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Prediction of design flood discharge by statistical downscaling and General Circulation Models

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SUMMARY

The global warming and the climate change have caused an observed change in the hydrological data; therefore, forecasters need re-calculated scenarios in many situations. Downscaling, which is reduction of time and space dimensions in climate models, will most probably be the future of climate change research. However, it may not be possible to redesign an existing dam but at least precaution parameters can be taken for the worse scenarios of flood in the downstream of the dam location. The purpose of this study is to develop a new approach for predicting the peak monthly discharges from statistical downscaling using linear genetic programming (LGP). Attempts were made to evaluate the impacts of the global warming and climate change on determining of the flood discharge by considering different scenarios of General Circulation Models. Reasonable results were achieved in downscaling the peak monthly discharges directly from daily surface weather variables (NCEP and CGCM3) without involving any rainfall–runoff models.

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1. Introduction

For a hydraulic structure planned within the river, like a dam or a barrage, due consideration should be given to the design of the structure so as to prevent it from collapsing and causing further damage by the force of water released from behind the structure. Hence, an estimate of design flood is required. The magnitude of such flood may be estimated in accordance with the importance of the structure. The Probable Maximum Flood (PMF) is the extreme flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. In some situations where substantial risk for loss of life exists, it is appropriate to design the hydraulic structure against the worst possible condition, which is the PMF. The PMF is determined based on the unit hydrograph and probable maximum precipitation. In general, PMF is accepted as the standard for the design of spillway of dams where failure could lead to catastrophic situation including loss of life (Usul, 2005). Meanwhile when PMF is not applicable or possible, Flood Frequency Analysis (FFA) method used to determine the design flood. The objective of this method is to relate the magnitude of events to their frequency of occurrence through theoretical probability distributions based on determined return period. For instance, spillways for major and medium projects with storage more than 60 Mm^3 are designed using flood frequency method with 1000-year return period (Subramanya, 2005).

Climate change is currently taking place due to elevated concentrations of 'greenhouse gases' in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), mean global surface temperature increased 0.6 ± 0.2 °C in the 20th century. Average sea level rose 0.1–0.2 m globally, and precipitation increased by 0.5–1% per decade, with an increase in the frequency of heavy precipitation events. Increases in annual and seasonal precipitation may increase the magnitude and frequency of flooding (Houghton et al., 2001). General Circulation Models (GCM), based on mathematical representations of atmosphere, ocean, ice cap and land surface processes, are considered to be the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Accordingly, air temperature projected to increase by 1.4–5.8 °C and precipitation by 3–15% globally in the 21st century (Houghton et al., 2001; Swansburg et al., 2004).

Investigation of the hydrological impacts of climate change at the regional scale requires the use of a downscaling technique, which is a process of transferring the coarse spatial resolution of General Circulation Models (GCM) information to a form suitable for direct use in many types of climate impact models (Hashmi et al., 2011). Methods of downscaling were developed to obtain local-scale surface weather from regional-scale atmospheric

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variables that provided by GCMs. Two main forms of downscaling technique exist. One form is dynamical downscaling, where output from the GCM used to drive a regional, numerical model in higher spatial resolution, which therefore is able to simulate local conditions in detail. The other form is statistical downscaling, where a statistical relationship established from observations between large-scale variables, like atmospheric surface pressure, and a local variable, like the wind speed at a particular site. Statistical downscaling model facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate forcing (Wilby et al., 2002). Significant progress has already been made in the development of statistical downscaling techniques (Huth, 1999; Wilby et al., 2002; Hashmi et al., 2011).

Wilby and Wigley (1997) divided downscaling into four categories: regression methods, weather pattern-based approaches, stochastic weather generators, which are all statistical downscaling methods, and limited-area modeling. Among these approaches, regression methods are preferred because of its ease of implementation and low computation requirements. Regression based downscaling is the use of transfer function. The transfer function method relies on direct quantitative relationship between the local scale climate variable (predictand) and the variables containing the large-scale climate information (predictors) through some form of regression.

Scientific literature of the past decade contains a large number of studies regarding the development of downscaling methods and the use of hydrologic models to assess the potential effects of climate change on a variety of water resource issues. Hydrologic models provide a framework in which to conceptualize and investigate the relationship between climate and water resources (Xu, 1999). Precipitation, which is a key component of the hydrological cycle and one of the important parameters have taken the focus of noticeable scientists concerned with downscaling and climate change effects. The use of the downscaling in forecasting the precipitation concentrated in both the drought and flood cases. Precipitation downscaling improves the coarse resolution and poor representation of precipitation in global climate models, and helps end users to assess the likely hydrological impacts of climate change (Maraun et al., 2010).

