Journal of Environmental Management 151 (2015) 76–86

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Combined impacts of future climate and land use changes on discharge, nitrogen and phosphorus loads for a Canadian river basin

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ARTICLE INFO

Article history:
Received 22 September 2013
Received in revised form
20 November 2014
Accepted 4 December 2014
Available online

Keywords:
Land use projections
Climate change
Nitrogen
Phosphorus
SWAT

ABSTRACT

Both climate and land use changes can influence water quality and quantity in different ways. Thus, for predicting future water quality and quantity trends, simulations should ideally account for both projected climate and land use changes. In this paper, land use projections and climate change scenarios were integrated with hydrological model to estimate the relative impact of climate and land use projections on a suite of water quality and quantity endpoints for a Canadian watershed. Climatic time series representing SRES change scenario A2 were generated by downscaling the outputs of the Canadian Regional Climate Model (version 4.1.1) using a combination of quantile–quantile transformation and nearest neighbor search. The SWAT (Soil and Water Assessment Tool) model was used to simulate streamflow, nitrogen and phosphorus loading under different climate and land use scenarios. Results showed that a) climate change will drive up maximum monthly streamflow, nitrate loads, and organic phosphorus loads, while decreasing organic nitrogen and nitrite loads; and b) land use changes were found to drive the same water quality/quantity variables in the same direction as climate change, except for organic nitrogen loads, for which the effects of the two stressors had a reverse impact on loading.

1. Introduction

Studies that address the combined effects of climate change and land use changes in tandem on water quantity and/or quality have been documented variably in literature (Liu et al., 2000; Barlage et al., 2002; Legesse et al., 2003; Tu, 2009; Wilson and Weng, 2011; Dunn et al., 2012; Felzer, 2012; Sample et al., 2012; Tong et al., 2012; Seung-Hwan et al., 2013; Kim et al., 2013). Each of these studies involves numerical experiments whereby a calibrated hydrological model is forced with climatic inputs representing one or several global warming scenarios, and using current and/or projected land use maps.

Differences in these studies lie in the location of the study area, the hydrological model, the type of water quantity and quality variable under scrutiny, and the way climate change and land use scenarios are generated. Hydrological models range from very simple water balance models (Liu et al., 2000; Sample et al., 2012) to sophisticated watershed models, such as the Annualized Agricultural Non-Point Source model (AnnAGNPS: Bingner et al., 2007) and the Soil Water Assessment Tool (SWAT: Wilson and Weng, 2011; Kim et al., 2013) which are capable of simulating loads and concentrations of a variety of water quality targets. The approaches used to evaluate climate change vary as well: Liu et al. (2000), Legesse et al. (2003), and Tong et al. (2012) utilized the Delta-change method which consist of adding arbitrarily chosen variations historical data sets to represent global warming. Others used the outputs of global and regional climate models without any processing (Tu, 2009; Kim et al., 2013), or in combination with a statistical downscaling approach such as the Delta-change method (e.g. Dunn et al., 2012; Sample et al., 2012; Tong et al., 2012), bias correction (Wilson and Weng, 2011; Felzer, 2012), weather generators (Dunn et al., 2012; Seung-Hwan et al., 2013), or regression-based downscaling (e.g. Seung-Hwan et al., 2013).

However, Delta-change downscaling method and bias-corrected global climate model output generation may be too simplistic to characterize climate trends. Raw global climate outputs suffer from distortion even after bias removal, and the Delta-change method is often unable to capture changes in climate variability important for

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http://dx.doi.org/10.1016/j.jenvman.2014.12.012

use as input to regional hydrological simulations. Dibike and Coulibaly (2005), Chiew et al. (2010) and Chen et al. (2012) for instance, have shown that streamflow simulated by forcing hydrological models using climate data obtained using different downscaling techniques can vary or even give conflicting trends. Burger et al. (2012, 2013) have shown that downscaling techniques have very unequal performance in reproducing climate extremes. Burger et al. (2013) showed that downscaled climate extremes were more sensitive to the choice of the downscaling technique than the emission scenario, the climate model, and the geographic location. Given that extreme climatic events are linked to variability and climate variable distributions, and that hydrological processes can be very sensitive to extreme events, consequently the choice of downscaling technique is crucial for representing more realistic future hydrological scenarios.

Land use projection methods used in the above papers range from generalized assumptions about future conversions (e.g. Legesse et al., 2003; Tu, 2009; Dunn et al., 2012; Sample et al., 2012) to detailed land use allocation modeling platforms based on geographic and socio-economic drivers (e.g. Kim et al., 2013; Seung-Hwan et al., 2013). The choice of the land use model and its ability to produce realistic projections will impact modeling outputs in a potentially profound way in many situations where land use conversions play a significant role in watercourses impairment. Such situations are not uncommon as recent studies even suggest that the consequences of future land use changes on the water cycle may outweigh those from associated with climate change (e.g. Sala, 2000).

