Received: 28 March 2019 | Revised: 30 January 2020 | Accepted: 31 January 2020
DOI: 10.1002/rra.3604

Check for updates

SHORT COMMUNICATION

WILEY

Analysis of phosphorus and nitrogen concentrations in the Great Miami and Little Miami basins in Ohio, USA from 2015 to 2017

Eric Ariel L. Salas | Sakthi Kumaran Subburayalu

Agricultural Research Development Program (ARDP), Central State University, Wilberforce, Ohio, USA

Correspondence
Eric Ariel L. Salas, Agricultural Research Development Program (ARDP), Central State University, Wilberforce, OH 45384.
Email: esalas@centralstate.edu

Funding information
USDA-NIFA 1890 Evans Allen Award, Grant/Award Number: NI181445XXXXG007

Abstract

Concentrations of phosphorus (P) and nitrogen (N) in the Great Miami (GM) and Little Miami (LM) basins still remain among the highest detected in the United States. The recent nutrient analysis from the Ohio Environmental Protection Agency revealed slightly above average P and N for the recorded period. To assess the temporal changes of nutrient concentrations, this short communication examined datasets collected in the GM and LM basins for three consecutive years—from 2015 to 2017. Our results indicated abrupt spikes of N concentrations in 2017 for six sample sites. By mapping 3 years of data, we found high annual differences in levels of P in the middle and southeast zones of the watersheds. The concentration levels of N did not change much over 3 years, except for specific hotspots in the middle section of the region. Our results could benefit environmental scientists and watershed managers in identifying optimum conditions and adopting new strategies and tools to further mitigate the input of P and N nutrients into the river systems of the GM and LM basins.

KEYWORDS

nutrient loadings, nutrient management, nutrient pollution, Ohio watershed, temporal analysis

1 | INTRODUCTION

Phosphorus (P) and nitrogen (N) are essential nutrients in dynamic aquatic ecosystem when they occur in small amounts. However, when they are present in excessive quantities, they can result in negative human health and environmental effects (Salas & Subburayalu, 2019). Some of the negative impacts to the watershed when these nutrients are in surplus quantities include degradation of water quality (Paul & Meyer, 2001), destruction of biotic communities, eutrophication, fish anomalies and fish kills (Naramngam & Tong, 2013), severe harmful algal blooms (HAB) (OEPA, 2013), reduced dissolved oxygen (DO) concentrations, and increasing fluctuations in diel DO and pH (MCD, 2011). These adverse impacts are not only felt in river systems inside the watershed, but similar effect may be experienced in larger connecting river systems where the affected watershed eventually drains.

Agricultural land use covers the majority of the Great Miami (GM) and Little Miami (LM) watersheds in Ohio. With about 68% for GM and 56% for LM classified as agricultural areas, high rates of fertilizer application from county-level data have been recorded (Battaglin & Goolsby, 1995). Commercial fertilizers from farms, in addition to manure from livestock production, are the major sources of nutrients in surface and ground waters (OEPA, 2018). These mobilized agricultural nutrients are easily transported in significant quantities to the Ohio River and other coastal marine systems, such as the Gulf of Mexico, due to poor agricultural practices in the watersheds (Gorham, Jia, Shum, & Lee, 2017). The GM watershed is a major contributor of P and N nutrients to the Mississippi–Atchafalaya River watershed (Goolsby et al., 1999) and has the highest soluble reactive phosphorus concentrations amongst the 10 streams studied in Ohio (Baker, Richards, & Kramer, 2006). In addition, the growth of harmful algal blooms in the Gulf is believed to have been caused by transport of P and N nutrients during spring runoff (Scavia, Justic, & Bierman, 2004). The latest Water Quality Monitoring and Assessment Report showed the GM and LM basins as sources of recent algal blooms in the Ohio River (OEPA, 2018).

The water quality in the GM and LM river systems has seen improvement in the last two decades (MBI, 2014). Nevertheless, publicly available reports (OEPA, 2011; OEPA, 2012; OEPA, 2013) revealed that surpluses of P and N nutrients in the watersheds still occur. Elevated concentrations of nutrients detected in streams were occasionally at levels that surpassed the recommended statewide nutrient target concentration standards. Thus, the aim of this short communication is to understand the temporal trends of P and N concentration levels. We investigated datasets collected in the GM and LM watersheds for three consecutive years from 2015 to 2017, mapped the annual spatial distributions of P and N, and examined concentration differences between years. Our findings could help improve awareness and better understanding of the nutrient loading processes. By mapping distributions of P and N, it becomes easier to identify those river systems that contribute disproportionately high nutrient loadings to the watersheds.

