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Climate change impacts on an agriculture dominated Canadian watershed.

Los impactos del cambio climático en una cuenca hidrográfica canadiense dominada por la agricultura.

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ABSTRACT

Agricultural water management plays a vital role in the food production and food security(Abbaspour, et al. 2007).Improper management of agriculture leads to local or far field water quality.Runoff from an agriculture land is considerably enriched with different kinds of nutrients, sediments, and pesticides. Nutrient loadings carried with the runoff has caused eutrophication to various degrees and scales, from small and large bays around the Great Lakes (e.g., Green Bay in Lake Michigan) to wide-scale eutrophication in some of the Great Lakes themselves (e.g., Lake Erie)(Inamdar, S. and Naumov, A. 2006)..Water quality and watershed management programs are highly benefitted from simulation models since the advent of computer-based watershed models(Daggupati et al. 2018). To this extent, present study used Soil and Water assessment Tool (SWAT) to investigate the climate change impacts on nutrient loadings primarily occur from runoff from a Canadian agriculture dominated watershed. We found that non-point source pollutants especially total N and total P originating from agriculture land is decreasing during mid and late century projections. Streamflow during winter and fall is projected to increase compared to historical period.

Keywords: SWAT modeling, climate change impact, non-point source pollution.

RESUMEN

La gestión del agua agrícola juega un papel vital en la producción de alimentos y la seguridad alimentaria (Abbaspour, et al. 2007). La gestión inadecuada de la agricultura conduce a la calidad del agua local o lejana. La escorrentía de una tierra agrícola se enriquece considerablemente con diferentes tipos de nutrientes, sedimentos y pesticidas.

Las cargas de nutrientes transportadas con la escorrentía han causado eutrofización en varios grados y escalas, desde bahías pequeñas y grandes alrededor de los Grandes Lagos (por ejemplo, Green Bay en el lago Michigan) hasta eutrofización a gran escala en algunos de los mismos Grandes Lagos (por ejemplo, el lago Erie) (Inamdar, S. y Naumov, A. 2006). Los programas de gestión de la calidad del agua y de las cuencas hidrográficas se benefician enormemente de los modelos de simulación desde la llegada de los modelos de cuencas hidrográficas basados en computadora (Daggupati et al. 2018). En este sentido, el presente estudio utilizó la herramienta de evaluación del suelo y el agua (SWAT) para investigar los impactos del cambio climático en las cargas de nutrientes que se producen principalmente por la escorrentía de una cuenca hidrográfica dominada por la agricultura canadiense. Descubrimos que los contaminantes de fuentes difusas, especialmente el N total y el P total que se originan en las tierras agrícolas, están disminuyendo durante las proyecciones de mediados y finales de siglo. Se prevé que el caudal durante el invierno y el otoño aumente en comparación con el período histórico.

Palabras clave: modelado SWAT, impacto del cambio climático, contaminación de fuentes difusas.

INTRODUCTION

Algal blooms resulting from the nutrient loadings in the Lake Erie has been of prime concern for a long period of time. Sediments and nutrients are found in runoff from farm fields, city streets and the treated effluent from wastewater treatment plants. Analysis of the dynamic variations in sediments and nutrients level on a watershed scale facilitates water management agencies develop mitigation measures to reduce the nutrient loadings and the corresponding detrimental impacts. Continuous simulation of watershed-derived nutrients is imperative to estimate near shore water quality for the Great Lakes. The present study examines the sediment and nutrient loadings from Nith River, a sub-watershed of Grand River which drains into Lake Erie in Southern Ontario. The assessment is carried out based on the hydrological model of the watershed developed using Soil and Water Assessment Tool (SWAT). The model is calibrated and validated for hydrology using the climate and flow data from Environment Canada. This is followed by the validation of sediment and nutrient loadings using limited available data from different governmental agencies. The model performed satisfactorily in terms of water balance and flow time-series evaluation. The objective of the present study is to investigate the efficacy of SWAT model in simulating various nutrient, sediment and turbidity and to study the impact of climate change on an agricultural watershed in Southern Ontario, Canada.