The objective of this study was to estimate the tandem impacts of climate change and land use changes on streamflow and nitrogen and phosphorus loads for a Canadian river basin under mixed, but predominately agricultural, land use activities (Fig. 1). Hydrological simulations were run using the SWAT eco-hydrological model, for a variety of future climatic and land use configurations. The climatic data sets and the land use configuration sets contained both present and future (predicted) conditions. The impact of global warming (climate scenarios) and land use change scenarios on prediction endpoints, was analyzed to characterize the relative importance of these drivers on future changes of the hydrological regime. For a local water resources manager or stakeholder perspective, results such as those generated in the study will provide support watershed stewardship by informing policies such as source water protection strategies in environments that are becoming increasingly more urban and/or agricultural; by explicitly quantifying how land use boundaries interacting and climate events could impact important water quality factors in terms of ecological function of waterway system.

The current study differs from previous works dealing with the combined impacts of climate and land use changes on hydrological variables in the following ways:

1. The number and nature of water quality and quantity variables assessed.
2. The projected land use changes were generated with a detailed land use projection model that has been successfully modified and validated for the study area (El-Khoury et al., 2014). The model projected a large increase in cropland areas (from 62% in 2011 to 76% in 2050) and urban areas (0.2% in 2011 to 1% in 2050) and a decrease in forested areas (from 33% in 2011 to 19% in 2050). It also projected a relatively rapid urbanization in the areas close to the Ottawa/Gatineau metropolitan area and the disappearance of small forested areas and their replacement with croplands throughout the watershed.

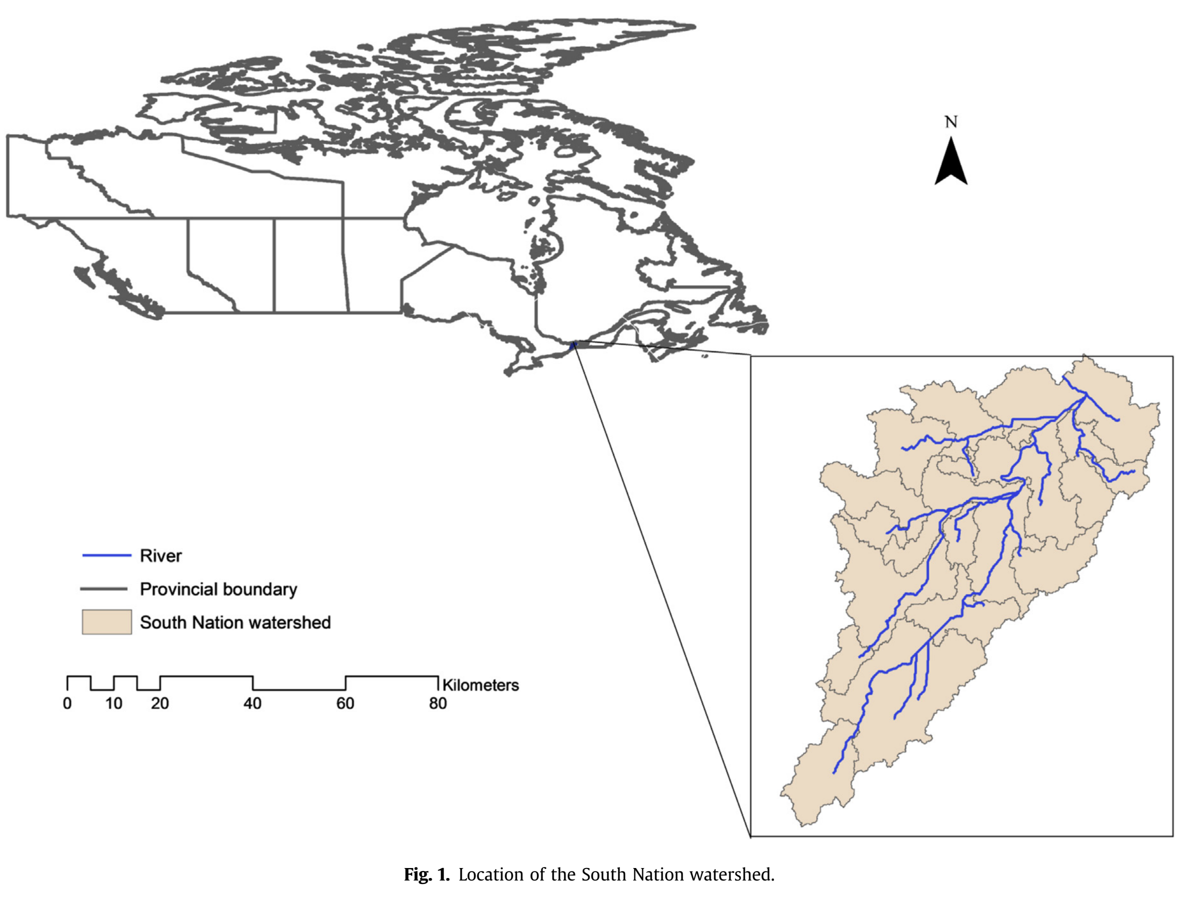

Fig. 1. Location of the South Nation watershed.