A number of studies were conducted by using statistical downscaling and different GCM scenarios to predict the runoff based on precipitation and rainfall–runoff models (Schmidli et al., 2007; Chen et al., 2012; Yonggang et al., 2013). To the extent of the author's knowledge, there are no studies conducted up to date using the observed flood discharge data directly for downscaling without the intermediate stage of using the rainfall–runoff models. Up-to-now, conventional statistical downscaling approaches linking GCMs to meteorologic and hydrologic models resolved at finer scales have been developed and implemented successfully, however, this is the state-of-the art approach to build a bridge between the hydroclimatic modeling at the river-basin fine-resolution scale and the coarse-resolution GCMs.

In this study, efforts is done to evaluate the possibility of using the discharge as predictand variable in the statistical downscaling, and as a second step efforts focused toward prediction of the peak monthly discharge which can be the base for calculation of design flood value on the basis of flood frequency analysis for the predicted discharge time series.

2. Study area and data

The first set of the data, which is the daily inflow data, were collected from Darbandikhan Dam. Darbandikhan Dam is a multipurpose embankment dam on the Diyala River (locally called Sirwan River), 65 km southeast of Sulaymaniy Governorate, and 285 km northeast from Baghdad, Iraq (Coordinates 35°06′46″N 45°42′23″E). It was constructed between 1956 and 1961. The purpose of the dam is irrigation, flood control, hydroelectric power production, and recreation. The Diyala River is a tributary of the Tigris that runs mainly through Eastern Iraq along the Sulaymaniy Governorate in Kurdistan region (Iraq). It covers a total distance of 445 km. The drainage area at Darbandikhan Dam is 17,800 km^2 and maximum daily discharge recorded in 50 years (1962–2012) is 5816 m^3/s. The reservoir impounded by Darbandikhan Dam had a total design capacity at normal operating level (485 m.a.s.l.) of 3000 Mm^3, of which 2500 Mm^3 is live storage 500 Mm^3 being dead storage. The available data was for the period starting from March 1962 and up to December 2012. The use of the data was limited to 36 years (March 1962 up to March 1998) because of the two new dams constructed on branches of the river within Iran country after 1998, which is affecting the inflow values due to storage of the new dams. Table 1 shows summary of the daily inflow data used in this study.

The second set of data contain have two components; first one is the NCEP re-analysis data with slight correction in computation of meridional wind from NCEP/NCAR has been introduced. Derived predictors such as divergence and vorticity are thus also recomputed. NCEP re-analysis data (The NCEP/NCAR Reanalysis data set) is a continually updating gridded data set representing the state of the Earth's atmosphere, incorporating observations and numerical weather prediction (NWP) model output dating back to 1948. It is a joint product from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The second part of predictor data is CGCM3 (Coupled Global Climate Model and have been developed from the CGCM3.1 experiments: historic, and A2 and A1B scenarios from the 4th member of the ensemble run. Daily time scale predictors were defined on the native CGCM Gaussian grid (Nakicenovic et al., 2000; Flato and Boer, 2001). Furthermore, the precipitation predictor is added as new predictor variable from both CGCM3.1 and NCEP/NCAR. This set represents the predictor variable data for two different scenarios (NCEP and CGCM3) downloaded from the Canadian Climate Change Scenarios Network (http://www.cccsn.ec.gc.ca/index.php). The available data from the website distributed according to grid boxes. Each grid box represents a mesh surrounding the corresponding model grid points (for more details see DAI CGCM3 Predictors, 2008). The dimension of each grid box is defined here by approx. 3.75° latitude and 3.75° longitude (Gaussian grid). In order to apply the downscaling to the inflow data for Darbandikhan dam, the required downscaling inputs are downloaded from Canadian Global Climate Model (http://loki.qc.ec.gc.ca/DAI/gcm_CGCM2-e.html) for the location of the dam. The downloaded data are for four different boxes (Box_13X_14Y, Box_13X_15Y, Box_14X_14Y and Box_14X_15Y). Each of the boxes represents a near Latitude and Longitude to the dam location and the closest grid box to the study area is selected, which is (Box_13X_15Y) as shown in Fig. 1. Each grid box (i.e. zipped file)

Table 1
Summary of daily inflow data collected from Darbandikhan dam (upstream of the dam).

Item	Descriptions
Start date of the daily inflow data	11 March 1962
End date of the daily inflow data	10 March 1998
Duration of the data	36 year
Maximum inflow in the data set (cubic meter/s)	5816
Minimum inflow in the data set (cubic meter/s)	1
Average inflow (cubic meter/s)	186.42
Number of the data set (days)*	13,153

* *Note*: 365 days per year, no leap years.

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