Advances in Water Resources 35 (2012) 110–120

Contents lists available at SciVerse ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

Comparison of the interannual variability of spring heavy floods characteristics of tributaries of the St. Lawrence River in Quebec (Canada)

Rabah Mazouz [a], Ali A. Assani [a,*], Jean-François Quessy [b], Guillaume Légaré [a]

[a] Section de Géographie (Geography Section), Laboratoire d'hydroclimatologie et de Géomorphologie fluviale et Centre de recherche sur les interactions bassins versants-écosystèmes aquatiques (RIVE), Pavillon Léon-Provencher, Université du Québec à Trois-Rivières, 3351 Boulevard Des Forges, Trois-Rivières, Québec, Canada G9A 5H7

[b] Département de Mathématiques et d'Informatique (Department of Mathematics and Computer Science), Université du Québec à Trois-Rivières, 3351 Boulevard des Forges, Trois-Rivières, Québec, Canada G9A 5H7

ARTICLE INFO

Article history:
Received 1 October 2010
Received in revised form 11 October 2011
Accepted 12 October 2011
Available online 19 October 2011

Keywords:
Flow characteristics
Spring floods
Lombard method
Linear regression
Kendall tau
Quebec

ABSTRACT

Comparison of the interannual variability of five characteristics (magnitude, duration, timing, frequency, and variability) of spring heavy floods was carried out for 17 natural rivers in Quebec for the period from 1934 to 2004 to detect any effect of climate warming on these characteristics. This was done using the Lombard method and Copula. Changes in the mean and variance of all characteristics of streamflow were observed, and all these changes are abrupt. Whereas little significant change was observed in the magnitude, duration and variability (CV) series of spring flood flows. A significant change was noted in the frequency (diminution) for five rivers and in the timing of spring floods for six rivers. However, the change in mean timing is the only one that has a hydroclimatic significance in time and space. This change was observed, on the one hand, in the Eastern hydrological region, located on the south shore of the St. Lawrence River, north of 47°N, and characterized by a maritime climate and, on the other hand, in the South-west hydrological region, located on the north shore and characterized by a continental climate. In both cases, the change took place after the second half of the 1970s and is characterized by the early occurrence of spring floods. In addition, in both hydrological regions, the timing of spring floods is correlated with the same hydroclimatic indices, showing a positive correlation with the North Atlantic Oscillation (NAO) and a negative correlation with the Atlantic Multidecadal Oscillation (AMO). Frequency is the only characteristic for which mean and variance changed significantly over time for the same rivers (4), all located north of 48°N, on both shores of the St. Lawrence. For all flow characteristics, the change in variance can predate, postdate or be synchronous with the change in mean. Finally, the dependence between the various characteristics of spring floods as determined using the Kendall tau statistic remained constant in time for most of the rivers.

1. Introduction

A consensus is growing regarding the fact that climate warming might, to some extent, affect flood flows throughout the world. Thus, a growing number of studies attempts to constrain the effect of this warming on the interannual variability of flood flows e.g. [5,8–10,12,13,15–17,20–22,30–37,39,42,47,52,55–63]. Although the most widely accepted notion is that the intensity (magnitude) of flood flows should increase [36], such an increase is still rarely observed. In spite of the increasing global temperature, analysis of many hydrological series of flood flows has revealed no significant change in their mean or variance (e.g. [5,11,35]).

However, all these studies generally deal with peak magnitude and not with other characteristics of floods (frequency, duration, timing, and variability). It is therefore important to determine which flow characteristic is most sensitive to climate variability or climate change in order to monitor its effect on flood conditions. Thus, this study has four objectives:

1. To compare the interannual variability of all fundamental characteristics of spring maximum flows in southern Quebec. The hypothesis to test is the uniformity of the interannual variability of all five fundamental characteristics of spring flood flows.
2. To determine which characteristics of spring maximum flows are most sensitive to climate warming in Quebec. These characteristics can then be used to detect and monitor the climate warming signal and the effect of climate indices.
3. To use the copula method to analyze the dependence between spring maximum flow magnitude (primary characteristic) and the other fundamental characteristics, to see if climate warming has any effect on this dependence. This issue has not yet been addressed in the scientific literature.

* Corresponding author. Tel.: +1 819 376 5011; fax: +1 819 376 5179.
E-mail address: ali.assani@uqtr.ca (A.A. Assani).

0309-1708/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advwatres.2011.10.006

4. To determine whether the mean and variance of hydrological series show a similar sensitivity to climate change or climate variability.

2. Methodology

2.1. Choice of rivers and composition of hydrologic series of spring maximum flow characteristics

The St. Lawrence River watershed in Quebec covers a 673,000 km^2 area. Tributaries of the St. Lawrence for which a continuous record of flow measurements over at least 50 years is available and which are not significantly affected by dams or other major human activity were selected for the study. In total, 17 tributaries were selected (Fig. 1 and Table 1). On the south shore, many gauging stations on these rivers are located near their confluence with the St. Lawrence River. The 17 rivers were subdivided into three homogeneous hydrological regions with respect to the interannual variability of flow at the annual, seasonal and daily scales [1,2,5,6]. The Eastern region (E), located on the south shore north of 47°N, is characterized by a maritime climate, whereas the South-west region (SW), located on the north shore, is characterized by a continental climate. Finally, the South-east hydrological region (SE) is characterized by a climate that is somewhere a mix between maritime and continental, but with a heavy maritime trend. This region is located on the south shore south of 47°N, and unlike the other two regions, is characterized by extensive agriculture (Table 2).