2 | MATERIALS AND METHODS

2.1 | Study area

The GM and LM basins drain about 7,354 miles^2 (19,047 km^2) in southwestern Ohio and southeastern Indiana (Figure 1). Since 1997, both

TABLE 1 The six selected sampling sites and their nearest weather stations

Site	Station	Name
1	USC00332651	Fairfield
2	US1OHBT0017	Hamilton 1.5 NW
3	US1OHBT0017	Hamilton 1.5 NW
4	US1OHBT0001	Hamilton 4.7 E
5	USC00335220	Middletown
6	USC00335220	Middletown

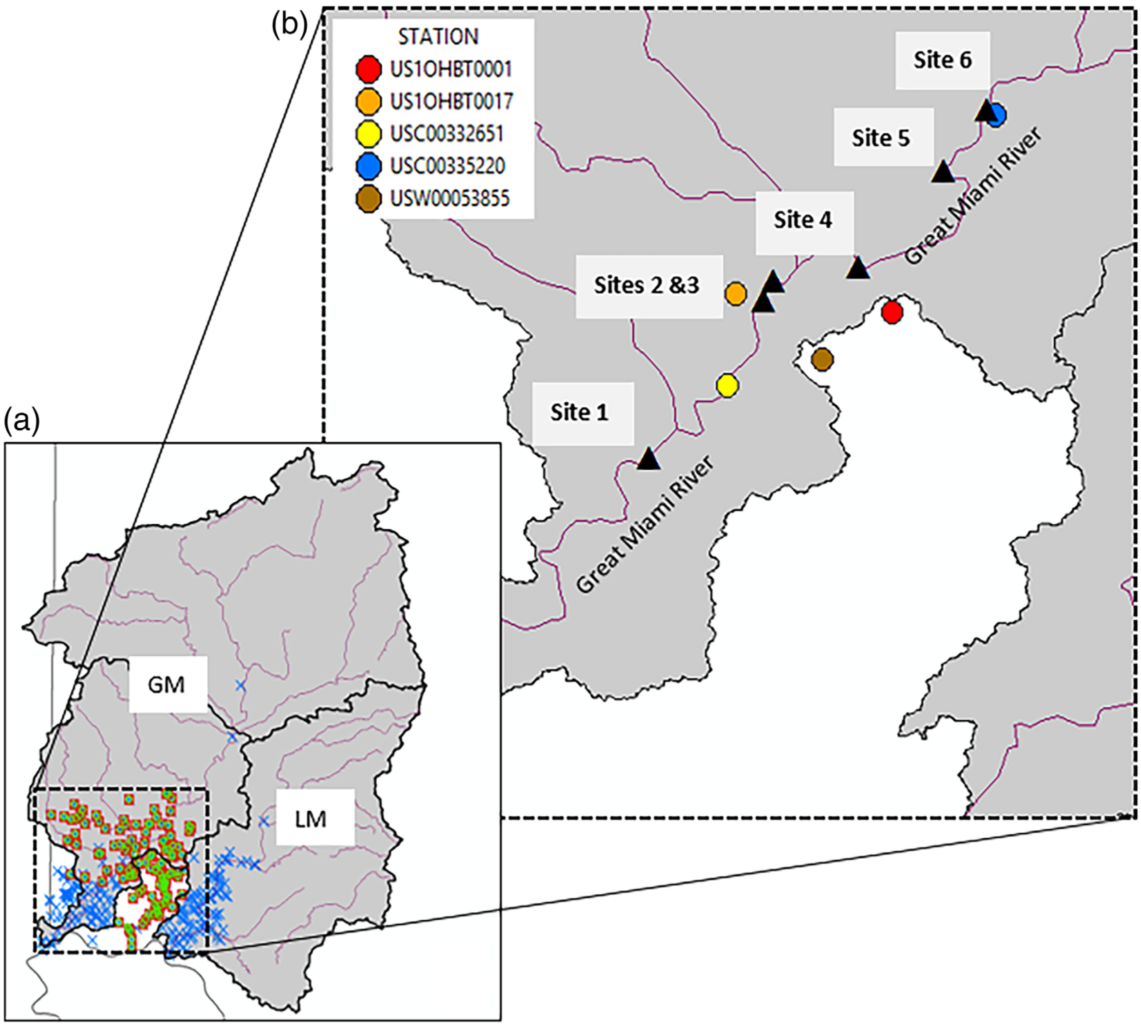

FIGURE 1 The Great Miami (GM) and Lower Miami (LM) basins. In panel (a) are locations of all sampling points from 2015, 2016, and 2017 data collection. In panel (b) are the selected six sample sites along the GM River that have available data for three consecutive years (2015, 2016, and 2017). Site 1 is located downstream of the river, while Site 6 is located upstream. The nearest weather stations for the selected sampling sites are also provided in (b)

basins have been part of the 51 major river basins in the nation that are called "study units" for long-term assessment of water-quality conditions under the USGS National Water-Quality Assessment (NAWQA) Program. Major rivers in the GM and LM are the Great Miami River and Little Miami River in Ohio and the Whitewater River in Indiana (Rowe & Baker, 1997). The study area is temperate continental with mean annual temperature that ranges from 49 to 55 °F (9.4 to 12.8°C). The average annual precipitation ranges from 35 to 43 in. (889 to 1,092 mm) and increases towards the south; about one-third of the precipitation becomes surface runoff (Rowe & Baker, 1997).

