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Ensemble hydrological prediction of streamflow percentile at ungauged basins in Pakistan

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SUMMARY

Streamflow records with sufficient spatial and temporal coverage at the site of interest are usually scarce in Pakistan. As an alternative, various regional methods have been frequently adopted to derive hydrological information, which in essence attempt to transfer hydrological information from gauged to ungauged catchments. In this study, a new concept of ensemble hydrological prediction (EHP) was introduced which is an improved regional method for hydrological prediction at ungauged sites. It was mainly based on the performance weights (triple-connection weights (TCW)) derived from Nash Sutcliffe efficiency (NSE) and hydrological variable (here percentiles) calculated from three traditional regional transfer methods (RTMs) with suitable modification (i.e., three-step drainage area ratio (DAR) method, inverse distance weighting (IDW) method, and three-step regional regression analysis (RRA)). The overall results indicated that the proposed EHP method was robust for estimating hydrological percentiles at ungauged sites as compared to traditional individual RTMs. The comparative study based on NSE, percent bias (PBIAS) and the relative error (RE) as performance criteria resulted that the EHP is a constructive alternative for hydrological prediction of ungauged basins.

1. Introduction

During the past decade, various methods were adopted to transfer the information available at a gauged site to a target-ungauged site where only morphological characteristics are available. These methods are generally called regional models. Many regional models have been used for regional estimation of streamflow at ungauged site. Such regional methods involve different significance level, applicability, and contrasting opinions by the researchers. Shu and Ouarda (2012) and Hrachowitz et al. (2013) have provided a detail summary of contemporary regional methods including their usefulness and comparative assessments.

Drainage area ratio (DAR) method is one of the straightforward methods for transferring hydrological information from gauging site to ungauged site. The standard implementation of the DAR method generally involves only one source site. Such an application is actually based on the assumption that a gauged basin shares the same geomorpho-climatic and hydrological attributes as the target ungauged site except the size of drainage basin. However, in reality, there are some other factors, in addition to drainage area, that have a significant influence on a catchment's unique hydrological behavior. Thus, using the DAR method with a single source site may result the risk of introducing systematic errors in the streamflow estimation at an ungauged site (Yusuf, 2008; Shu and Ouarda, 2012).

The inverse distance weighting (IDW) interpolation is one of the regional methods, which is mainly based on multivariate interpolation. Its general idea is based on the assumption that the attribute value of an unsampled point is the weighted average of known values within the neighborhood (Lu and Wong, 2008). Despite its simplicity, the IDW also have some flaws, including the priori choice of weighting parameters and uniformly application of distance decay parameter within the region without considering the data distribution. In other words, a constant distance decay parameter may lead to less accurate prediction (Lu and Wong, 2008).

Another highly promising and extensively used technique for the estimation of streamflow at ungauged sites is associated with the use of regional regression analysis (RRA). Many researchers have used to estimate the flow statistics at ungauged basin (e.g., Vogel et al., 1999; Archfield et al., 2007; Griffis and Stedinger, 2007; Haddad and Rahman, 2012; Farmer and Vogel, 2013). In contrast, RRA has also been criticized by many researchers

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(Andreassian et al., 2001; McIntyre et al., 2005) due to number of reasons (e.g., assumption of linearity, interdependencies between model parameters). Numerous studies had used stepwise regression (hereafter Reg(stepwise)) to develop the regional model for streamflow estimation at ungauged site (e.g., Yusuf, 2008; Castellarin et al., 2004; Chang and Ouarda, 2012). However, in general, the use of the stepwise regression method for ungauged catchment prediction has been criticized due to a number of reasons; including incorrect p-value, unbiased parameter estimation, selection of lowest Mallows C_p, multicollinearity, rarely selection of best model, and upwardly biased coefficient of determination (Arditi, 1989; Helsel and Hirsch, 2002; Kroll and Song, 2013).

In the current study, we introduced an ensemble hydrological prediction (EHP) method, which was mainly based on the blended hydrological estimator. The basic idea behind the concept was to use the relative performance weights of the three well-known regionalized methods (i.e., IDW, DAR and RRA) and to provide significant final prediction at ungauged site by exploiting the advantages and minimizing the disadvantage of these regional transfer methods (RTMs). The main objective of this study was to improve the ability for significant hydrological prediction at ungauged site.

