The Effects of Agricultural Runoff on the Kansas River Water Quality

Caleb McCaffrey, Vincent Otchere, and Megan Nelson

Final Report for NRES Capstone

Kansas State University

May 2024

Abstract

Agricultural runoff poses a significant threat to water quality in the Kansas River, impacting both ecological integrity and human health. This study utilizes GIS geoprocessing tools, excel statistics, agricultural data analysis, and water quality monitoring to investigate the relationship between land use, agricultural practices, and water quality variables. Our research shows temporal variations in cropland extent, land cover, and water quality indicators, emphasizing the ever-changing relationship between agricultural influences and aquatic ecosystems. Our results showed little change in overall land cover and land use, but that doesn't mean it is completely insignificant. Notable fluctuations in nitrogen, phosphorus, pH, and turbidity over the years show the complexity of nutrient runoff dynamics. These results show the important need for informed land management decisions to mitigate water quality degradation. Mitigation must be made a priority to safeguard the health of communities and ecosystems dependent on the Kansas River.

Table of Contents

List of Figures

Introduction

The Kansas River is an important part of northeast Kansas' agricultural infrastructure and provides drinking water to a significant portion of the state's populace. Surrounding this crucial water source are vast expanses of cropland predominantly dedicated to the growing of corn and soybeans. These crops rely heavily on water pulled directly from the river and are subjected to various chemical applications, including fertilizers, pesticides, and herbicides. These chemical inputs contain substantial amounts of nitrogen and phosphorus, which strongly influence nearby ecosystems. The overall effect of these agricultural practices on the river's ecosystem is highlighted by the clear link between nearby crop production and changes in water quality, primarily due to nutrient-rich runoff. This prompts investigation into how surrounding land use and landcover affect water quality and the extent of nutrient runoff's influence.

Contaminants such as pesticides and fertilizers are used to influence food production, however, can end up in waterways. These fertilizers are natural substances and can be added to soil to increase its fertility, resulting in a larger crop species yield. Examples such as nitrogen and phosphorus fertilizers are used on different crops based on their soil recommendations. Similarly, pesticides may be considered herbicides, insecticides, or fungicides and are mixtures of chemical substances that are intentionally released into the environment to deter, control, or kill populations of insects, weeds, rodents, fungi, or other harmful pests. The benefits it provides are an increase in yields, as it protects crops from harmful pests' consumption and prevention of diseases. However, the movement of these excess contaminants across the soil surface can contribute negatively to surrounding bodies of water. Pesticides, fertilizers, and other sources are all driving factors to poor water quality in polluted lakes/streams. Although they provide a lot of benefits in today's food production, residue and excess chemicals can also end up in waterways and negatively impact the environment.

The main concerns of impacts to water quality are habitat degradation, eutrophication, aquatic ecosystem decline, biodiversity loss, economic loss, and drinking water quality. Fertilizers and pesticides are essential to feeding our growing population, but they can do more harm than good in certain situations. Nitrogen and phosphorus are two of the main nutrients that heavily contribute to eutrophication and ecosystem/habitat decline. Nitrogen is a very mobile nutrient and leaches into undesirable areas quickly. Phosphorus is less mobile but. The monitoring of water quality parameters has been conducted systematically at specific sites along the Kansas river, especially at the downstream area, but the overall assessment of the water quality with the changes in land use land cover or cropland has not been done yet.

Objectives

The present study aims to evaluate the impact of agricultural runoff on the ecological integrity of aquatic systems, with a specific focus on the water quality of the Kansas River. Our research is structured around three primary areas, the assessment of land cover and land use patterns in the vicinity of the river, the types and quantities of chemical treatments applied within the catchment, and lastly, the analysis of variations in water chemistry over several years. Through this approach, we aim to understand and convey valuable insights into the relationship between agricultural practices and aquatic ecosystem health.

Literature Review

One of the foremost contributors to agricultural runoff, a major concern in the field of environmental science, is land cover and land use. Earlier research has investigated the impact of land utilization in various ecosystems, primarily focusing on agricultural pollution. A study done in northwest China monitored nitrogen levels within the Weihe River watershed, determining that land dedicated to agricultural practices, including crop cultivation and livestock farming, substantially increased downstream nitrogen levels (Shi et al. 2019). Similarly, research done in the eastern region of Mazandaran Province, Iran, found that agricultural and residential zones played a pivotal role in both bed and suspended sediment pollution, particularly within 250 meters of riverbanks (Mohammad et al. 2022). Another study done along the River Raisin in Michigan, discerned that nitrate levels downstream of agricultural sites, peaked most notably during spring, coinciding with the primary planting season in the United States. Elevated phosphorus concentrations were found downstream of wastewater treatment facilities and agricultural land, while headwaters and undisturbed areas exhibited lower nutrient loads compared to areas influenced by humans (Castillo et al. 2000). A study done at the confluence of the Illinois, Missouri, and Mississippi Rivers attained similar results, particularly concerning sediment loading. The results showed that urban expansion and agricultural activities play a significant role in loading dynamics (Jordan et al. 2014) These research studies highlight the influence that anthropogenic land use and land cover have on water quality, emphasizing the need for broader environmental based land management practices.