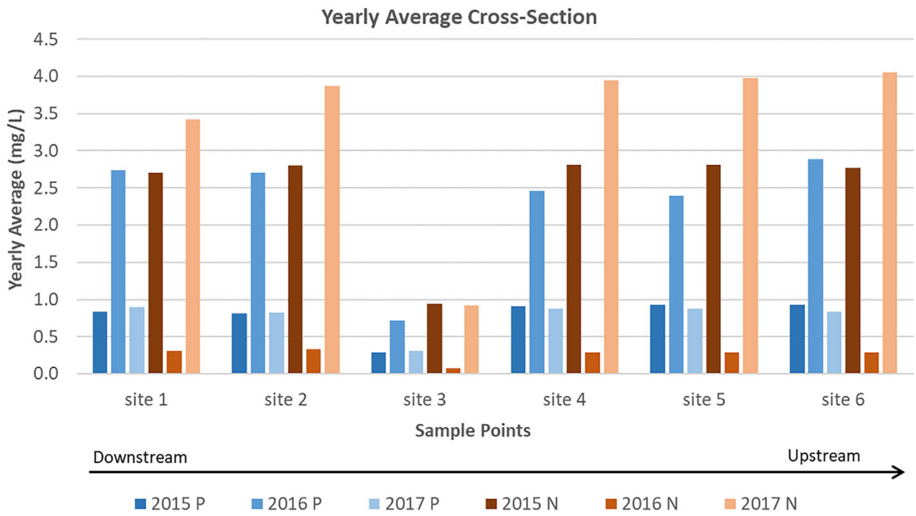

FIGURE 2 A plot of the yearly average P and N concentrations per sampling site. Consecutive sampling years cover 2015 to 2017

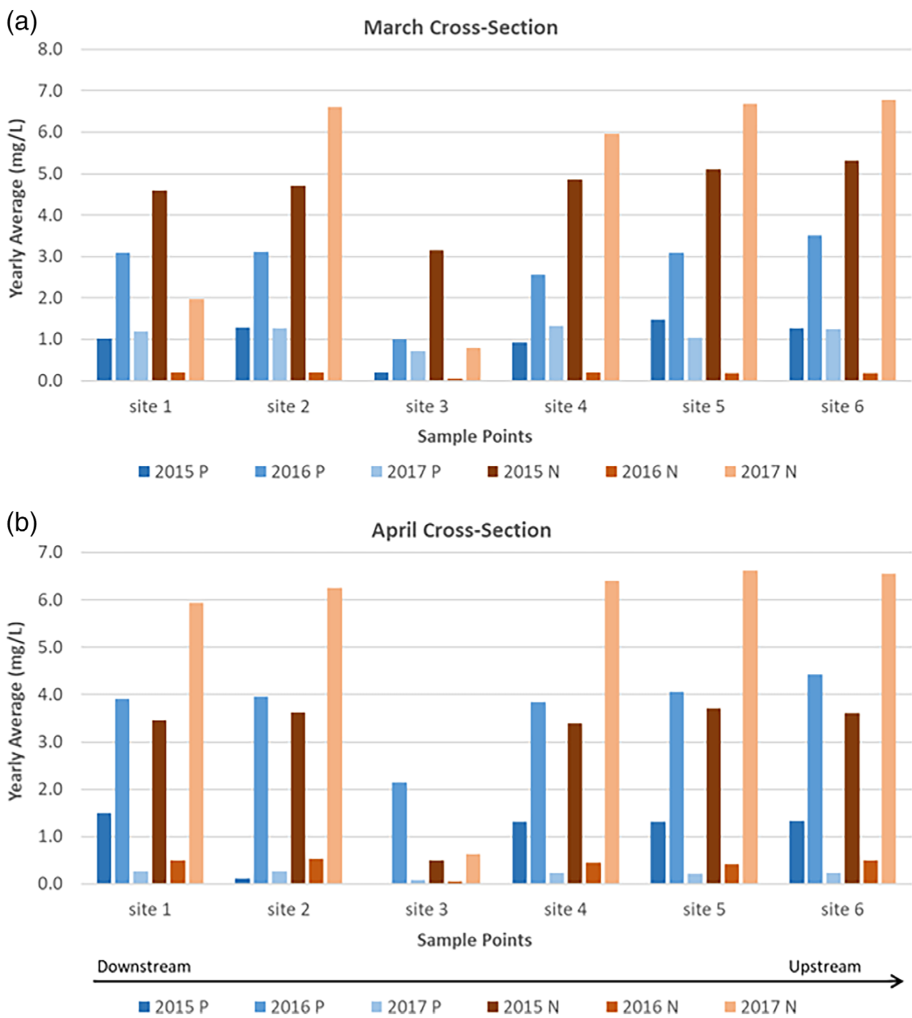

FIGURE 3 A plot of the P and N concentrations per sampling site for the months of (a) March and (b) April from 2015 to 2017

Commercial fertilizers N and P (P in the form of P_2O_5 phosphate and K_2O potash) are used widely in both watersheds, which are predominantly cropland (OEPA, 1996). These commercial fertilizers from row-crop farming, in addition to manure from livestock production, are the major sources of nutrients in surface and ground waters (OEPA, 2018).

