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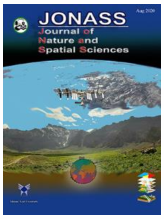

Research Article

Climate change impacts on nitrogen and phosphorus loading in New England watersheds

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ABSTRACT

Background and objective: Nitrogen and phosphorus yields in watersheds can be influenced by air temperature and precipitation. Rising air temperature can affect the natural nutrient cycling process since most nutrient cycles are temperature-dependent. It is hypothesized that increasing air temperature and precipitation can alter the hydrologic cycle and impact the yield of both nitrogen and phosphorus in watersheds. This research's primary objective is to evaluate the influence of climate and land use characteristics of the watershed on nutrient loads in New England watersheds.
Materials and methods: Nutrient data from the Spatially Referenced Regression on Watershed Attributes (SPARROW) model, land use data came from National Land Cover Database (NLCD), temperature and precipitation from USGS are used in statistical analysis with univariate and robust regression functions. The scatter analysis shows that nitrogen and phosphorus have more variability at higher temperatures.
Results and conclusion: Nitrogen and phosphorus have more variation at mid-range precipitation levels and are more diluted with higher precipitation. Robust regression results found that temperature and agricultural land significantly affect nitrogen yields in streams. Temperature, forested land, and agricultural land have the most significant impact on phosphorus in streams. Nutrient management is suggested to target areas to increase watershed resilience to climate change.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) has projected global warming of 1.4° to 5.8° C by 2100 (Arheimer et al. 2005). Along with the rising air temperature comes more frequent and

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extended droughts. Previous studies have shown that climate change accelerates the decline of water quality (Erol and Randhir 2012; Joyner and Rohli 2013) and has significant impacts within the watershed on water quality (Ross and Randhir, 2022; Marshall and Randhir 2008; US Environmental Protection Agency, 2015). Many chemical processes depend on temperature (Benitez-Gilabert et al., 2010; Rehana and Mujumdar, 2012); therefore, the chemical processes will become disrupted and change water quality as air temperature increases. Previous studies have also found several ways climate change is affecting water quality. For example, Benitez-Gilabert et al. (2010) found that one possible outcome of climate change will be drought will become more frequent and have a higher magnitude in Spain. These droughts will cause more evaporation in streams and rivers, causing nutrient loads to become more concentrated. Increased air temperature (a surrogate for increased available energy) also causes high evapotranspiration; therefore, decreasing water volume (Murdoch et al. 2000). Another expected result of climate change is an increase in the frequency and magnitude of floods, which will flush more nutrients into streams and rivers from soils (Benitez-Gilabert et al. 2010), causing the yield of nutrients to have high fluxes. In other cases, nutrient loading to streams from agriculture and municipal wastewater will become more concentrated due to decreased water volume (Whitehead et al., 2009).

Since the early-20th century, phosphorus loads in streams have increased significantly (Ahmadi et al. 2014). Phosphorus enters streams mainly through overland runoff and municipal wastewater. Municipal wastewater discharge has been shown to increase in times with increased air temperature due to the increased water use (Jiang et al., 2014). It has been demonstrated that phosphorus levels are the highest during the growing season (Whitehead et al. 2009; Joyner and Rohli 2013; Jiang et al. 2014; Ahmadi et al. 2014) due to excess phosphorus being flushed off the land. It has been observed that phosphorus loads have also increased in the winter from increased runoff from the upland areas (Ahmadi et al., 2014). In addition, watersheds with increased precipitation often have increased erosion, which leads to higher loads of phosphorus entering streams (Howarth et al., 2006). In the grasslands of Ireland, it has been found that an increase of phosphorus to streams is affected more by climate change than population or land-use change (Jennings et al., 2009).

Human-derived nitrogen loads in streams have increased ten times since the 1860s (Alam and Dutta 2013). Nitrate concentrations in groundwater are influenced by fertilizer use (Mojarad et al., 2021). Climate change is causing an increase in nitrogen discharge to streams (Boyacioglu et al., 2012; Tu 2009). Human activities in disturbed areas input 20 to 25% of the nitrogen in streams (Howarth et al. 2006). Climate change has significant impacts on nitrogen loads in streams. While higher air temperature can disrupt the natural process of denitrification (Boyacioglu et al., 2012; Greaver et al., 2016), higher precipitation lowers denitrification (Howarth et al., 2006). If denitrification slows down or stops, then nitrogen loads in streams can increase exponentially, which will degrade the water quality more. During extended periods of drought, nitrification can be inhibited, causing nitrogen to accumulate in the soil (Greaver et al., 2016). Once precipitation occurs, this excess nitrogen is flushed from the soil into streams (Arheimer et al. 2005; Whitehead et al. 2006; Greaver et al. 2016). Nitrogen loads are the highest in the winter (Aubert et al., 2013; Joyner and Rohli, 2013). One cause of nitrogen loads occurring in the winter months is increased nitrogen leaching caused by increased mineralization (Greaver et al. 2016). The cause of the increased mineralization is higher temperatures, higher soil moisture content (Qanbari and Jamali 2015; Greaver et al. 2016; Jamali et al. 2018; He et al. 2020), and increased microbial activity in the soil, increasing the export of nitrate to streams (Whitehead et al. 2006).