MATERIAL AND METHODS

Study area

Nith River is a tributary of Grand River, longest river in the southern Ontario that drains to Lake Erie (see Fig. 1). Nith River watershed is with an area of 1130 sq. km(Grand River Water Management Plan. 2013). The geology of the upper Nith River basin is a silty till which promotes substantive runoff during the springtime. It also has very intensive agricultural production and a dense municipal and tile drainage network. The major soils of the basin are 25% silt loam, 19% silty clay loam and 8% sandy loam(Lake Erie Source Protection Region Technical Team 2008). The Nith River watershed (NRW) has a moderate to cool temperate climate. Weather patterns in the watershed consist of four seasons including winter, in which the majority of the precipitation is in the form of snow, and summer, which is hot and humid. A warm winter with little snow accumulation will lead to moderate spring flows, whereas a cold winter with heavy snow can lead to heavy spring runoff and floods (GRCA, 2008).

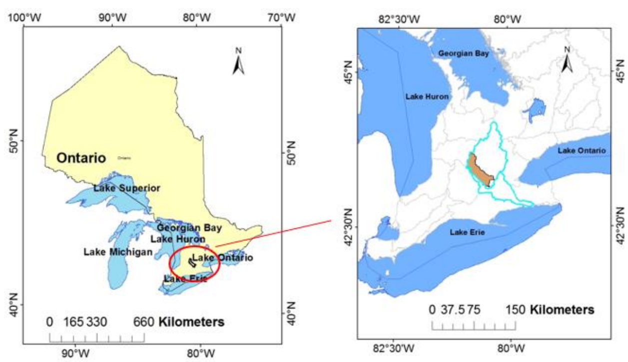

Figure 1. Location map of the Nith River watershed in the Great Lakes region

July is the hottest month and January is the coldest month. Precipitation is uniform throughout the year with characteristics of short intense rainfalls and thunderstorms in spring and summer, to steady gentle rainfalls in the autumn, and to heavy snowfalls in winter. Snowfall generally begins in the month of November and ends around April, while August has the highest average precipitation. Because of varying geology, different hydrologic conditions exist in the watershed.

SWAT model setup

SWAT is a continuous time scale, physically based eco-hydrological model operating on a daily time step for a watershed (Arnold et al 1998). The major components of SWAT model include hydrology, weather, sediments and nutrients, crop growth, pesticides and land management practices. SWAT is a comprehensive model, and it has been widely used to study the impacts of climate and land use change on water balance and nutrient cycle (Neitsch, S. L.et al 2011)

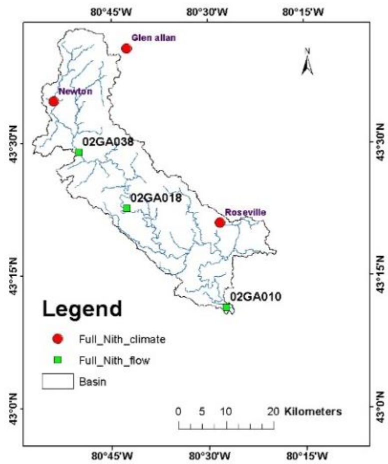

Figure 2. Climate and streamflow gauge stations in the Nith River watershed

All the data layers were projected and pre-processed in ArcGIS interface before incorporating into the SWAT. Table 1 presents the data and sources used in this study for the SWAT model setup.

Table 1. Data used for the SWAT model setup

Data	Remarks	Reference
Climate	3 climate stations	https://weather.gc.ca/canada_e.html
Flow	ID # 02GA010 watershed near outlet	https://wateroffice.ec.gc.ca/
PWQMN	02GA018 - Total N and P	https://www.ontario.ca/environment-and-energy/map-provincial-stream-water-quality-monitoring-network
DEM	GRCA, 10 x 10 m	
Soil	CanSIS, scale of 1 in 1 million	https://sis.agr.gc.ca/cansis
Land use land cover	SOLRIS Version 2	https://geohub.lio.gov.on.ca

PWQMN- Provincial Water Quality Monitoring Network, DEM-Digital Elevation Model, GRCA- Grand River Conservation Authority, CanSIS-Canadian Soil Information Service, SOLRIS-Southern Ontario Land Resource Information System.