Over time, fertilizers and pesticides have also contributed to water pollution within water reservoirs. A similar study observed the movement of atrazine and deethylarazine concentrations in Perry Lake Reservoir throughout one year using a three-dimensional visualization on GIS. The results concluded that the inflow of atrazine and triazine came from the Delaware River's surrounding agricultural fields (Fallon et al. 2002). Likewise, months of increased precipitation showed peak concentrations of herbicide in the reservoir. High-intensity rainfall and crop residue have been shown to influence natural and chemical substances within runoff. Times of intense but short-duration rainfall can affect losses of nitrogen, phosphorus, and sulfur pollutants from fields immediately after harvest. A study done in Hays, Kansas showed that the removal of wheat and sorghum residue can increase sediment and nutrient loss in runoff due to high-intensity rain (Blanco et al. 2009). A similar study by Damodhara Mailapalli observed different constituents such as sediment, nitrate, ammonium, and phosphate in runoff water from furrow-irrigated fields. Biomass residue in the furrows increased infiltration, affecting amounts of constituents in the runoff. An increase in irrigation increased runoff and influenced amounts of (NPK) constituents within the water samples (Mailapalli et al. 2013).

Methods

In this study, our investigation is centered around the Kansas River, which begins at the confluence of the Smoky Hill and Republican Rivers and ends at its convergence with the Missouri River near Kansas City. Our choice for this specific region stems from its significance to the infrastructure of northeast Kansas and our familiarity with it. Our focus is directed towards the ten counties through which the river passes through, namely Geary, Riley, Pottawatomie, Wabaunsee, Shawnee, Jefferson, Leavenworth, Douglas, Johnson, and Wyandotte. Utilizing land cover and land use datasets sourced from the United States Geological Survey (USGS), we conducted an analysis to better understand the land cover and use patterns within our study area. Employing ArcGIS Pro, these datasets were reclassified to generate a comprehensive map showing the distribution of land types across the previously mentioned counties. USGS data was also used to quantify changes in total cropland within each county during the years 2013, 2016, 2019, and 2021. From this data, percentage changes were calculated for each county across various temporal intervals. These values were inputted into ArcGIS to produce choropleth maps depicting fluctuations in cropland extent over specified time intervals, thereby allowing us to view trends in cropland dynamics within our study area.

Additionally, the USDA “Statistics by State” tool reported estimates of cropland usage and primary crops within the counties for years 2017 and 2022. Similarly, common fertilizers and herbicides were selected for the primary crops that showed most square miles harvested within those areas. These estimates determined recommendations for crops such as Corn, Soybeans, Wheat, Forage, and Sorghum. Fertilizer recommendations are reported from the KSRE (K-State Research and Extension) “Soil Interpretations and Fertilizer Recommendations in Kansas” guide and determined amounts of NPK fertilizer for primary crops within the counties. Likewise, herbicide recommendations were based off the KSRE “2023 chemical weed control” guide. The guide consists of specific herbicides for different crops in areas of diverse weather conditions.

We also collected data from the United State Geological Survey, specifically, their National Real-Time Water Quality (NRTWQ) and the Kansas Real-Time Water Quality (KRTWQ). The KRTWQ sensors take instantaneous, hourly measurements of temperature, pH, turbidity, nutrients, computed discharge, and others. These water-quality constituents are calculated by ordinary least square regression models. This allowed us to see the amount of nitrogen and phosphorus present in the river in 2013, 2016, 2019 and 2022. We also collected data on pH and turbidity to provide more context. The hourly data was transitioned into daily and then, to monthly averages by using Python codes and graphed as shown in figures eight, nine and ten. We did come across one inconsistency with the samples, where the data for instantaneous total nitrogen for 2013 at the Wamego site was the same number repeating. This issue was isolated and did not affect our other data. We would have added dissolved oxygen data as well, but it was not available in most of the years we were studying.

Results

The cartographic depiction of the USGS data yielded multiple thematic maps, a landcover/land use map and four maps illustrating total cropland percentage changes. These depictions help show temporal changes spanning 2013 to 2021, as well as intermediate intervals. Our findings reveal a composition of mainly cultivated crops and urbanized areas near the river (Figure 2). Total cropland across the ten counties showed marginal variation from 2013 to 2021, with the exception being Wyandotte County which experienced a 6.36% reduction in total cropland. Conversely, Jefferson County demonstrated the largest increase in cropland, with a 1.45% change within the same timeframe. Notably, between 2019 and 2021, a decline in cropland was observed across all ten counties, with some experiencing declines of up to 3% within the brief two-year period (Figure 4). Throughout 2013-2016 and 2016-2019, all counties showed variable fluctuations in cropland extent. Overall net change in cropland from 2013 to 2021 for all 10 counties was a loss of 1.44 square miles. Total cropland went from 956.81 sq. miles to

955.37 sq. miles. It must be noted that cropland data was unavailable for Leavenworth County for the years 2019 and 2021, so 2016 data was carried over to the later maps.