2.2 | Watershed datasets

We used datasets from StreamBank, a centralized online repository that publishes water quality datasets for public use (StreamBank, 2018). These datasets were collected by trained volunteers from Butler County Stream Team, Lower Great Miami Citizens' Water Quality Monitoring, Saturday Stream Snapshot by Greenacres, and the Mill Creek Volunteer Water Quality Monitoring program. Volunteers were taught how to collect field water samples and analyze them in the laboratory using strict quality assurance protocols.

2.3 | Sampling sites and analysis

We selected six sampling sites along the GM river that had three-year consecutive records of P and N. These sites represented a 40-km stretch of the GM river, with Site 6 located in the upstream section and Site 1 in the downstream section. We analyzed the monthly and annual P and N concentrations for each location. We also interpolated the P and N values to map nutrient distributions. Finally, we correlated P and N concentrations against the "3-day cumulative rainfall" and "actual rainfall" events using datasets from the nearest weather stations (Table 1).

3 | RESULTS

Phosphorous concentrations in 2016 had the highest average of all sampling sites along the river studied (Figure 2). The years 2015 and 2017 displayed comparable average P values across the individual sampling sites. For N concentrations, 2017 had the highest average N measurement at all sites (except Site 3), while 2016 had the lowest average N.

Monthly analysis of P and N concentration levels indicated much lower values in August and September for all years. Significant results included a drop of N from 6.78 mg/L at Site 6 (upstream) to 1.97 mg/L at Site 1 (downstream) in March 2017. We also found a sudden decrease of P levels at Sites 2 and 3 during 2015 and 2017 in the month of April (Figure 3).