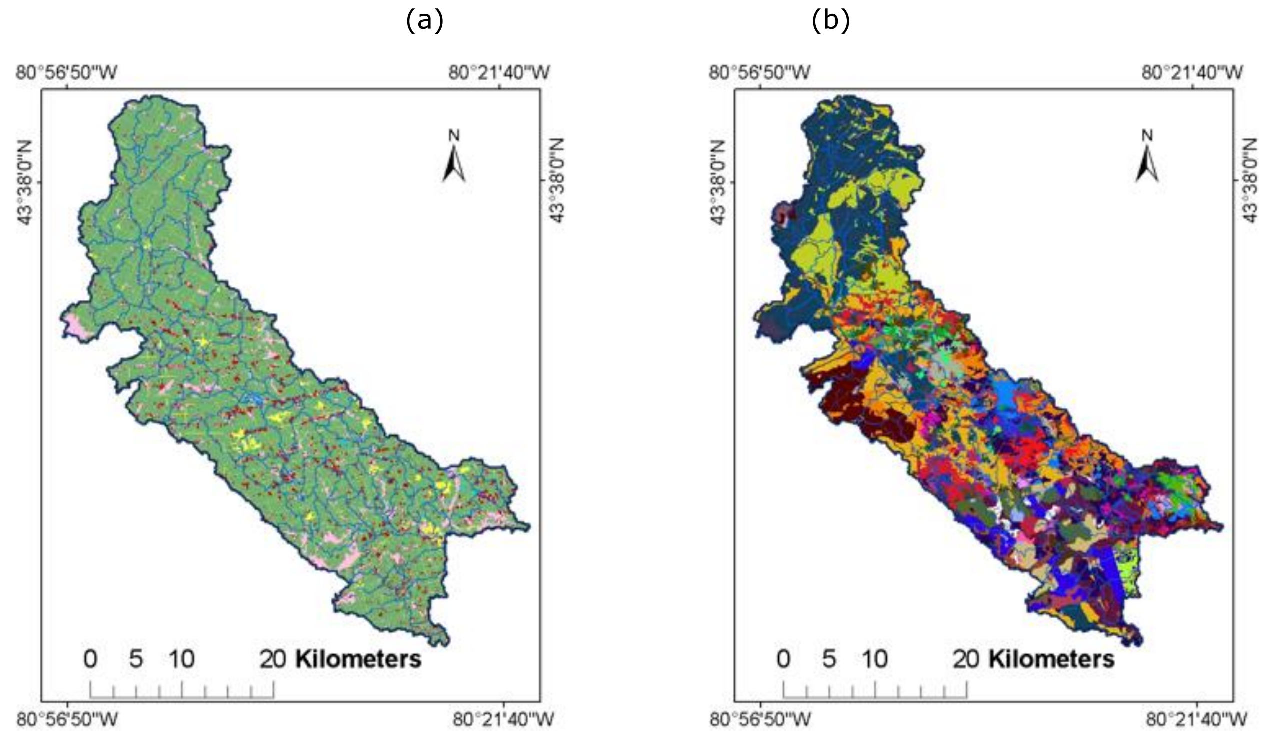

Figure 3. (a): Land use in the Nith River watershed, (b): Soil classification in the watershed

Major land use in the watershed is agriculture (81.2%), followed by wet land (7%), forest (6%) and urban (4%). The major soil type is silt loam (32%) (see Fig. 3(a)). The SWAT model for Nith River watershed was calibrated for a period of 5 years (01/01/1992–31/12/1996) and validated for 4years (01/01/1997–31/12/2000). Calibration was performed using semi-automatic tool SWAT_CUP. Table 2 presents the SWAT model parameters used for calibration.

