The Socioeconomics of TMDLs in the James River Watershed

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Abstract

Non-point source pollution of surface water is regulated by Total Maximum Daily Loads (TMDLs) under the Clean Water Act in the United States. The relationship between environmental quality and socioeconomics is well established; however, the relationship between socioeconomic factors, environmental regulation, and non-point source pollution is less clear. This study was conducted as a preliminary analysis to investigate the relationship between income, poverty, and TMDLs. This study's data were retrieved from publicly available data sets from the Census Bureau and the Virginia Department of Environmental Quality GIS application. The relationship between Household Income and Poverty Rate was evaluated with the count of TMDL Impairment Watersheds within a locality using regression analysis. The relationship between TMDL amendment per locality and income was also evaluated. A statistically significant positive linear relationship was found between Median Household Income and TMDL Impairment Count. A statistically significant negative linear relationship was found between Poverty Rate and TMDL Impairment Count. There was no relationship between Median Household Income and New and Amended TMDLs. Higher TMDL impairment count in wealthy localities may be explained by sprawling suburban land use and higher political capital of wealthier areas. This study establishes that there is likely a connection between TMDL and socioeconomic factors and provides a basis for future studies.

Background

In the Commonwealth of Virginia, the James River (JR) is a vital waterway that is of economic, social, and environmental significance located within the Chesapeake Bay Watershed (CBW). The JR flows from west to east, starting at the confluence of the Cowpasture and Jackson Rivers located in Botetourt County, and ends in the lower portion of the Chesapeake Bay near the cities of Hampton and Virginia Beach. Major urban areas in the James River Watershed (JRW) are Lynchburg, Charlottesville, Richmond, and a large portion of the Hampton Roads area. As the JRW is within the greater Chesapeake Bay Watershed, management of pollutant loading is of high priority due to the effects of legacy pollution, frequent eutrophication, and algal blooms in the Bay and lower JRW (Anderson et al., 2008; Wood et al., 2014).

Total Maximum Daily Load (TMDL) is a regulatory tool to address non-point source pollution authorized under Section 303d of the Clean Water Act. TMDLs establish the amount of loading of a constituent pollutant that a body of water receives so that it meets its designated uses to comply with the Clean Water Act. TMDLs within this region are unique in that there are large basin-wide TMDLs to which the James River must comply. An example of this is the Chesapeake Bay TMDL, which covers the entire watershed and many other large river systems like the JRW.

The relationship between environmental quality and socioeconomic factors has been elucidated for other natural resources like air (Brajer & Hall, 1992; Clark et al., 2017). However, there is a gap in the knowledge about the relationship between income TMDL and non-point source water pollution. As of 2014, it is estimated that the United States has spent $1.9 trillion since the 1960s to improve water quality. This considerable expense surpasses spending for most other environmental initiatives. Though the United States has reaped the benefits of this massive spending, to whom specifically these environmental benefits accrue to within society, have been challenging to clarify. Additionally, analysis concerning household income, environmental quality, and spending on localities issues has not been adequately investigated (Keiser et al., 2019). This presents a dilemma of accountability and equity of the distribution of these resources throughout society.

However, due to the importance of the Chesapeake Bay, the effects of restoration have been examined. Regarding the Chesapeake Bay TMDL, it has been determined that the ecosystem service benefits that have been accrued are estimated to be $22.5 billion (in 2013 dollars). These benefits have been primarily achieved through land conservation initiatives (Phillips & McGee, 2016). Though the dollar amount of the benefits of this restoration has been estimated, it is still unclear how these benefits of improved water quality are distributed throughout the Chesapeake Bay Watershed population and impact or improve local communities.

As income often varies with environmental quality, and TMDLs are implemented within degraded water quality areas, this analysis aims to examine the relationship between these factors and socioeconomic data. The JRW was selected as a starting point due to its lack of interstate boundaries, a wide variety of land uses, and locality-specific economic profiles. Notably, there is a lack of literature examining the link between TMDL and income, and this preliminary analysis aims to elucidate this relationship to guide further exploration.