Although there was there was no significant difference of cropland change, according to the USDA “Statistics by State” tool, soybeans were selected as the primary crop used amongst the 10 counties for both years 2017 and 2022 (Figure 13,14). Forage and corn are second and third in terms of area used for harvest in ten counties. Likewise, fertilizer recommendations were selected for soybeans as 0 lbs. of nitrogen is required for both pre and post emergence. Other field crops such as corn, wheat, sorghum, and forage require at least 30lbs N and can use up to 300lbs N depending on cropland size. Nitrogen based fertilizers such as urea, ammonium nitrate and anhydrous ammonia were found commonly used as they provide necessary macronutrient levels for those crops. For phosphorous, diammonium and monoammonium phosphate fertilizers were found commonly used as all described crops are applied at least 15lbs P2O5 per acre. In terms of pesticides, herbicide rates can vary. Herbicides such as 2,4-D, Liberty, and Glyphosate were found commonly used in soybeans and contain various levels of nitrogen and phosphorus.

Our results show variation from year to year in all constituents (nitrogen, phosphorus, pH and turbidity) but with a statistically insignificant difference in nitrogen concentration from the Wamego site between 2013 and 2022 as our t-test yielded a p-value of 0.051 (Figure 12). This t-test was done using a two-tail and unequal variance method in Ms-Excel. However, 2019 has notable change in all subjects and locations. Nitrogen levels in the Kansas River near DeSoto, KS increased by 27% from 2016 to 2019 and decreased by 40% from 2019 to 2022 (see Figure 8). At the Wamego, KS site pH decrease by 3% from 2016 to 2019 then increased 5% from 2019 to 2022 (see Figure 9) while phosphorus increased by 11% and then decrease by 14.2% respectively (see Figure 10).

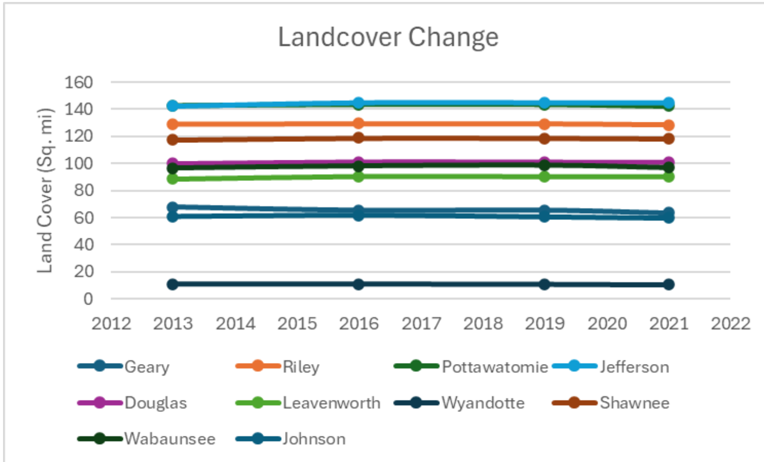

Figure 1. Cropland changes by county in square miles. Wyandotte County and Geary County experienced the greatest declines while Jefferson County experienced the largest increase.

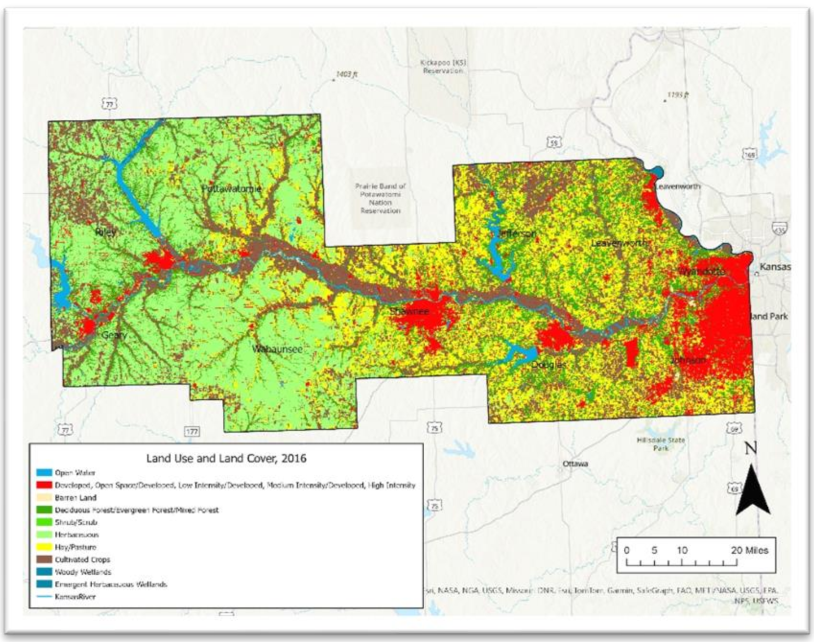

Figure 2. Land Use and Land Cover for area of study. The area around the Kansas River is predominantly made up of cultivated crops and urban/developed land.