While the effect of climate change on water quality is a critical issue affecting watershed systems (Marshall and Randhir, 2008), there is a need for further research in this area (Benitez-Gilabert et al. 2010; Tu 2009; Whitehead et al. 2009; Boyacioglu et al. 2012; Joyner and Rohli 2013). There is a need to study the full effects of climate change on water quality (Boyacioglu et al., 2012). Climate change is an essential variable for researchers when modeling to help make catchment decision plans (Jennings et al., 2009; Teodoro Carlón Allende et al., 2021).

There is a gap in research on the direct impact of climate change on nutrient loading at a spatially explicit, regional scale. This study is unique in addressing this gap in studying statistical relationship between climatic variables (temperature and precipitation) and nutrients (nitrogen and phosphorus) in the New England region. This study had four primary objectives: (1) to assess baseline levels of nutrients at a watershed scale in New England; (2) to evaluate potential impacts of climate change (temperature and precipitation) on nutrient loads; (3) to evaluate effects of watershed land cover and land use on nutrient loads; and (4) to identify management priorities at a regional scale.

It is hypothesized that temperature and precipitation changes have a significant influence on nitrogen and phosphorus loadings in watersheds. It is hypothesized that the causal functions can be used in developing adaptation policies for climate change. The paper presents the methodology and data processing in the next section, followed by results and discussion, and conclusion.

2. Methods

The study area includes New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont). In New England, there are approximately 42,000 sub-watersheds (Preston et al., 2011). Nitrogen and Phosphorus data were obtained from SPARROW (Spatially Referenced Regression on Watershed attributes). SPARROW is a spatial water quality model developed by the United States Geological Survey (USGS) (Preston et al. 2011) in cooperation with the Environmental Protection Agency (EPA) and the New England Interstate Water Pollution Control Commission (NEIWPCC) (Preston et al. 2009). SPARROW is a hybrid model of empirical and process-based mass balance (Schwarz et al. 2006). The model comprises a nonlinear regression equation used to determine and explain the transport of nutrients from point sources to streams (Schwarz et al., 2006). SPARROW is used to determine major sources of nutrients and environmental factors that impact the transport, long-term supply, and fate of contaminants in streams (Schwarz et al., 2006; Preston et al., 2011). The main objective of SPARROW modeling is to create a mathematical relationship between water quality and watershed attributes (Schwarz et al., 2006). SPARROW model's secondary objective is to recognize and quantify pollution sources that affect stream water quality (Schwarz et al., 2006). There are eight Major River Basins (MRB) in SPARROW; New England is in MRB 1 (Preston et al., 2011).