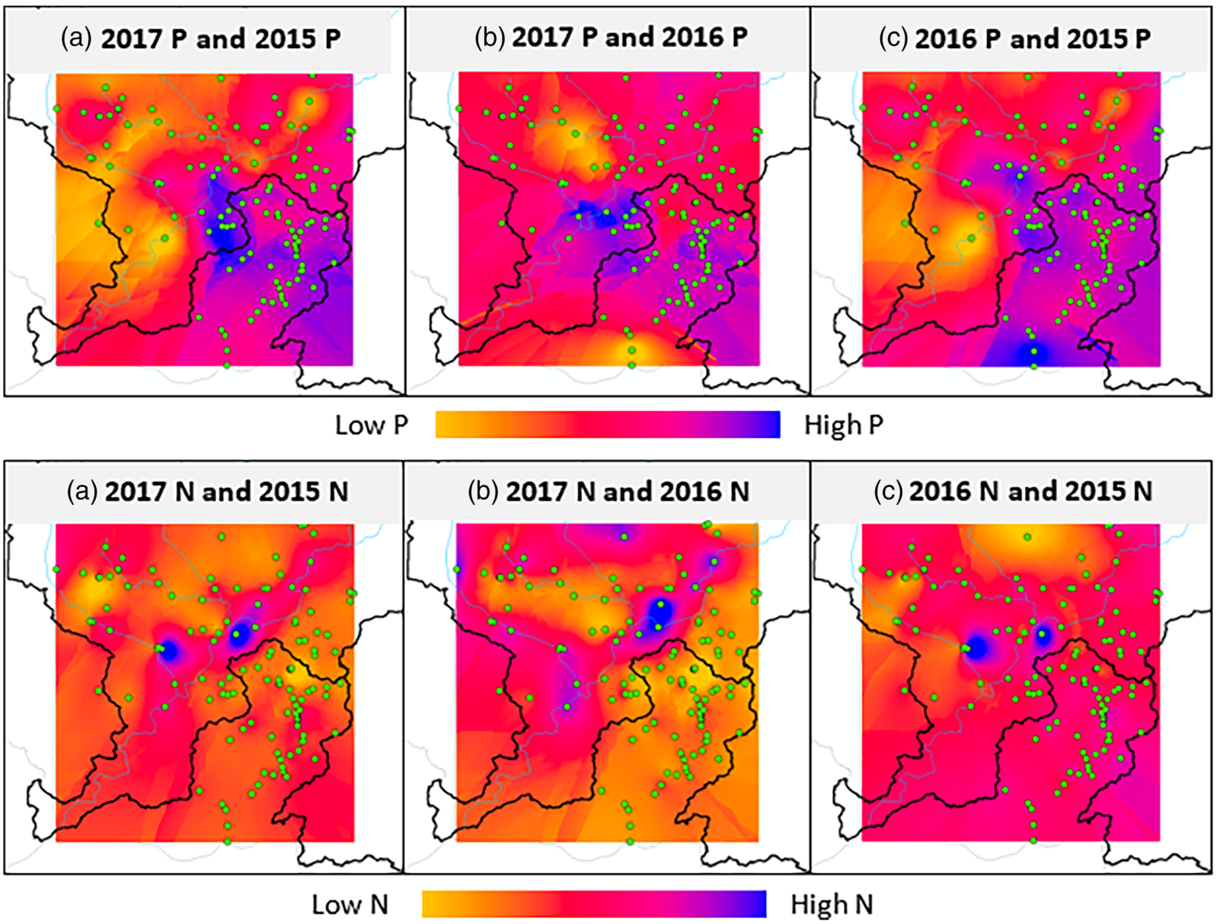

FIGURE 4 Map differences of interpolated surfaces for phosphorous (P) (top row) and nitrogen (N) (bottom row) for (a) years 2017 and 2015, (b) years 2017 and 2015, and (c) years 2016 and 2015. Green dots represent the sampling points used in mapping the distribution

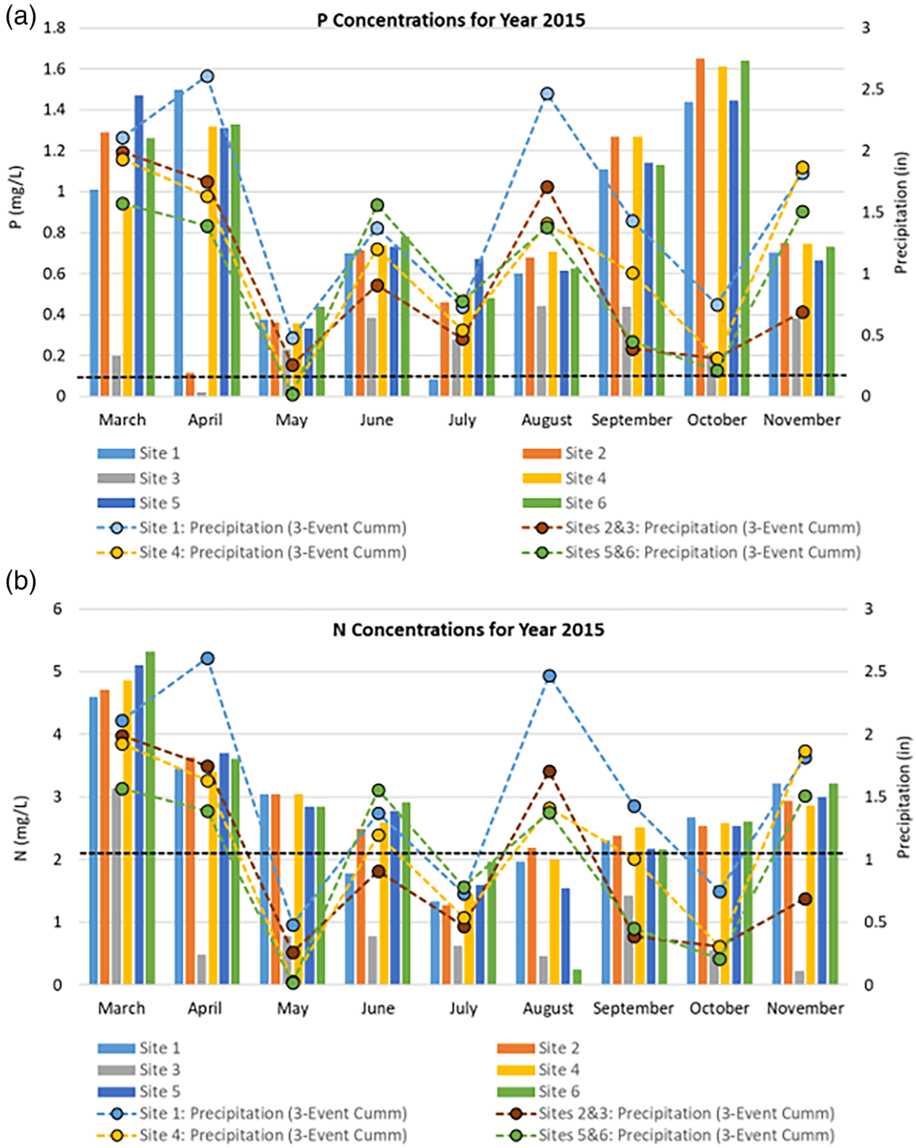

FIGURE 5 Plots of three-event cumulative rainfall versus (a) phosphorous and (b) nitrogen concentrations for each site for year 2015. Note that the black dash line signifies the EPA threshold for P = 0.1 mg/L and N = 2.2 mg/L. A “3-Event Cumm” means the cumulative of three previous rainfall events within the month before the sample date collection

After interpolating P and N values, we found that P concentration over 3 years were uneven. High annual differences of P were detected in the mid and southeast zones for the entire period of analysis (Figure 4). Site 2 fell within the mid region with high P concentrations. For N, we did not observe a major change over the 3 years, except for hotspots in the middle reach of the study area. Site 3 was a low N concentration location in the northwest of the study region (Figures 4).