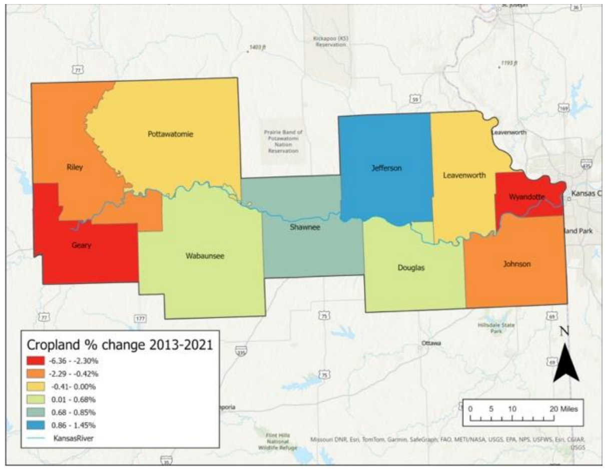

Figure 3. Cropland percentage changes from 2013-2021. The greatest increase in cropland percentage was Jefferson County while Geary and Wyandotte County experienced the largest decline.

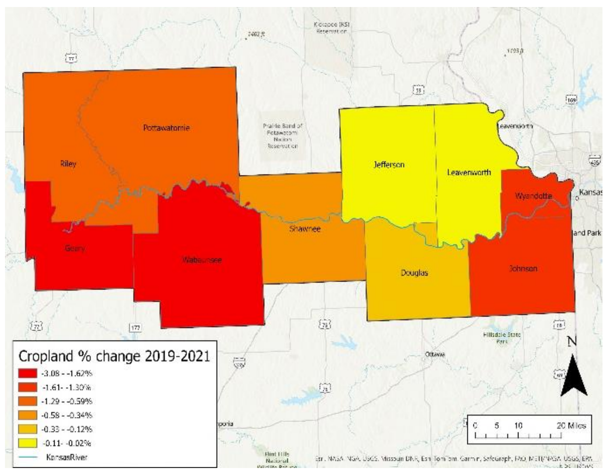

Figure 4. Cropland percentage changes from 2019-2021. All ten counties within the study area experienced declines in overall cropland percentage.

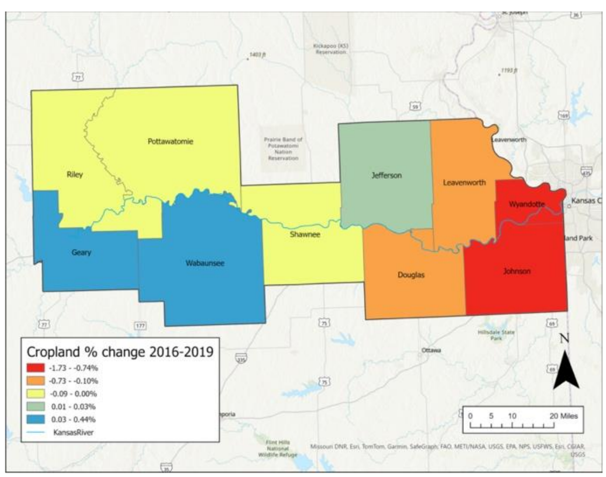

Figure 5.Cropland percentage change from 2016-2019. All counties experienced declines in cropland percentage with the exceptions of Geary, Wabaunsee, and Jefferson County.

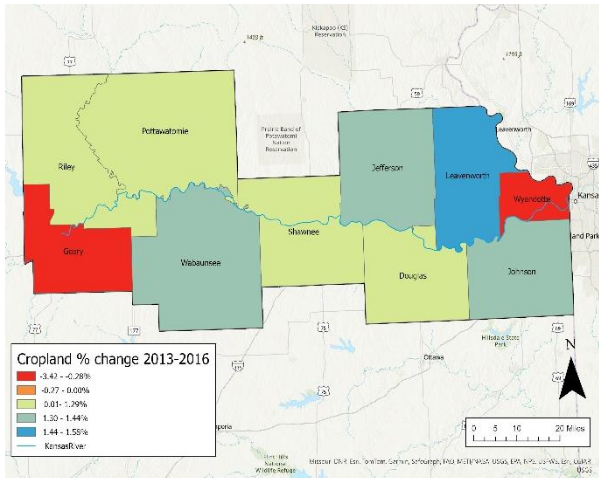

Figure 6. Cropland percentage changes from 2013-2016. All counties experienced increases in cropland percentage with the exceptions being Wyandotte and Geary County.

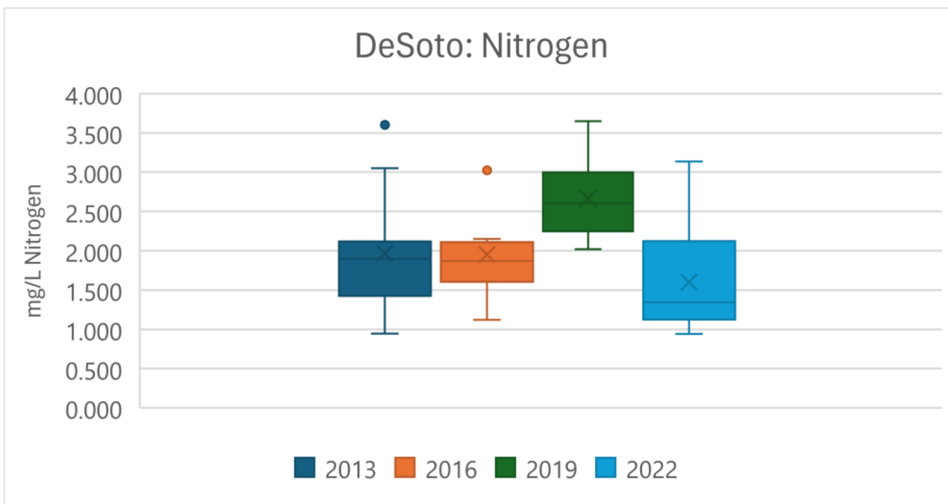

Figure 7. Instantaneous nitrogen levels taken near DeSoto, KS. The year 2019 experienced a dramatic uptick in nitrogen, more than likely because of excessive precipitation that year.