2. Database

The study area consists of eight catchments (Fig. 1) in the northern part of Pakistan (ranged approximately 33.50–35°N and 73.89–75°E). The catchments were initially selected based on the degree of development, the absence of significant regulation, independency, the record length more than 15 years, and the appropriate accuracy of observations (e.g., missing value, continuity). The minimum, maximum and mean of record length of selected catchments are 18 (1991–2008), 39 (1970–2008), and 26 (1970–2008) years, respectively. The study area is mountainous sub-humid having significant variability in uniform distribution of rainfall. The data were collected from Water and Power Development Authority (WAPDA) and National Development Consultancy (NDC) of Pakistan.

We referred geomorpho-climatic attributes of the catchment, i.e., drainage area (DA), mean elevation (ML), land use and land cover, average slope (SL), length of channel (CL), mean annual precipitation (MAP), and Horton shape factor (HSF = DA/CL^2) as predictors. Whereas mean annual runoff (MAR), high flow segment of flow duration curve (FDC) ($Q_{0.1}$, $Q_{0.5}$, Q_2, Q_5 and Q_{10}), medium flow segment of FDC (Q_{40}, Q_{45}, Q_{50}, Q_{55} and Q_{60}), and low flow segment of FDC (Q_{75}, Q_{80}, Q_{85}, Q_{90} and Q_{99}) were predicted as catchments hydrological variables (response variables). Information about the study area is summarized in Table 1.

3. Regional traditional methods

Three regional transfer methods (RTMs) for hydrological prediction at ungauged sites were used in the current study. These methods included the DAR method, the IDW method and the RRA, which are extensively used for ungauged prediction.

3.1. Drainage area ratio (DAR) method

The DAR method is one of the straightforward methods for obtaining streamflow at ungauged sites from gauged sites. This method assumes that the flow per unit area of hydrologically similar catchments is almost same as described in Eq. (1).

$$\frac{Q_{P,i,1}}{A_1} = \frac{Q_{P,i,2}}{A_2} \tag{1}$$

where $Q_{P,i,1}$ and $Q_{P,i,2}$ are the estimated and observed hydrological variables (ith percentile in the current study) of site 1 (ungauged/target) and site 2 (gauged/donor), respectively, and A represents the respective area. Some studies also consider the value of power raised to area ratio (McCuen, 2005). However, a simple case is considered here with the preliminary step to find the similarity between the selected pair of catchments.

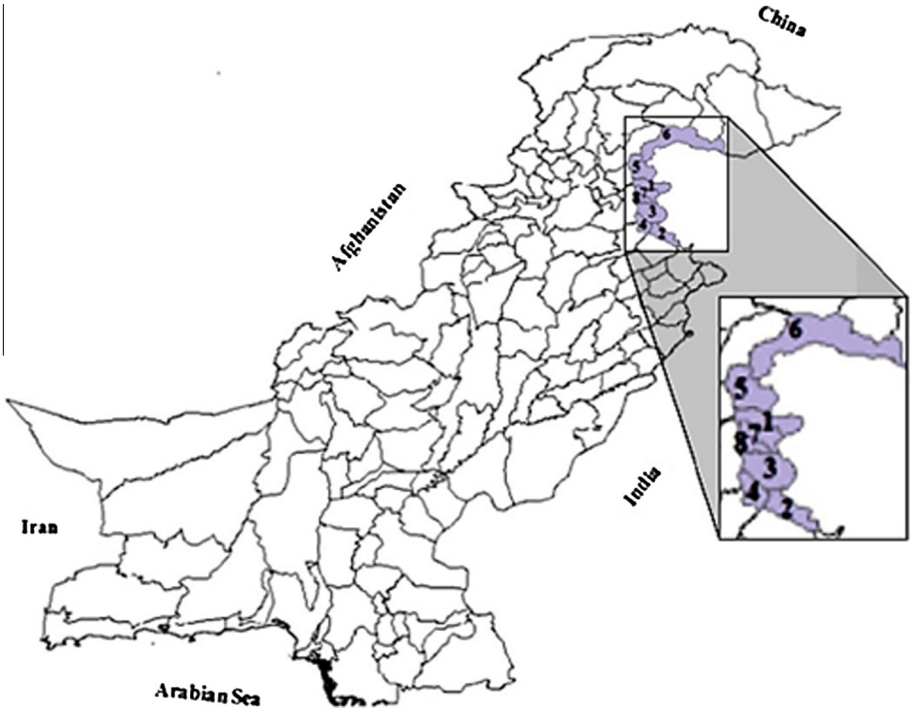

Fig. 1. Location of study catchments, the northern part of Pakistan.