Followed by the streamflow calibration, future projection scenarios were created using a climate model outputs for RCP 4.5 (4.5 is for average climate change scenario, Representative Concentration Pathway(T. Barker, "Climate Change 2007). More details on climate change models and RCP scenarios can be found at http://sedac.ipccdata.org/ddc/ar5_scenario_process/RCPs.html. The future projections mid-century (2041-2070) and end-century (2071-2100) were generated.

Table 2. Parameters used for calibration in SWAT_CUP

Parameter	Description	Optimal range
SFTMP	Mean air temperature at which precipitation is equally likely to be rain as snow/freezing rain (^{0}C)	-0.62 - 0
SMTMP	Threshold temperature for snow melt (^{0}C)	-2 - 0
SMFMX	Snow melt factor on June 21 (mm H2O/day-^{0}C)	2.5 - 3
SMFMN	Snow melt factor on December 21 (mm H2O/day-^{0}C)	0.8 – 0.96
TIMP	Snow temperature lag factor	0.45 – 0.6
SNOCOVMX	Threshold depth of snow, above which there is 100% cover	21.9 – 32.1
ESCO	Soil evaporation compensation factor	0.68 – 0.78
EPCO	Plant uptake compensation factor	0.8 – 1.02
SURLAG	Surface runoff lag co-efficient (days)	11.6 – 11.9
CN2	Runoff curve number for moisture condition-II	-0.12 – 0.09
SOL_AWC	Available water capacity of soil top layer (mm H_2O/mm soil)	-0.39 - 0
GW_DELAY	Groundwater delay (days)	136.5 – 137.5
ALPHA_BF	Baseflow alpha factor	0.68 – 0.9
GW_REVAP	Groundwater "revap" coefficient	0.1 – 0.3
GWQMN	Threshold water level in shallow aquifer for base flow (mm H_2O)	1386 - 1387
REVAPMN	Threshold water level in shallow aquifer for revap to occur(mm H_2O)	726.4 -726.8
CH_K2	Hydraulic conductivity of main channel(mm/h)	70 – 70.5
CH_N2	Manning's n for main channel	0.25 – 0.29

Note: More details on the SWAT parameters can be found in Neitsch et al., 2011

RESULTS AND DISCUSSION

Fig. 4 presents the monthly streamflow hydrograph during the calibration period (1992-1996) and for the actual watershed processes. Nutrient loading simulation by SWAT model for the Nith River watershed can be seen in Fig. 5. It is observed that the total P (Fig. 4(a), total N (Fig. 4(b), and turbidity (Fig. 4(c)) are significantly high during spring to summer months (March-May).