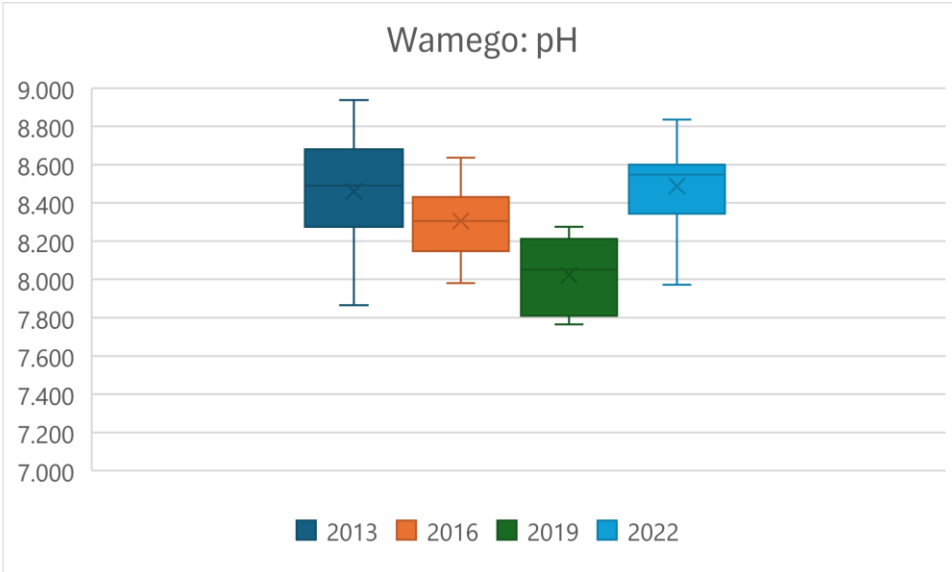

Figure 8. Instantaneous pH levels taken near Wamego, KS. Water

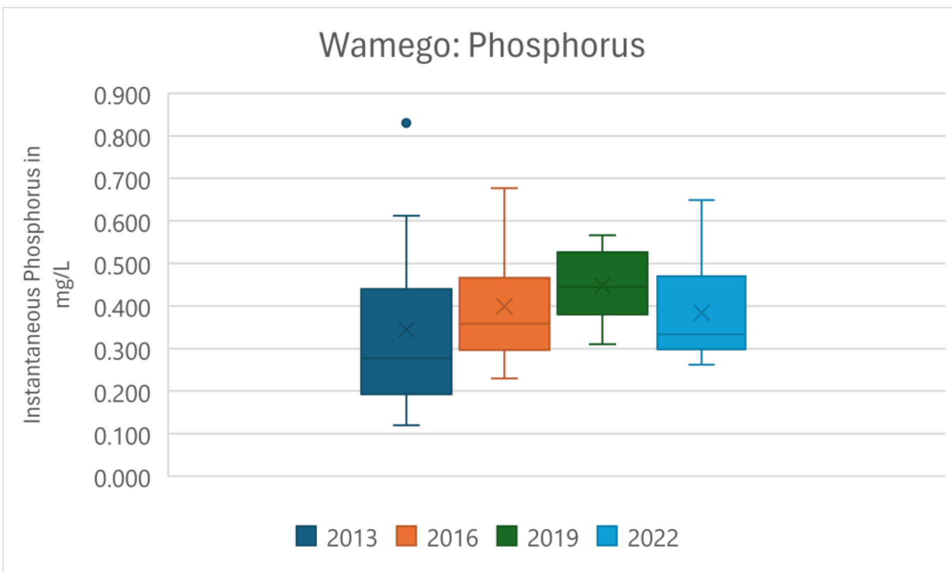

Figure 9. Instantaneous phosphorus levels taken near Wamego, KS. A dramatic drop-off in phosphorus occurred after 2019 due to the decrease in precipitation from the unusually wet year of 2019.