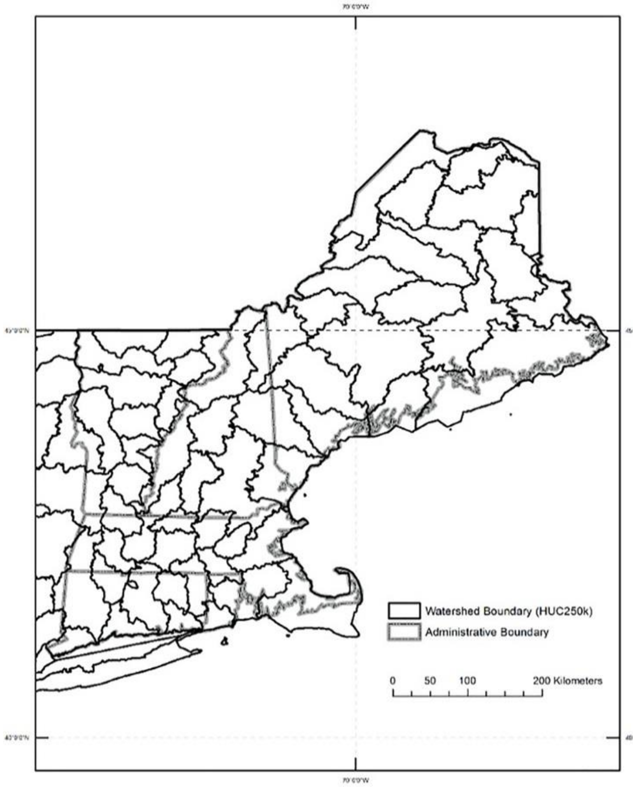


Fig. 1– Waterdhed of New England

Land Cover data was obtained from the 2011 National Land Cover Data (NLCD) set (Homer et al. 2015) (Fig. 1. NLCD updates its land cover data every five years; 2011 is the most recent version available during the study. First, the land cover was separated into developed, forested, agriculture, wetland, open water, shrubland, and barren. Next, the percentage of land use was calculated for each catchment. Finally, baseline data for temperature and precipitation were

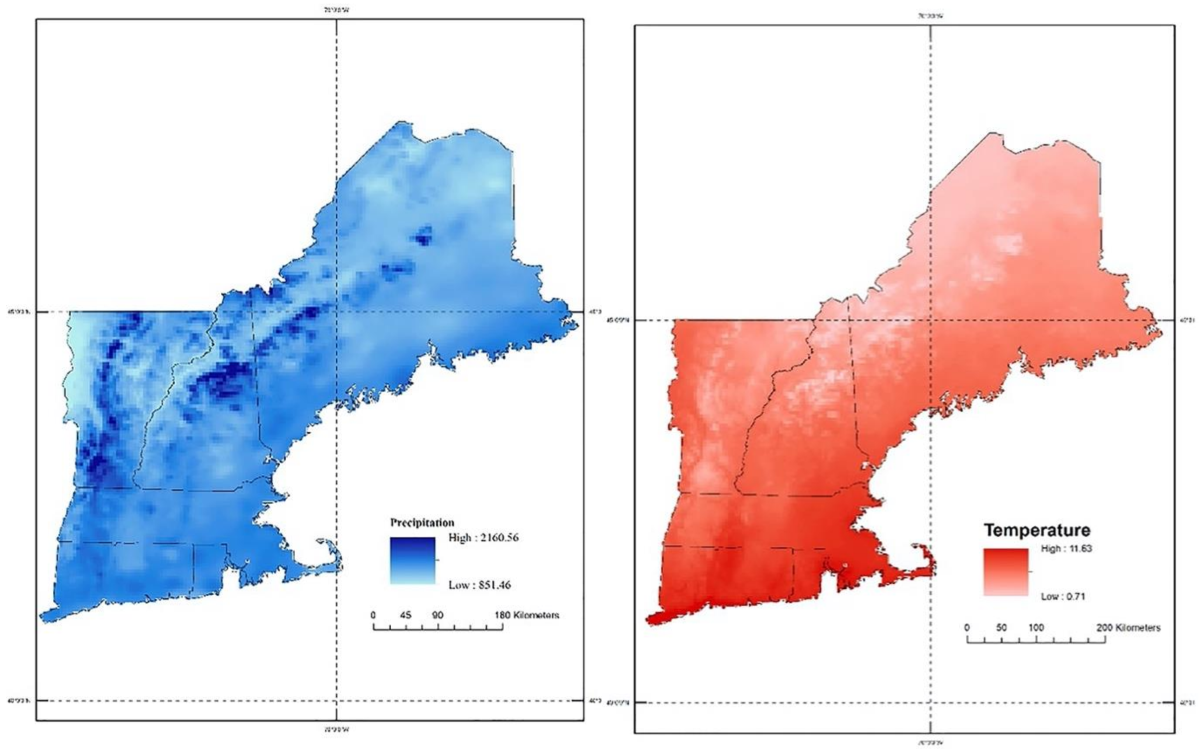
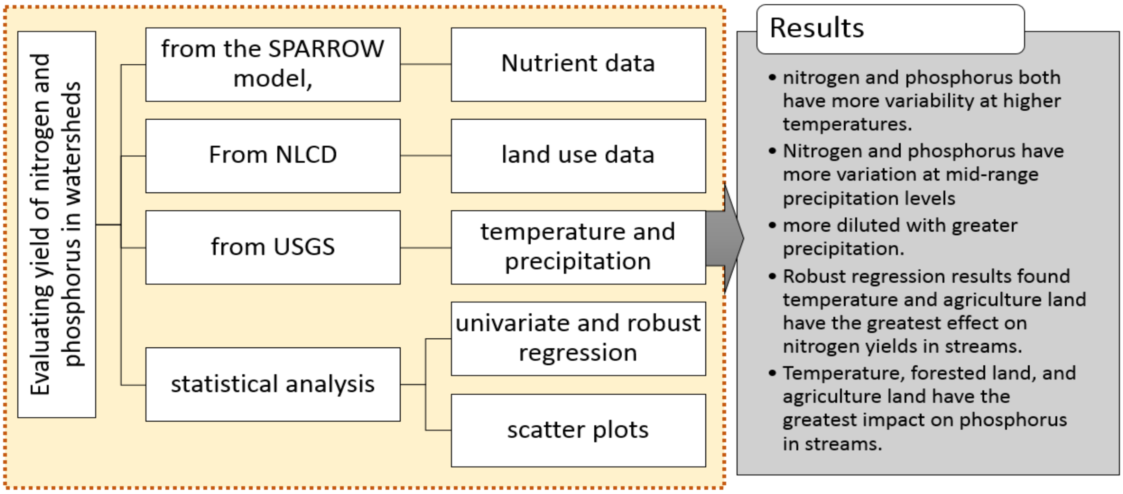