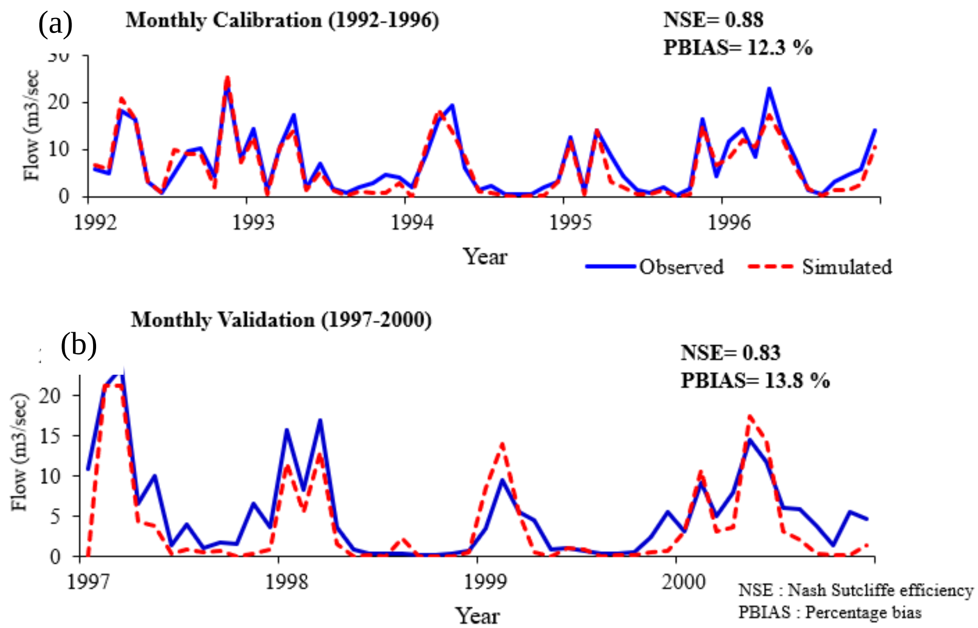

Figure 4. Streamflow hydrographs during calibration and validation of Nith River watershed. The hydrograph is corresponding to Environment Canada flow station 02GA010 (Figure 2.) near the watershed outlet.

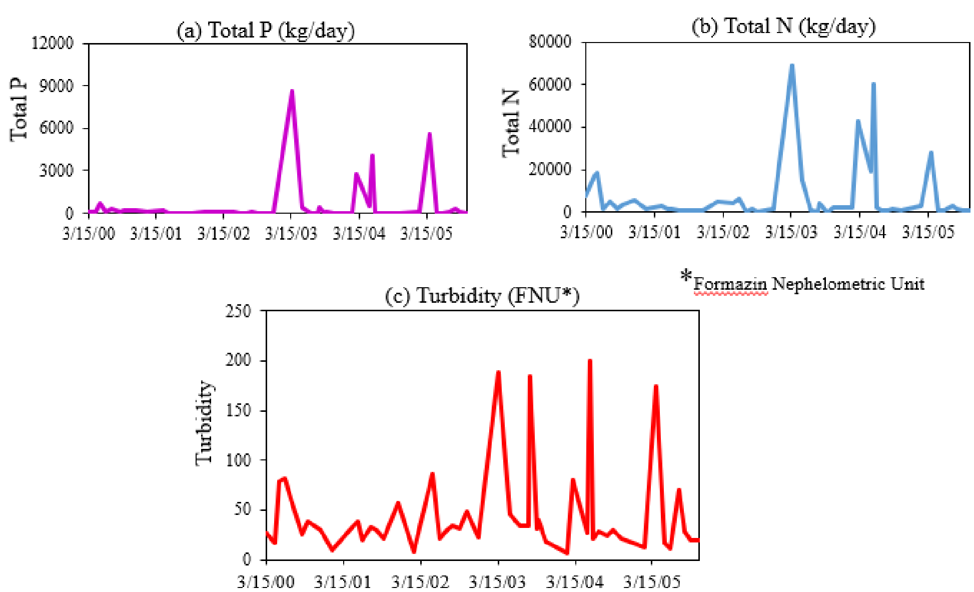

Figure 5. (a) Total N, (b)total P, and (c) turbidity simulation by SWAT

Nith River watershed is an agriculture dominated watershed, Summer is the peak season for pesticide and nutrient application for the crops in the watershed. Consequently, more nutrient and sediment loading can be observed in the spring-summer runoff.