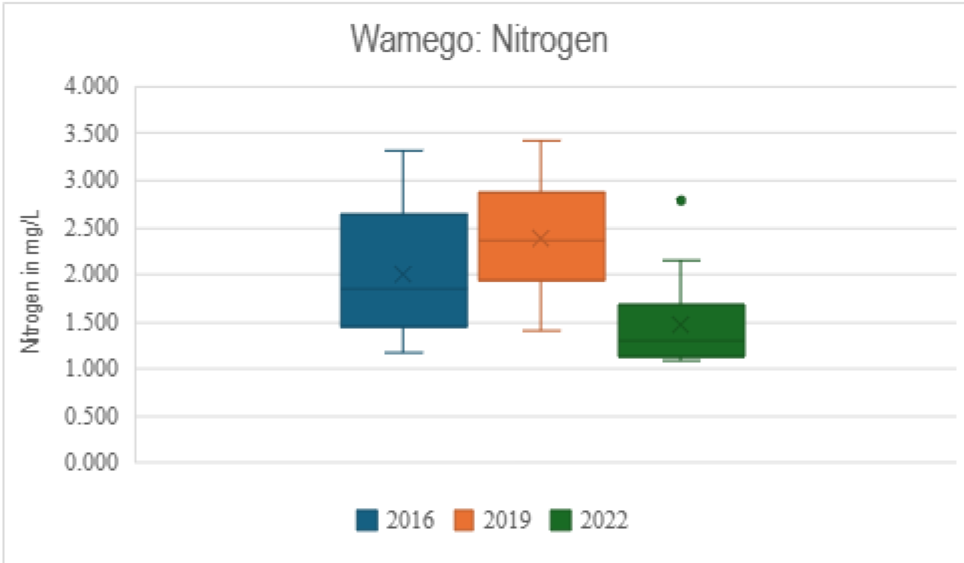

Figure 11. Instantaneous nitrogen levels taken near Wamego, KS.

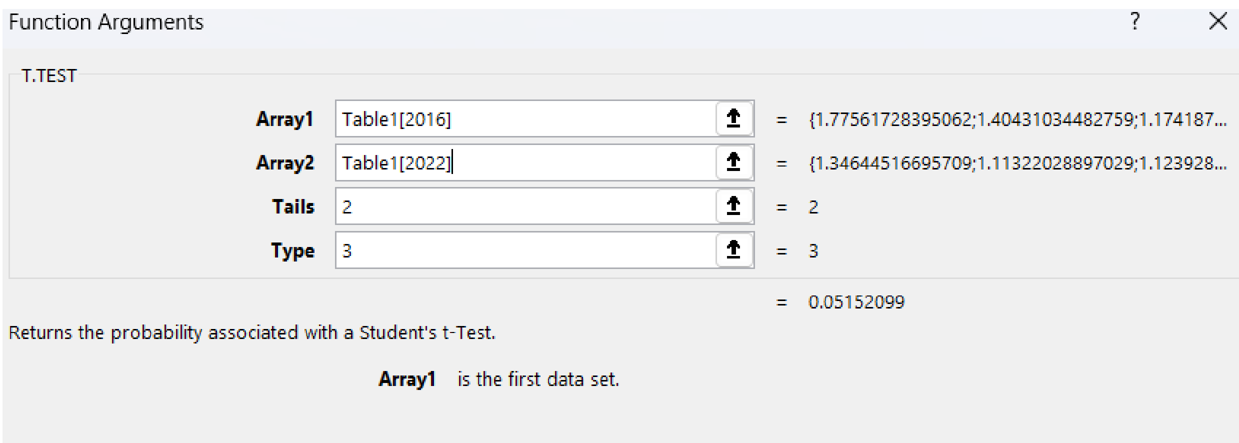

Figure 12. T-Test for Wamego nitrogen between year 2016 and 2022 (statistically not significant at 95% level of significance)

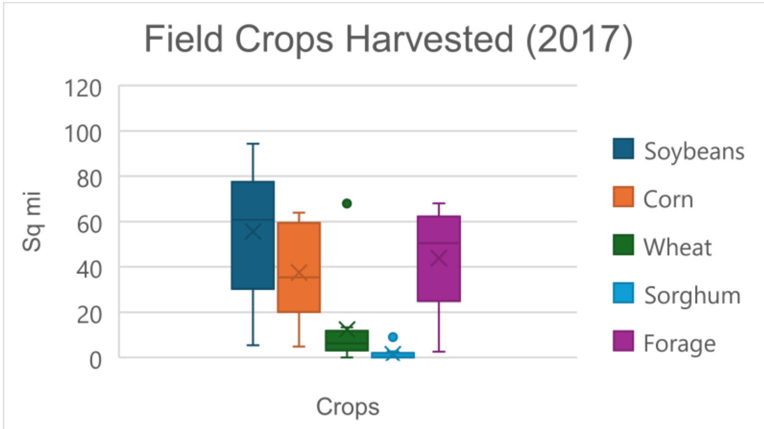

Figure 13. Field crops harvested for all counties in 2017 (Sq mi).

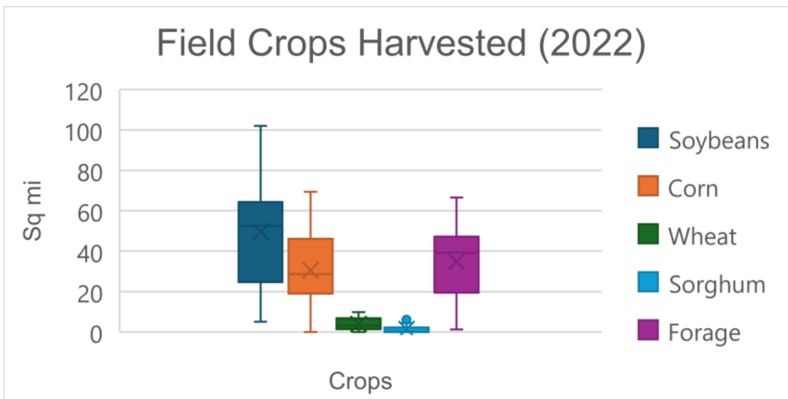

Figure 14. Field crops harvested for all counties in 2022 (Sq mi).

