewable source of energy that harnesses the power of the naturally flowing water streams and its potential is strongly impacted by the hydrological regime. The objective of the present research is to carry out a hydrological model based study to assess the impacts of climate change on hydropower generation by using the regional climate model (RCM) data available through coordinated regional downscaling experiment (CORDEX), and subsequently to analyse the effect of using model ensemble in projecting the future hydrology and energy generation scenario. C.H.Corn hydroelectric project located on River Ochlockonee near Tallahassee in Florida, USA, has been considered as a case study. A hydrologic model of the basin, draining into the dam, is developed using a conceptual model HYMOD with the historical climate and flow data extracted from the model parameter estimation experiment (MOPEX) dataset. The future projected climate scenario (2091–2100) is generated following the Representative Concentrated Pathways (RCP) 4.5 with the ensembles of six climate models. The impact of the future climate on water availability indicates a significant seasonal variability among the model ensemble results with an overall annual increase of statistics for the climate variables, corresponding inflows and a marginal increase in the energy generation.

1. Introduction

The energy supply acts as a catalyst for an overall development of a society [1] and the supply of electricity, which is one of the major sources of energy and also the highest-value energy carrier [1], is imperative for basic humane comfort of living and to uphold an overall social and economic growth. Electricity generation for mass usage primarily comes from two broad sources: renewable and non-renewable. Non-renewable sector relies on burning fossil fuels whereas the renewable sector of electricity consists of hydro, solar, wind, biomass and geothermal. Though most of the nations fulfill the major segment of their energy demands through non-renewable sources [2], about twenty-one countries worldwide are able to manage 80% of the electricity consumption through renewable means [3]. Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations [2]. The installed capacity of hydro across the globe is 926 GW by the year 2009 [2] which constitutes about 19% of the total installed capacity. In the renewable sector alone its contribution is about 85% in terms of annual energy generation [4]. Among all the energy sources the hydropower has the best conversion efficiencies of the order of 90% (from water to wire) [2] and is termed as one of the cleanest energy resources.

The hydropower potential is strongly impacted by the hydrological regime which in turn is influenced by the local as well as regional climate pattern. Climate change is a complex phenomenon which is under an intense study by scientific community for the risk it poses to the sustainable human development. Any infrastructure project that has a life span of few decades is prone to the potential dangers of climate change unless the system is designed for the prevailing environmental conditions. The hydropower installations which are huge investment schemes with a proposed life of several decades [5], are equally prone to the environmental changes as their functioning is commensurate to the regions' hydrology, which is under pressure due to the climate change phenomena [6]. Impacts of changing climate on hydropower would be an additional stress which the system already faces due to other factors, such as demographic variations, land use changes, and changing economic activity [5,6]. Different researchers have carried out studies on impact of climate change on water resources [7–10]. Bates et al. [6]

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presents in detail the impacts of climate change on fresh water system and is a much cited technical paper by Intergovernmental Panel on Climate Change (IPCC), which is a leading international body on assessment of climate change. There have been several studies on the streamflow projection under climate change [11–16]. As the energy production in hydropower is directly dependent on the quantum of water available in a given stream, the changing climate conditions are posing threat to the hydropower resource potential [2]. The studies related to hydropower are limited in comparison to the climate change effect in other sectors. Schaefli [5] presents a review of various model-based studies pertaining to climate change and hydropower. In particular the impacts on hydropower have been reported in some of the studies in recent decades [5,17–22]. The study on Colorado river basin by Christensen et al. [20] is a much cited work in this field and is an extension to their earlier work [19]; the same basin has also been studied later [22] and [23]. The operational aspect of hydropower in the climate change scenario was included by some of the researchers [20,21,24–27]. A coupled model of hydrology and power market has been reported in Ref. [28], whereas there are studies including an energy based model without incorporating the streamflow and reservoir-volume generation computations [26]. An extensive literature review on the impact of climate change on the electricity sector has been carried out by Chandramowli et al. [29].

Changing climate implies a variability of precipitation and temperature pattern which in turn may affect the streamflow regime and thus altering the resource potential of a given basin [5]. As the hydrological inputs are foremost in assessing the exploitable potential for a hydropower system, the climate change impact assessment (CCIA) study should also integrate a hydrologic model, decently representing the catchment that feeds to the system. Any climate change study that incorporates hydrological modeling is bound to possess uncertainty in the results [14,30–33]. Poulin et al. [33] mentions various sources of uncertainties in the climate change modeling, among which the uncertainty due to the climate model and the emission scenario is found to be the major source in quantifying the climate change impacts [14,31,34]. In order to better assess the future impacts and enumerate the uncertainty many researchers suggest conducting an ensemble based study [5,21,31]. Some of the hydrologic-model-based climate change studies for assessing the effects on hydropower have also included climate model ensembles [20–22].

