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ScienceDirect
Procedia Earth and Planetary Science 16 (2016) 156 – 165
Procedia
Earth and Planetary Science

The Fourth Italian Workshop on Landslides

Variability and trends in streamflow in northeast United States

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Abstract

There is general consensus that climate is undergoing change but whether climate change is occurring or not is still being debated in certain scientific, political, and religious quarters. Hydrologic variability influences the design of civil works and assessment of long-term climate change would help improve design criteria.To this end,long-term variability of streamflow was estimated using Shannon entropy. Three statistical tests were applied to determine trends in annual and seasonal daily streamflow with 5% two-sided confidence limit. Daily streamflow data spanning 70 years (from 1943 to 2012) from 669 stream gauge stations located in 23 states in the northeastern part of United States of America, covering six different water regions were employed.The time variability of annual and seasonal daily streamflow was assessed using the *Mean Decadal Apportionment Disorder Index* (*MDADI*).Analysis showed that in all cases minimum and maximum streamflows had higher variability than average and median streamflows.A significant number of stations exhibited trends.Considering annual minimum, average and median daily streamflows, approximately 50% of the stations followed trends and for almost all these stations trendswere increasing. Only for annual maximum daily streamflow, 15% of the stations showed increasing trend and 10% decreasing trend. In terms of geographical distribution, the stations with increasing trend were essentially located along the Atlantic coast and near Great Lakes and in the Upper Mississippi Water Region. Similar considerations apply for seasonal time series as well.

Peer-review under responsibility of the organizing committee of IWL 2015
*Keywords:*variability; trend analysis; entropy;streamflow;disorder index.

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Peer-review under responsibility of the organizing committee of IWL 2015
doi:10.1016/j.proeps.2016.10.017

1. Introduction

The occurrence of climate change is not without controversy. Since hydrologic variability influences the design of civil works, assessment of long-term climate change would nevertheless help improve design criteria.

Global warming intensifies the hydrological cycle and thus increases globally averaged precipitation, evaporation, and runoff[1]. Changes in the hydrologic cycle severelyimpact the amount, timing, and distribution of rain, evaporation,temperature, snowfall, and runoff, leading to changes inthe availability of water as well as in the competition for water resources.These changes are also likely in the timing, intensity, andduration of water related-disasters, i.e., landslides, floods, droughts,with associatedchanges in water quality[2].

Several studies reported large increasesin precipitation and streamflow across the United States over thesecond half of the 20th century, with the largest increases generallybeing reported in the fall precipitation[3,4] and low to moderate flows[5,6,7]. All water resourcesregions of the conterminous U.S. between 1940 and 1999 exhibit increased streamflows: the patterns of these increases ismost pronounced in the central two-thirds of the nation and, to a lesser extent, in the eastern coastal regions and in the Great Lakes basin[8].

Most studies have investigated the existence of trends in the historical streamflow data, without defining the temporal variability and the possible mutual influence.To that end, anentropy-based approach[9] seem to be an attractive approach forevaluating the variability/disorder based on streamflow patterns within a region. As well statistical tests can assess the existence of trend.

2. Study area and streamflow data set

The data set consisted of records of daily streamflow of water courses throughout the continental United States, obtained from the*National Water Information System* (*NWIS*) database of the *U.S. Geological Survey*,available online[10]; there are daily data of more than 25000 measuring stations of both flow andwater level of rivers and lakes. The values contained in this database can be “approved”, whereby the quality is guaranteed and the data are eligible for publication, or “provisional”, especially for the most recent data, whereby the accuracy is not verified and the data are subjected to possible revision.

The U.S.Water Resources Council defined 21 major geographic areas, or regions, in order to assess the state of water resources throughout the nation[11].For the selection of data, we firstidentified stations located within the northeast United States, between Souris-Red-Rainy and New England regions.Then, we assessed for different time periods record lengths from 30 to 110 years (with steps of 10 years) and the number of stations for which the corresponding time series showed a percentage of missing values less than 0.1%.Hence, weidentified 669 stations across the study areawith period of record of 70 years from 1943 to 2012.The location of 669 stream gauge stations within each of six Water Resource Regions of the northeast United States are shown in Fig. 1.

For each of the selected stations, whereby the average daily streamflow time series are available, the corresponding annual and seasonal time series relating to minimum (Q_0), median (Q_{50}), maximum (Q_{100}) and average values (Q_{mean}) were obtained. For the annual series the reference period was the calendar year (January to December), while the seasonal series spanned the period from December to November: in particular, the winter season falls within in the months from December to February.

3. Data analysis and discussion of results

3.1. Definition of time series to be analyzed

Starting from the daily streamflows time series, the corresponding annual and seasonalseriesof minimum, median, average and maximum values were extracted for each station. A total of 20 time series were obtained (annual and seasonal series for each of the four values).

For each time series, the time variability was first assessed on a decadal basis using a Shannonentropy-based approach. The identification of trends within the time series and the correlation between temporal variability and trends was further discussed.