Assani et al. [5,6] showed that streamflow is correlated with the ENSO climate index (El Niño/Southern Oscillation) in the Eastern region, to AO (Arctic Oscillation) in the South-east region and to AMO (Atlantic Multidecadal Oscillation) in the South-west region. In the present study, two other indices were also correlated with streamflow characteristics, namely the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO). The data for these five indices were extracted from the following websites: http://www.cdc.noaa.gov/climateindices/list. (AMO, SOI, NINO3.4 and PDO, extracted 2006 May 15), http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html (NAO, extracted 2006 May 15) and http://jisao.washington.edu/data/ao/ (AO, extracted 2006 May 15). For each index, we calculated the seasonal means (seasonal climate indices) for the following two seasons: winter (January to March) and spring (April to June). These various climate indices affect the interannual variability of winter and spring temperature and precipitation in North America, which therefore affects the five characteristics of spring heavy floods. Numerous authors have described the physical mechanisms underlying the impact of these climate indices on the interannual variability of climate and streamflow, e.g. [18,23,34,41,53,54].

For ease of comparison of the interannual variability of the characteristics of these tributaries, a common time interval over which flows were measured was selected, from 1934 to 2004 (70-year span). Daily flow data were taken from the Environment Canada website (http://www.wsc.ec.gc.ca/hydat/H2O/index_f_cfm?). In Quebec, the hydrologic year begins in October and ends in September. The highest flow is measured during spring snowmelt (April to June).

The procedure developed by Assani et al. [6] was used to make up the hydrologic series of spring maximum flow characteristics. This procedure is based on the ecological concept of the natural flow regime [43,46], according to which streamflow can be decomposed into five characteristics, namely magnitude, frequency, duration, timing, and variability. These five characteristics were subdivided into three categories: primary (magnitude), secondary

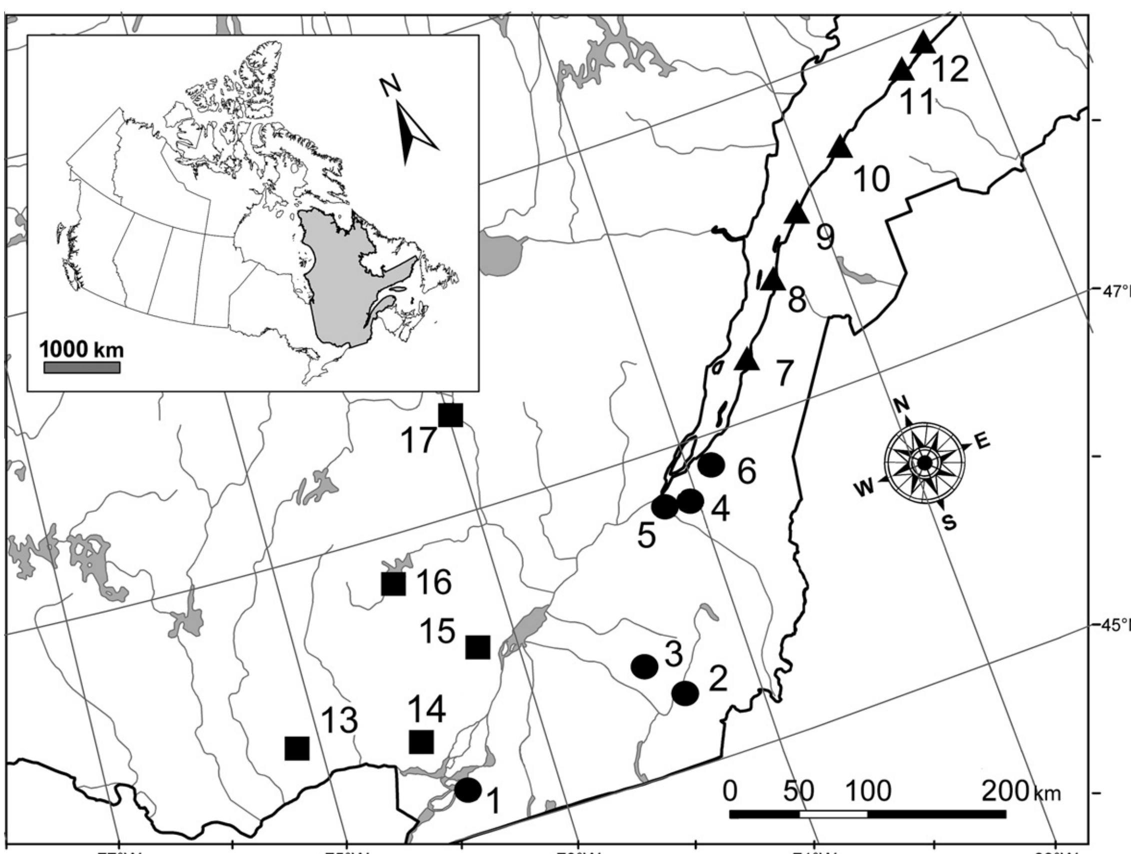

Fig. 1. Location of analyzed rivers. Point: South-east hydrologic region; triangle: East hydrologic region and rectangle: South-west hydrologic region.