Discussion

Changes in land cover and land use seemed to have less of an effect on phosphorus and nitrogen in the river system than we originally thought it would. Many of the counties surrounding the De Soto river gauge lost cropland between 2013 and 2021, yet phosphorus and nitrogen peaked in 2019. In 2022, levels for these nutrients dropped, but this could be due to a reduction in overall precipitation. Based on previous studies by Castilo et al., 2000 and Shi et al., 2019, that sites downstream of agricultural and urban areas have greater amounts of nitrogen and phosphorus. Our data supports this theory because levels for nitrogen and phosphorus were both higher at De Soto than those found at Wamego, which is further upstream. The amount of cropland also more than likely played a major role in the nitrogen and phosphorus levels at our two water sites. Looking at our study area's landcover map we can see that the Kansas River is surrounded by miles of cropland. This cropland is pinned right against the river and based on a study by Mohammadi et al., 2022, this plays a major role in nutrient pollution. This cropland receives chemical treatments that ultimately make it back into the river system in the form of runoff.

The herbicide and fertilizer recommendation rates for cropland vary. Herbicide content is likely found in the Kansas River, as these chemical substances have previously been known to reach water reservoirs downstream from surrounding agricultural land (Fallon et al., 2002). Herbicides such as 2,4-D, Liberty, and Glyphosate are sprayed based on the crop and broadleaf weed species. Likewise, nitrogen and phosphorus content levels vary within herbicides, as farmers mix adjuvants which can enhance or reduce the performance. Fertilizers such as diammonium phosphate, urea, and anhydrous ammonia are applied based on previous crop adjustments and soil test results. Since soybeans require no nitrogen, high phosphorus levels in 2019 could be influenced by the usage of phosphorus fertilizer (Figure 10). Other factors such as precipitation, and landcover change could have contributed to the peak, however, there is no evidence herbicides and fertilizers are the main source of nitrogen and phosphorus concentrations within the Kansas River.

Increased rainfall is a factor that we investigated as the cause of the spike in nutrients found in the river in 2019 which corresponds to decrease in pH for that year (Figure 8). Using Kansas State University's Mesonet data, we were able to look back and see precipitation data in the same time frames as our water quality data. In 2013, there was 24.29 inches of rainfall compared to 46.01 inches in 2019 and 33.31 inches in 2022. This rainfall pattern fits with our water data as it follows the same shifts. If we look at phosphorus, this holds true as phosphorus does not leach through the soil like nitrogen does. Phosphorus clings to soil particles so runoff is where it is most mobile and causes the most impact to water systems. However, there are many potential causes for the increase, and it does not reside with just one cause.

Conclusion

Overall, agricultural runoff is an issue as it can pose a threat to environments, especially aquatic ecosystems. In the study, land cover and land use change, especially change in cropland area in the ten counties is not that significant, in fact the net decrease in the crop land over the years. There is no drastic fluctuation in nitrogen and phosphorus concentration except for 2019. However, the chemical treatments done on the cropland are more important as farmers want to experience high yield. In addition, the overall use of pesticides and fertilizers provide benefits; however, precipitation and excess chemical treatment can increase nitrogen and phosphorus levels as well as surface runoff in water. This was identified in 2019 as a result of the water quality parameters. Likewise, farmers surrounding the Kansas River may want to consider this as it may experience eutrophication in the future.

References

Bhuyan, S. J., Koelliker, J. K., Marzen, L. J., & Harrington, J. A. (2003). An integrated approach for water quality assessment of a Kansas watershed. *Environmental Modelling & Software : With Environment Data News*, *18*(5), 473–484. https://doi.org/10.1016/S1364-8152(03)00021-5

Blanco-Canqui, H., Stephenson, R. J., Nelson, N. O., & Presley, D. R. (2009). Wheat and Sorghum Residue Removal for Expanded Uses Increases Sediment and Nutrient Loss in Runoff. Journal of Environmental Quality, 38(6), 2365–2372. https://doi.org/10.2134/jeq2009.0021

Burke, M., Shahabi, M., Xu, Y., Zheng, H., Zhang, X., & VanLooy, J. (2018). Identifying the Driving Factors of Water Quality in a Sub-Watershed of the Republican River Basin, Kansas USA. International Journal of Environmental Research and Public Health, 15(5), 1041. https://doi.org/10.3390/ijerph15051041

Castillo, M. M., Allan, J. D., & Brunzell, S. (2000). Nutrient Concentrations and Discharges in a Midwestern Agricultural Catchment. *Journal of Environmental Quality*, *29*(4), 1142–1151. https://doi.org/10.2134/jeq2000.00472425002900040015x

Dorivar Ruiz Diaz. (2024). Soil Test Interpretations and Fertilizer Recommendations in Kansas. *K-State Research and Extension*, 36, https://bookstore.ksre.ksu.edu/pubs/mf2586.pdf

Fallon, J. D., Tierney, D. P., & Thurman, E. M. (2002). Movement of Atrazine and Deethylatrazine Through a Midwestern Reservoir. Journal AWWA, 94(11), 54–66. https://doi.org/10.1002/j.1551-8833.2002.tb10230.x