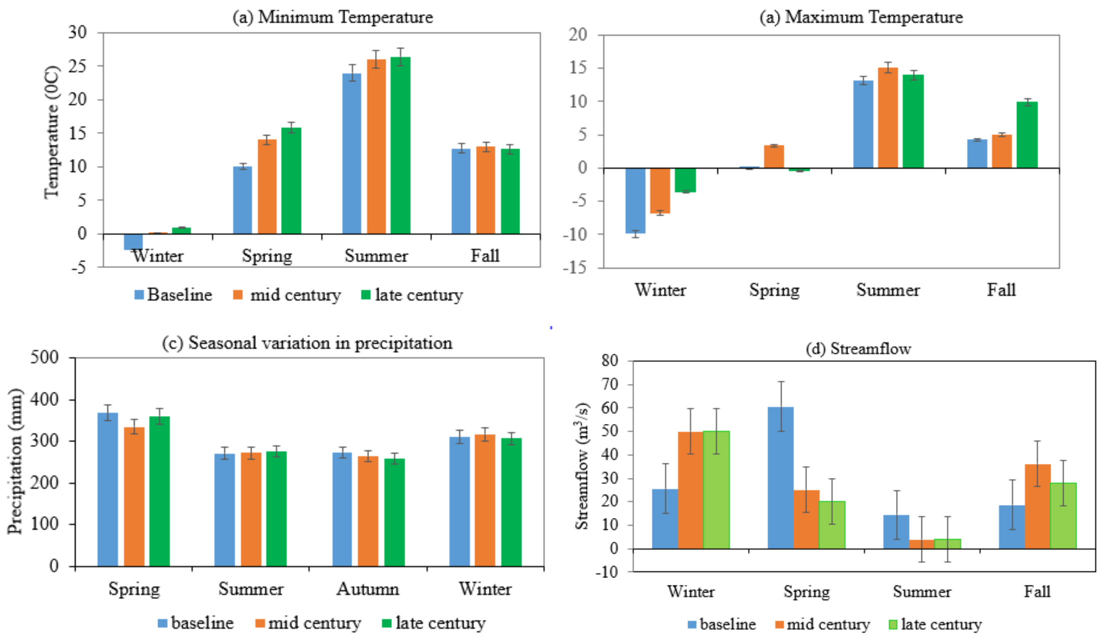

Figure 6. (a)Minimum temperature, (b)maximum temperature, (c)seasonal variation in precipitation, (d)seasonal variation in streamflow.

Fig. 6 shows climate change impacts on various hydrologic processes. Baseline scenario is corresponding to the calibration and validation period (1992-2000). Projected climate change scenarios were generated for mid (2040-2070) and end century (2071-2100) under the RCP 4.5. Min and max temperature during spring and summer (Fig. 6(a), and (b)) is projected to be increased for the RCP 4.5. Whereas the total precipitation is found to be consistent with the historical period. SWAT simulated streamflow (Fig. 6(d)) is significantly high during winter period.From Fig. 6(d) it is found that, observed streamflow during spring period is considerably high, but for the projected streamflow during the mid and end century is not following this trend. Spring and summer flow are generally observed to be high because of the seasonal snow melt in the Canadian watershed, because of climate change this trend may alter and the effects can be reflected such as variations in the seasonal rainfall, temperature, and flow pattern. We can see that the summer streamflow is projected to decrease significantly compared to the baseline scenario.

SUMMARY AND CONCLUSION

- Agricultural non-point source pollutants (Nitrogen and Phosphorous) are the major source of concern
- SWAT is an effective modeling tool to estimate their quantity for a present as well as future scenario
- Streamflow is projected to
  - increase during the winter and autumn period
  - Decrease during spring and summer period
- Significant changes in the pattern of flow, rainfall, and temperature can be expected in the mid and end century due to climate change
- Scenario analysis using watershed-based models can be an effective tool for the water resources managementand policy making

REFERENCES

Abbaspour, et al. (2007). Modelling hydrology and water quality in the pre-alpine / alpine Thur watershed using SWAT. Journal of Hydrology, 413–430.

Daggupati et al. (2018). Hydrological responses to various land use, soil and weather inputs in Northern Lake Erie basin in Canada, Water, 10(2), pp. 1–17.

Grand River Water Management Plan. 2013 Update Broad Water Objectives for the," 2013.

Lake Erie Source Protection Region Technical Team, "Grand River Watershed Characterization Report: Draft," no. January, p. 318, 2008.

Inamdar, S. and Naumov, A. (2006). Assessment of Sediment Yields for a Mixed-landuse Great Lakes Watershed : Lessons from field measurements and modeling. Journal of Great Lakes Research, 32(3), pp. 471–488.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R. (2011). SWAT 2009 Theoretical Documentation. Texas Water Resource Institute Technical Report No. 406 Texas A&M University System. Retrieved from http://swat.tamu.edu/docs/.

Retrieved from http://www.ipcc.ch.

T. Barker, "Climate Change 2007 : An Assessment of the Intergovernmental Panel on Climate Change," no. November, pp. 12–17, 2007.

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