The 2015 P and N concentrations for each site were highly correlated with the “3-day cumulative rainfall” events (Figure 5) than “actual rainfall” (Figure 6). The 2015 plots also showed that P and N concentrations were mostly above the EPA threshold for N = 2.2 mg/L and P = 0.1 mg/L. Similar trends of elevated nutrient concentrations were observed for 2016 and 2017.

4 | DISCUSSION

The elevated concentrations of nutrients detected in the GM and LM streams were occasionally at levels that surpassed the recommended statewide nutrient target concentration standards (OEPA, 2013). Rowe and Baker (1997) found that P and N measurements have decreased by 50% and 40%, respectively, since 1974, yet, still persist to be among the highest concentrations recorded in the United States. P concentrations at 0.3 mg/L remains higher than the EPA guideline of 0.1 mg/L. In a recent biological and water quality study, nutrient surplus was listed as one of the most persistent sources of impairment in the upper GM watershed system (OEPA, 2011; OEPA, 2018).

In our analysis of the 3-year record for six sites along a stretch of the GM river, a trend is hard to detect. Nonetheless, it is noteworthy that observed spikes of N occurred in 2017 at all sites. The rise and fall of total P and total N concentrations were directly related to river discharge and runoff events. The spring and early summer runoff events in 2015 resulted in the highest concentrations of N. For P, an increasing trend was observed for extended periods of lower flows during the summer and early autumn. This increase was likely due to discharges from wastewater treatment plants (MCD, 2015). In 2018, the OEPA (2018) reported data collected from 2015 to 2017 and highlighted that nutrient enrichment remained a major contributing