Fig. 2 - Thirty-year mean-annual of precipitation and temperature in New England. Precipitation units are in mm multiplied by 100 (for display reasons). The temperature is in Celsius. (PRISM, 2017).

obtained from the USGS as a 30-year average (1981-2010) Fig. 2. It is shown that precipitation is the highest, and the temperature is the lowest in New England's higher elevations.

Robust regression was used to fit the data using the computer software SYSTAT 13 (Systat Software Inc). Robust regression was done on nutrient, temperature, precipitation, and land use data Fig.3. A robust regression reduces the weight given to the outliers, so they do not influence the results. Nitrogen and phosphorus data were also positively skewed when graphed. Robust estimation used the Ordinary Least Squares (OLS) method for parameter estimation of outlier-free data. This data was logged and then run through the robust regression to convert the data to be normally distributed.



- nitrogen and phosphorus both have more variability at higher temperatures.
- Nitrogen and phosphorus have more variation at mid-range precipitation levels
- more diluted with greater precipitation.
- Robust regression results found temperature and agriculture land have the greatest effect on nitrogen yields in streams.
- Temperature, forested land, and agriculture land have the greatest impact on phosphorus in streams.

Fig. 3 - Flow Chart overview of the analysis of SPARROW, temperature, and precipitation data to determine impacts on water quality and management strategies.