Jordan, Y. C., Ghulam, A., & Hartling, S. (2014). Traits of surface water pollution under climate and land use changes; a remote sensing and hydrological modeling approach. *Earth-Science Reviews*, *128*, 181–195. https://doi.org/10.1016/j.earscirev.2013.11.005

Kansas River. (n.d.-a). https://www.americanrivers.org/river/kansas-river/

Kreiling, R. M., Thoms, M. C., & Richardson, W. B. (2018). Beyond the edge; linking agricultural landscapes, stream networks, and best management practices. *Journal of Environmental Quality*, *47*(1), 42–53. https://doi.org/10.2134/jeq2017.08.0319

Lubowski, R. N., Plantinga, A. J., & Stavins, R. N. (2008). What Drives Land-Use Change in the United States? A National Analysis of Landowner Decisions. *Land Economics*, *84*(4), 529–550. https://doi.org/10.3368/le.84.4.529

Mahmood, I., Imadi, S. R., Shazadi, K., Gul, A., & Hakeem, K. R. (2016). Effects of Pesticides on Environment. In K. R. Hakeem, M. S. Akhtar, & S. N. A. Abdullah (Eds.), Plant, Soil and Microbes (pp. 253–269). Springer International Publishing. https://doi.org/10.1007/978-3-319-27455-3_13

Mailapalli, D. R., Burger, M., Horwath, W. R., & Wallender, W. W. (2013). Crop Residue Biomass Effects on Agricultural Runoff. Applied and Environmental Soil Science, 2013, 1–8. https://doi.org/10.1155/2013/805206

Mallin, M. A., Johnson, V. L., & Ensign, S. H. (2009). Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. Environmental Monitoring and Assessment, 159(1–4), 475–491. https://doi.org/10.1007/s10661-008-0644-4

Mohammadi, M., Khaledi Darvishan, A., Dinelli, E., Bahramifar, N., & Alavi, S. J. (2022). How does land use configuration influence on sediment heavy metal pollution? Comparison between riparian zone and sub-watersheds. *Stochastic Environmental Research and Risk Assessment*, *36*(3), 719–734. https://doi.org/10.1007/s00477-021-02082-1

Rice, P. J., & Horgan, B. P. (2017). Off-site transport of nitrogen fertilizer with runoff from golf course fairway turf: A comparison of creeping bentgrass with a fine fescue mixture. Science of The Total Environment, 580, 533–539. https://doi.org/10.1016/j.scitotenv.2016.11.209

Sherman, J. F., Young, E. O., Coblentz, W. K., & Cavadini, J. (2020). Runoff water quality after low-disturbance manure application in an alfalfa–grass hay crop forage system. Journal of Environmental Quality, 49(3), 663–674. https://doi.org/10.1002/jeq2.20058

Shi, P., Zhang, Y., Song, J., Li, P., Wang, Y., Zhang, X., Li, Z., Bi, Z., Zhang, X., Qin, Y., & Zhu, T. (2019). Response of nitrogen pollution in surface water to land use and social-economic factors in the Weihe River watershed, northwest China. *Sustainable Cities and Society*, *50*, 101658-. https://doi.org/10.1016/j.scs.2019.101658

Singh, S., Kumar, V., Chauhan, A., Datta, S., Wani, A. B., Singh, N., & Singh, J. (2018). Toxicity, degradation and analysis of the herbicide atrazine. Environmental Chemistry Letters, 16(1), 211–237. https://doi.org/10.1007/s10311-017-0665-8

USDA. (n.d.). *USDA Statistics by State* [dataset]. Retrieved January 1, 2024, from https://www.nass.usda.gov/Statistics_by_State/Kansas/Publications/County_Estimates/index.php

Wang, S., Stiles, T., Flynn, T., Stahl, A. J., Gutierrez, J. L., Angelo, R. T., & Frees, L. (2009). Modeling Approach to Water Quality Management of an Agriculturally Dominated Watershed, Kansas, USA. *Water, Air, and Soil Pollution*, *203*(1–4), 193–206. https://doi.org/10.1007/s11270-009-0003-2

Wang, W., Liang, T., Wang, L., Liu, Y., Wang, Y., & Zhang, C. (2013). The effects of fertilizer applications on runoff loss of phosphorus. Environmental Earth Sciences, 68(5), 1313–1319. https://doi.org/10.1007/s12665-012-1829-2

WINSTEN, J. R., BAFFAUT, C., BRITT, J., BORISOVA, T., INGELS, C., & BROWN, S. (2011). Performance-based incentives for agricultural pollution control: identifying and assessing performance measures in the United States. *Water Policy*, *13*(5), 677–692. https://doi.org/10.2166/wp.2011.055

Yasarer, L. M. W., Bingner, R. L., Garbrecht, J. D., Locke, M. A., Lizotte, J., Momm, H. G., & Busteed, P. R. (2017). Climate Change Impacts on Runoff, Sediment, and Nutrient Loads in an Agricultural Watershed in the Lower Mississippi River Basin. *Applied Engineering in Agriculture*, *33*(3), 379–392. https://doi.org/10.13031/aea.12047