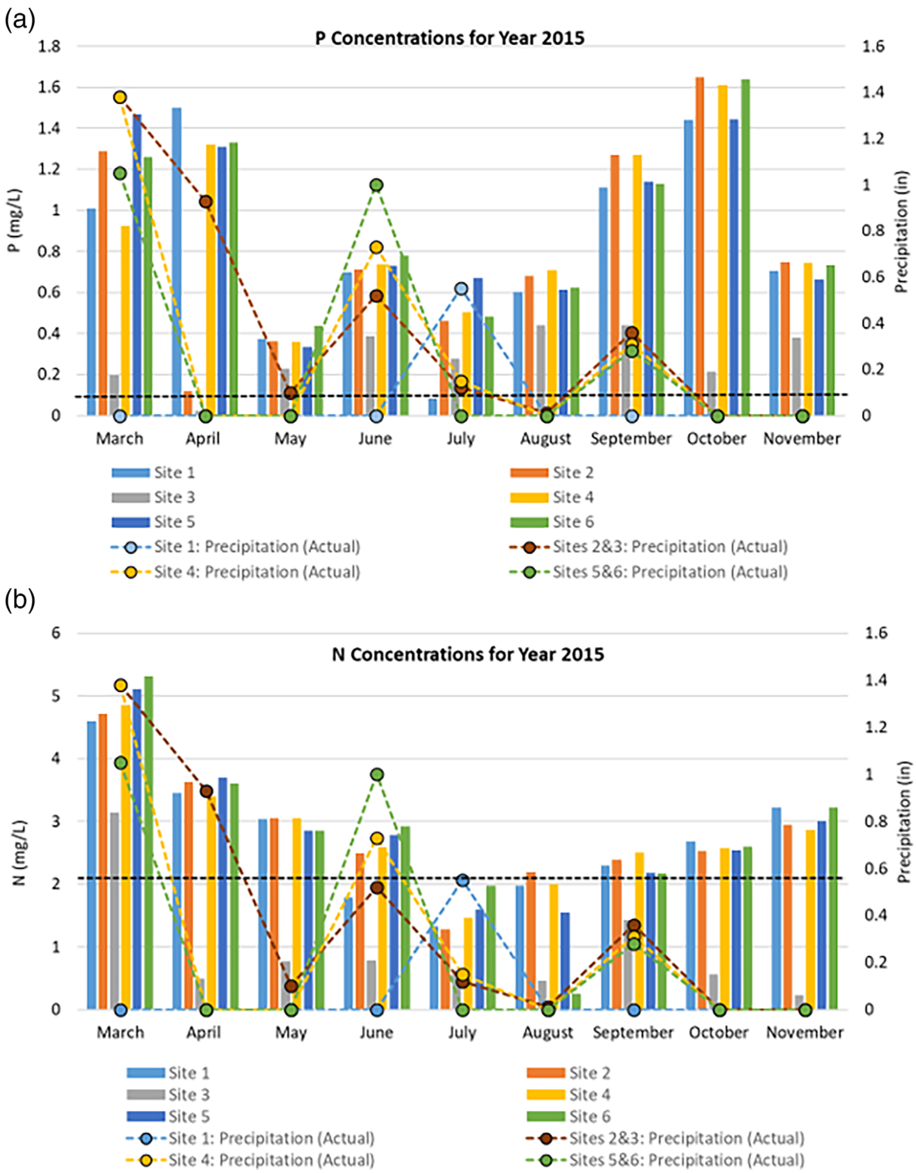

FIGURE 6 Plots of actual rainfall event versus (a) phosphorous and (b) nitrogen concentrations for each site for year 2015. Note that the black dash line signifies the EPA threshold for P = 0.1 mg/L and N = 2.2 mg/L. "Actual" means the amount of rainfall on the same date of the sample collection

factor of impairment of aquatic life and the recent widespread HABs that have been detected in Lake Erie, the Ohio River, and other water bodies in Ohio.

At present, two obstacles persist that could hinder the reduction of P and N pollution from agriculture and wastewater treatment facilities: (a) the large number of wastewater producers and (b) the changing nature of nutrient loading. Existing watershed models projected that P and N contributions to surface waters from agriculture and other sources would continue to increase in the coming decades, locally and globally (Galloway et al., 2004; Kroeze & Seitzinger, 1998; Salas & Subburayalu, 2019). From 1960 to 1995, the use of N and P fertilizer has increased sevenfold and threefold, respectively, with another threefold projected to occur by year 2050 unless something is done to increase the efficiency of fertilizer use (Tilman et al., 2001).

Numerous academic sources have identified cost-effective approaches to help reduce nutrient pollution (Kronvang, Bechmann, Pedersen, & Flynn, 2003; Osmond et al., 2012). Specific solutions include awareness and better understanding of nutrient loading processes, nutrient sources, transport pathways, nutrient interactions with climate, and nutrient interconnection with various agricultural practices and land use. A better understanding of the farmers' conservation operations and what affects them could better guide the execution of these approaches. The nutrient reduction strategy report recommended conducting more educational activities that include conferences, meetings, educational materials, and newsletters on farm demonstration plots and research activities directed at appropriate nutrient utilization and water quality concerns (OEPA, 2015).

5 | CONCLUSION

This short communication is one of the few studies to investigate and map the temporal trends and spatial distributions of P and N concentrations in the GM and LM watersheds. The results from this analysis could have many potential applications. Environmental scientists and watershed managers could use the results to identify optimum conditions and adopt new strategies and tools to further mitigate the inflow of P and N to the river systems. Attempts to conform with the Clean Water Act (CWA), also known as Federal Water Pollution Control Act Amendments, and manage all sources of pollution in the watershed is progressing as there have been substantial improvements in water quality in the watersheds through enhancing wastewater treatment. In addition, through the CWA, other surface water quality services have expanded, such as community-based and voluntary pollution control projects. However, there are still things to be done as publicly available OEPA reports indicated that surpluses of P and N nutrients in the watershed are still occurring. We hope, in the future, to investigate additional sampling sites from major rivers and streams in the GM and LM basins and identify the river systems that contribute disproportionately high nutrient loadings to the watersheds over time.

ACKNOWLEDGEMENTS

This study was supported by USDA-NIFA 1890 Evans Allen Award Grant Number NI181445XXXXG007. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the article.

CONFLICTS OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in StreamBank at http://streambank.info (StreamBank, 2018).

ORCID

Eric Ariel L. Salas https://orcid.org/0000-0001-9019-730X

REFERENCES

Baker, D. B., Richards, R. P., Kramer, J. W. (2006). Point source-nonpoint source trading: applicability to stream TMDLs in Ohio. Proceedings: Innovations in Reducing Nonpoint Source Pollution: Methods, Policies, Programs, and Measurement, Rivers Institute at Hanover College, Hanover, Indiana, USA, 328–347.

Battaglin, W. A., & Goolsby, D. A. (1995). Spatial data in geographic information system format on agricultural chemical use, land use, and cropping practices in the United States. *Water-Resources Investigations Report* (Series No. 94–4176). Retrieved from https://pubs.usgs.gov/wri/1994/4176/report.pdf

Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., … Holland, E. A. (2004). Nitrogen cycles: Past, present, and future. *Biogeochemistry*, *70*, 153–226.

Goolsby, D. A., Battaglin, W. A., Lawrence, G. B., Artz, R. S., Aulenbach, B. T., Hooper, R. P., Keeney, D. R., & Stensland, G. J. (1999). Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin: Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. Retrieved from http://www.cop.noaa.gov/pubs/das/das17.pdf

Gorham, T., Jia, Y., Shum, C. K., & Lee, J. (2017). Ten-year survey of cyanobacterial blooms in Ohio's waterbodies using satellite remote sensing. *Harmful Algae*, *66*, 13–19.