3. Results and Discussion

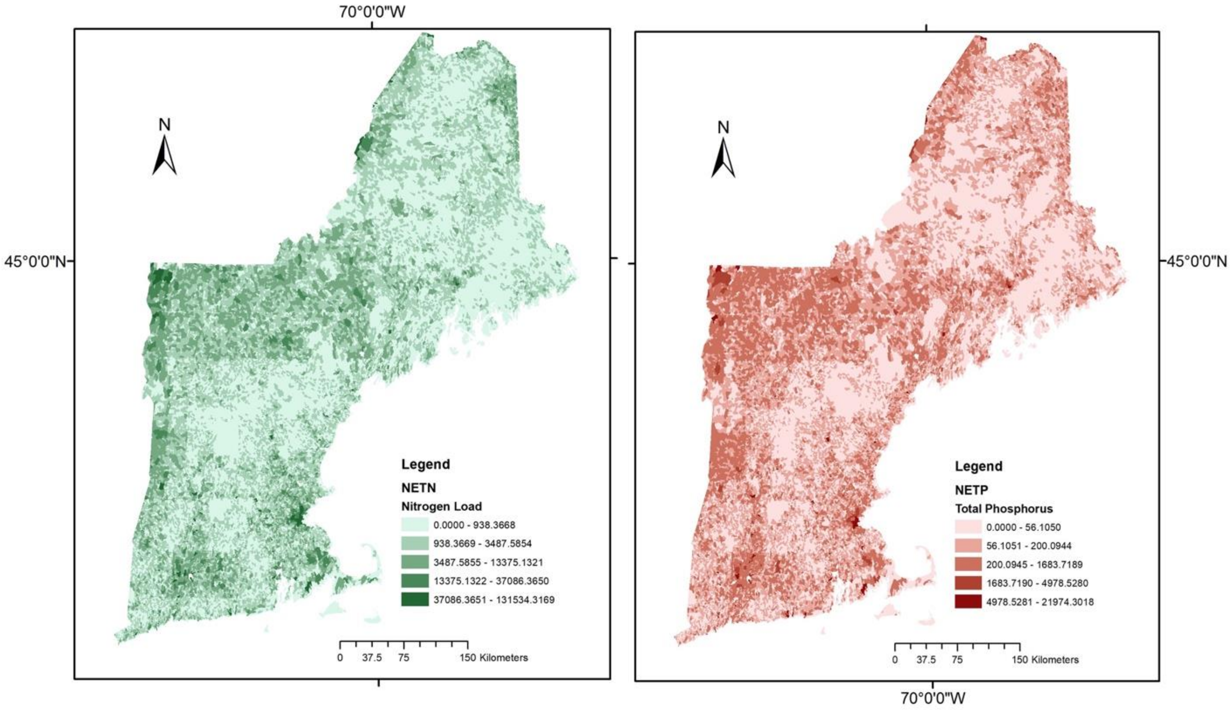


Fig. 4 - Nitrogen and Phosphorus loads (kg/km2/year) for Northeast USA (Data from Ator, 2019).

Baseline nitrogen data were assessed to see the areas with the highest total yield in kilograms/hectare Fig. 4. It is shown that the highest total nitrogen yield occurred in north-eastern Maine and around large cities throughout Massachusetts. In addition, the most recent SPARROW data was assessed, and it was found that there was a mean total yield of nitrogen of 399 kg/hectare with a standard error of 6.1.

Phosphorus data was also reviewed to see where the highest total yield occurred Fig. 4. The baseline phosphorus data has a high yield in north-eastern Maine, similar to nitrogen. There is also a high total phosphorus yield along the border of New England and New York. The total phosphorus yield from SPARROW was found to be 28 kg/hectare, with a standard error of 1.8.

The relationship between nitrogen and temperature was graphed on a scatter plot Fig. 5. The scatter plot shows a higher variability of nitrogen yield at higher temperatures and lower variability at lower temperatures. Therefore, as air temperature continues to rise, this will cause nitrogen yields in streams also to increase in magnitude and variability. Similar results were obtained using a simulation model in the Narragansett Bay Watershed in Southern New England region (Ross and Randhir, 2022).

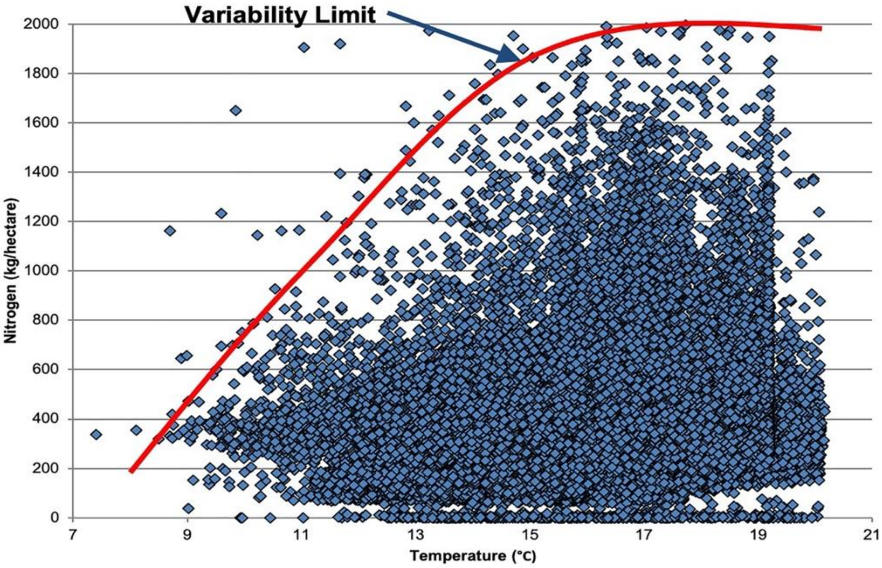


Fig. 5 - Temperature (°C) versus Nitrogen (kg/hectare) total yield to determine correlation. The graph was truncated at 2,000 kg/hectare for extreme outliers.

The relationship between precipitation and nitrogen was also graphed in a scatter plot Fig. 6. Results show that the total nitrogen yield had higher variability in the mid-range (approximately 900 mm to 1300 mm) precipitation. At the high range of precipitation, nitrogen has a lower variability. It appears that when there is more precipitation, the nitrogen load in streams becomes diluted.