Climate change studies rely on various climate models that simulate the future climate scenario for different greenhouse gas emission scenarios (GHGES) [1]. The projected data for an array of climate variables can be extracted from the results of the various simulation runs of different category of climate models, most common among them being general circulation model (GCM). A GCM typically represents climate simulation based on coarse grid of approximately 2.5° (~250 km) on map. For CCIA study, the climate information at a smaller scale is imperative in order to generate more reliable estimates. Therefore for a regional climate variable to be represented in detail, the climate simulations at finer resolutions shall be used. Regional climate models (RCM) offers a solution in this respect. RCMs are high resolution climate models that provide climate information at spatial scales much finer than the GCMs' grid and are driven using the information provided by GCMs as lateral boundary condition [35,36]. The RCM resolution also assists in reducing the uncertainty [14] but the uncertainty inherent in the driving GCM persists in RCM [36]. There have been various international projects to accomplish the downscaling of climate data at a regional scale, Coordinated Regional Downscaling Experiment (CORDEX) [37] is one among others and is described in further sections.

Most of the CCIA studies for hydropower have used data from GCM's only and limited studies are available that implement RCM data. Pereira et al. [28] implemented results from three RCM's under one emission scenario to study the coupled hydrological and power market model. Data from various RCMs were incorporated in a study of hydropower system in Swiss Alps [38] and RCM ensemble were used in the study of northern European basins [15]. Queiroz et al. [39] in their study on several hydropower projects in Brazilian river basins using one climate model, presents the effects of different climate scenarios in the water inflows and shown that climate change may drastically impact the system assured energy. It is quite apparent from the diverse scientific literature that in order to assess the impact of the changing climate at a local scale, it is vital to utilize the results of climate simulation conducted at an advanced resolution like that in RCM. Hence it is realised that for a meaningful CCIA study for hydropower, the ensembles of such climate model data shall be utilized. CORDEX offers an opportunity to directly exploit the downscaled data for impact assessment studies; and as per the knowledge of the authors none of the studies have implemented the RCM simulation outputs from CORDEX for quantifying the impacts on hydropower system. Therefore the objective of the present research is to carry out a hydrological model based study to assess the impact of climate change on hydropower generation using the RCM data available through CORDEX, and also to analyse the effect of using model ensemble in projecting the future hydrology and energy generation scenario.

2. Description of study area

The present study considers C.H.Corn Hydroelectric project [40] located on Ochlockonee River in United States as a case study (Fig. 1). The project which is located 20 miles southwest of Tallahassee is one of the only two hydroelectric facilities in the state of Florida and is a dam toe type of scheme. With an installed capacity of 12 MW, water for power generation is stored in the lake Talqin formed behind Bluff dam. The facility comprises a total of three turbines with one unit of Kaplan and other two as Propeller turbines. When working at full capacity it fulfills about 3% of Tallahassee's typical power needs. The project was built in 1929 by West Florida Power Company but was abandoned as a power plant in 1970. Refurbished in 1981 by City of Tallahassee as a hydroelectric demonstration project it became fully operational in 1985 under City of Tallahassee Electric Utility Services. Lake Talquin stretches upstream towards Tallahassee and apart from electricity generation is used as recreational lake and also for flood control purpose.

3. Methodology

The climate change impact assessment for the C.H.Corn hydroelectric project has been carried out by first developing a

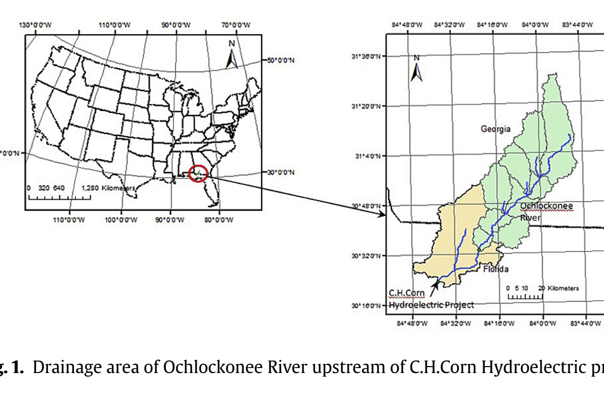

Fig. 1. Drainage area of Ochlockonee River upstream of C.H.Corn Hydroelectric project.