Kroeze, C., & Seitzinger, S. P. (1998). Nitrogen inputs to rivers, estuaries and continental shelves and related nitrous oxide emissions in 1990 and 2050: A global model. *Nutrient Cycling in Agroecosystems*, *52*, 195–212.

Kronvang, B., Bechmann, M., Pedersen, M. L., & Flynn, N. (2003). Phosphorus dynamics and export in streams draining micro-catchments: Development of empirical models. *Journal of Plant Nutrition and Soil Science*, *166*, 469–474.

MBI. (2014). Midwest Biodiversity Institute. Biological and water quality assessment of the Great Miami River and tributaries 2013, Hamilton County, Ohio (No. 121). Retrieved from http://www.msdgc.org/downloads/initiatives/water_quality/2013_great_miami_biological_water_quality_study.pdf

MCD. (2011). *Nitrogen and phosphorus concentrations and loads in the Great Miami River watershed, Ohio 2005 – 2011 (Report 2011-29)*. Dayton, Ohio, USA: Miami Conservancy District Retrieved from https://www.mcdwater.org/wp-content/uploads/PDFs/2012NutrientMonitoringReport_Final.pdf

MCD. (2015). *Water data report, Great Miami River Watershed, Ohio (Report 2015-24)*. Dayton, OH: Miami Conservancy District. Retrieved from https://www.mcdwater.org/wp-content/uploads/PDFs/2015-Water-Data-Report-FINAL-reduced.pdf

Naramngam, S., & Tong, S. T. Y. (2013). Environmental and economic implications of various conservative agricultural practices in the upper little Miami River basin. *Agricultural Water Management*, *119*, 65–79.

OEPA. (1996). *Ohio water resource inventory, executive summary: Summary, conclusions, and recommendations (no. 155)*. Columbus, OH: Division of Surface Water and Monitoring Assessment Section, Ohio Environmental Protection Agency. Retrieved from https://www.epa.ohio.gov/portals/35/documents/96vol1.pdf

OEPA. (2011). *Biological and water quality study of the Upper Little Miami River. Clark, Clinton, Greene, Madison, Montgomery, and Warren Counties, Ohio (no. 193)*. Dayton, OH: Division of Surface Water, Ohio Environmental Protection Agency. Retrieved from https://epa.ohio.gov/Portals/35/documents/LMR_Upper_Basin_2011_TSD.pdf

OEPA. (2012). *Integrated water quality monitoring and assessment report (no. 70)*. Columbus, OH: Ohio Environmental Protection Agency. Retrieved from https://epa.ohio.gov/portals/35/tmdl/2012IntReport/IR12SectionDfinal.pdf

OEPA. (2013). *Ohio nutrient reduction strategy*. Columbus, OH: Ohio Environmental Protection Agency. Retrieved from http://www.epa.state.oh.us/Portals/35/wqs/ONRS_final_jun13.pdf

OEPA. (2015). *Ohio nutrient reduction strategy (no. 71)*. Columbus, OH: Ohio Environmental Protection Agency. Retrieved from https://epa.ohio.gov/Portals/35/wqs/ONRS_addendum.pdf

OEPA. (2018). *Report on Integrated Water Quality Monitoring and Assessment (no. 533)*. Columbus, OH: Ohio Environmental Protection Agency. Retrieved from https://www.epa.ohio.gov/Portals/35/tmdl/2018intreport/2018IR_Final.pdf

Osmond, D., Meals, D., Hoag, D., Arabi, M., Luloff, A., Jennings, G., … Line, D. (2012). Improving conservation practices programming to protect water quality in agricultural watersheds: Lessons learned from the National Institute of Food and Agriculture–conservation effects assessment project. *Journal of Soil and Water Conservation*, *67*, 122A–127A.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics*, *32*, 333–365.

Rowe, G. L., & Baker, N. T. (1997). *Great and Little Miami River Basins (no. 4)*. Columbus, OH: U.S. Geological Survey. Retrieved from. https://pubs.usgs.gov/fs/1997/0117/fs1997117.pdf

Salas, E. A. L., & Subburayalu, S. K. (2019). Implications of climate change on nutrient pollution: A look into the nitrogen and phosphorus loadings in the great Miami and little Miami watersheds in Ohio. *AIMS Environmental Science*, *6*, 186–221.

Scavia, D., Justic, D., & Bierman, V. J. (2004). Reducing hypoxia in the Gulf of Mexico: Advice from three models. *Estuaries*, *27*, 419–425.

StreamBank. (2018). Regional water quality database. Retrieved from http://streambank.info.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., … Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science*, *292*, 281–284.

How to cite this article: Salas EAL, Subburayalu SK. Analysis of phosphorus and nitrogen concentrations in the Great Miami and Little Miami basins in Ohio, USA from 2015 to 2017. *River Res Applic*. 2020;1–8. https://doi.org/10.1002/rra.3604