The relationship between temperature and phosphorus shows higher magnitude and variability of phosphorus at higher temperatures Fig.7. This is similar to observation by Ross and Randhir (2022).

Conversely, at lower temperatures, there is decreased variability of the phosphorus. This could be due to lower phosphorus mobilization. Increase in water use for domestic consumption can reduce water flows in summer at higher air temperatures, which causes an an increase in phosphorus from wastewater discharge in urban areas. Therefore, climate change can influence phosphorus contamination through complex hydrologic processes.

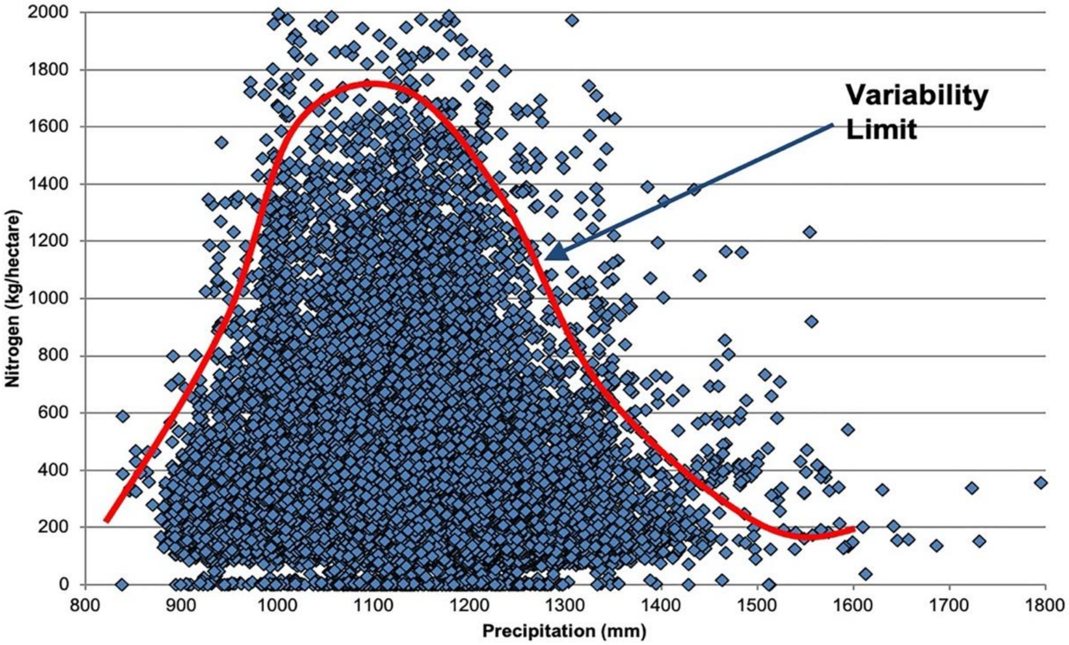


Fig. 6- Precipitation (mm) versus Nitrogen (kg/hectare) total yield. The graph was truncated at 2,000 due to extreme outliers.

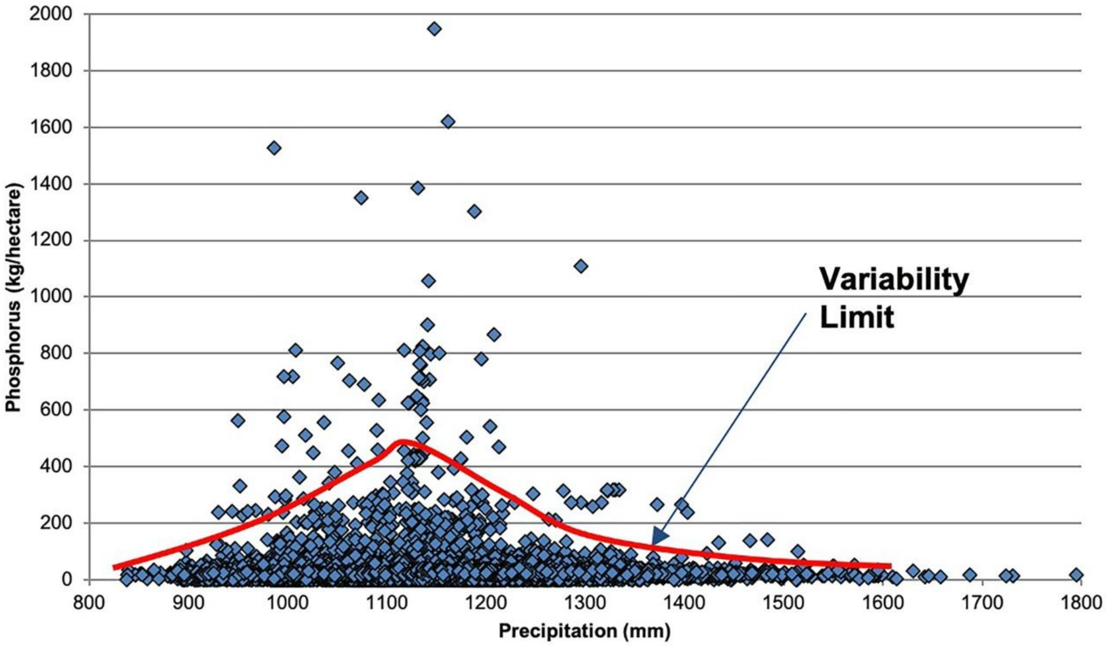


Fig. 7- Temperature (°C) versus the total yield of phosphorus (kg/hectare) to determine correlation. The graph was truncated at 200 kg/hectare due to extreme outliers.

The relationship between total phosphorus load and precipitation is similar to that of nitrogen and precipitation. There is high variability in phosphorus yield at the mid-range of rainfall (approximately 900 mm to 1300 mm) Fig. 8. With increased rainfall, there is lower variability with phosphorus yield. It seems that as precipitation increases, the phosphorus yield in streams will become diluted.

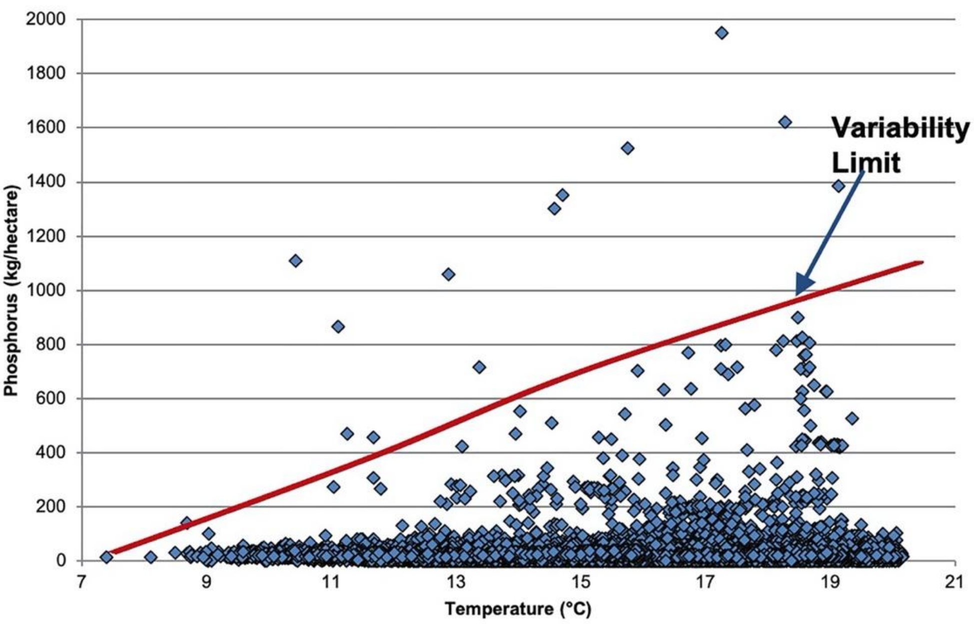


Fig. 8- Precipitation (mm) versus phosphorus (kg/hectare) total yield. The graph was truncated at 200 kg/hectare due to extreme outliers.

As shown in Table 1, precipitation and developed land negatively correlate with nitrogen yields in streams. Conversely, temperature and agricultural land use positively affect nitrogen yields. The regression model explains only about 12.5% of the variation. This indicates the role of other watershed factors in influencing nitrogen yields.

Table 1: Nitrogen Loads Regression

Effect	Coefficient	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Constant	5.52193	0.04738	5.42907	5.61480
Temperature	0.08431	0.00152	0.08133	0.08729
Precipitation	-0.00100	0.0003	-0.00106	-0.00094
Forest	-0.00007	0.00013	-0.00032	0.00019
Developed	-0.00156	0.00020	-0.00195	-0.00117
Agriculture	0.00164	0.00023	0.00119	0.00209

R= 0.35; R square = 0.125; Adj R square = 0.125

Robust regression results show that precipitation and developed land negatively affect phosphorus yields in streams (Table 2). Conversely, temperature, forest land, and agricultural land all have positive relationships with phosphorus yield, which means they have the most significant impact on the phosphorus load in streams. Approximately 4.6% of the variation is explained in this model. This indicates the role of other watershed factors in influencing phosphorus yields.

Table 2: Phosphorus Load Regression

Effect	Coefficient	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Constant	2.46521	0.04272	2.38148	2.54894
Temperature	0.04834	0.00137	0.04564	0.05102
Precipitation	-0.00033	0.00003	-0.00038	-0.00027
Forest	0.00022	0.00012	-0.00001	0.00045
Developed	-0.00007	0.00018	-0.00042	0.00029
Agriculture	0.00133	0.00021	0.00092	0.00173

R= 0.22; R square= 0.046; Adj. R square = 0.046

4. Conclusion

Climate change causes variable impacts on nutrients. Forty-two thousand subwatersheds in New England were assessed in this study. Nitrogen and phosphorus data were collected from SPARROW, a spatial water quality model. The 2011 NLCD was used to obtain land cover data for New England. Land cover data were reclassified into the total forest, agriculture and developed to run statistical analysis. Thirty-year averages (1981-2010) were downloaded from USGS for temperature and precipitation. Robust regression was used to fit nutrient data using temperature, precipitation, and land use data from watersheds throughout the study region.

Baseline nitrogen and phosphorus data were first assessed to determine areas that already have high yields of nutrients in streams. Univariate relationships were graphed on scatter plots. Temperature versus nitrogen and temperature versus phosphorus both showed higher variability of nitrogen and phosphorus at higher temperatures. Precipitation versus nitrogen and precipitation versus phosphorus found the most increased nitrogen and phosphorus variability at mid-range precipitation levels. Higher precipitation levels appear to dilute the nitrogen and phosphorus yields in streams. When the robust regression model was run, only about 10% of the variation was explained in the nitrogen regression. The temperature has an impact on nitrogen yield. Agriculture also modest impact on nitrogen yield, but not as much as temperature. Nitrogen data were positively skewed, so it log-transformed before the robust regression. This model only explained about 12% of the variation.

Furthermore, temperature and agriculture have a more significant impact on nitrogen yield than precipitation, forest land, and developed land. Phosphorus data was also run through the robust regression, and only 4% of the variation was explained—temperature, forest land, and agricultural land all impact phosphorus yields in streams. Phosphorus data were positively skewed, so it was log-transformed before robust regression. Only 5% of the model explained the variation when the data was re-run. Temperature, forest land, and developed land were again found to impact the phosphorus yield in streams.

A previous study by Jiang et al. (2014) found that increased air temperature causes increased water use, which will cause an increase in municipal wastewater discharge. This study supports the finding by Jiang et al. (2014). Howarth et al. (2006) found that watersheds with increased precipitation will have higher phosphorus loads entering streams due to increased erosion. This study found an opposite result, with increased precipitation resulting in a decreased concentration of nutrients in streams. The decrease could be due to excess water volume that dilutes the pollutants. During a drought, nitrogen accumulates in soils (Greaver et al. 2016) and gets flushed out once a precipitation event occurs (Arheimer et al. 2005; Whitehead et al. 2006; Greaver et al. 2016). This explains the results of this study that nitrogen yields can increase during a precipitation event, but with high precipitation levels, the nitrogen will become diluted.

Nutrient management through source management is needed in New England watersheds to mitigate the adverse effects of climate change. Assessment of source, transfer, and the fate of nutrients should be done at a watershed scale (Talib and Randhir, 2016). This could help target areas for increasing resilience through best management practices (BMPs), incentives, and awareness policies.

This study could be improved with better data availability. One improvement could be HUC 10 instead of HUC 12, reducing the number of subwatersheds being assessed. Another extension of the current study is to use the hydrologic calendar (growing season to growing season) instead of the calendar year. This will determine how nutrient yields in streams change throughout the year with changes in vegetation growth. Further extension of the study could analyse data from a drought year and check how the nutrient yield in streams is affected. This could also be repeated for a wet year to evaluate what impacts nutrient yields in streams.

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Declarations:

Ethical Approval: The paper follows standard ethics guidelines.

Consent to Participate: There are no human subjects involved in the study

Consent to Publish: Authors consent to publishing

Authors Contributions: All co-authors contributed to the manuscript

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Competing Interests: There are no conflicts of interest or competing interests to report.

Availability of data and materials: Data and software applications that support and underlie this study are publicly available sources.

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