Methods

The James River was chosen for this investigation because of its relative lack of interstate boundaries. The negligible portion of the James River that exists outside of Virginia was excluded from this analysis. Data on TDML impairment in Virginia were obtained from VADEQ using the publicly available VEGIS datasets. These data were then merged with an open-source overlay of the James River Watershed to match the impaired TMDL segments with their localities. All GIS data were overlaid with the localities of Virginia. Only localities at the county and city levels were included in this analysis. These datasets were then merged and then cleaned for duplicates. Impaired segment count per locality was calculated and then analyzed for relationships with household income data obtained from the Census Bureau Quick Facts portal, using regression analysis. TMDL Impairment Count Per locality measured impaired segments of all counts of TMDL pollutant impairment listings per impaired segment of all water bodies located within the locality. Localities that other water bodies outside of the JRW were not excluded in this count, as economic data in these localities were based solely on political boundaries and not the geographic boundaries of the JRW.

Results

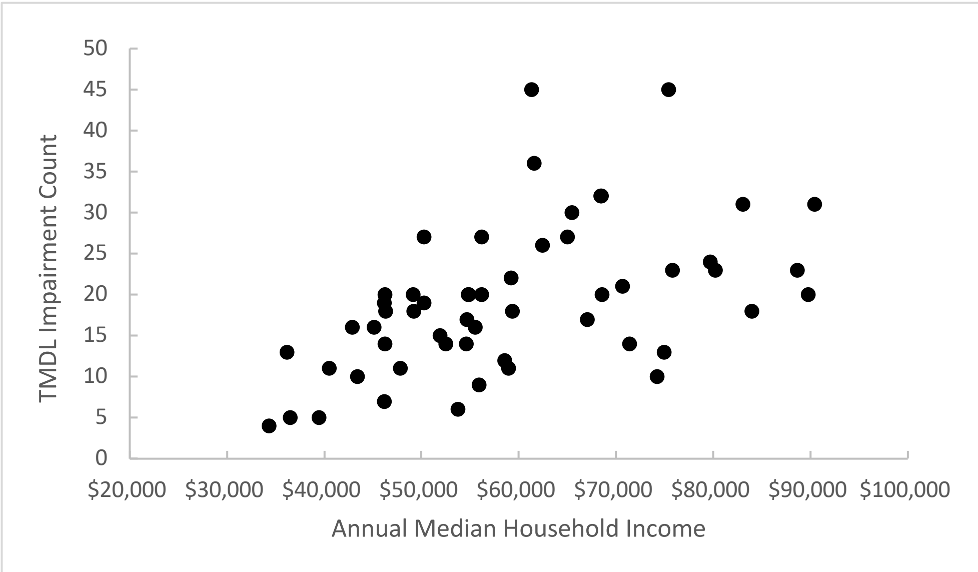

Figure 1- Relationship between 2018 Median Household Income and TMDL Impairment Count of localities located in the James River Watershed. (n=55, $y=3.18*10^{-4}x+3.52*10^{-1}$, $r^2=0.26$, $p<0.0001$)

The results from regression indicated that multiple statistically significant relationships exist between socioeconomic variables and TMDL impairment count per locality. Within the 55 localities within the JRW, the range of Annual Median Household Income Per Jurisdiction (MHI) ranged from $34,273 to $90,967. TMDL Impairment Count (TIC) per locality varied between 4 and 45 with a mean TMDL Impairment Count per locality of 19.

Regression analysis with MHI and TIC displayed a positive linear relationship between these two factors (Figure 1). This suggests that localities with lower MHI had low TIC, and areas with high MHI had high TIC. Areas with lower MHI and TIC tended to be classified as rural areas with lower population density. Middle-income localities tended to have the most variation in TIC and were located in different areas throughout the state. Jurisdictions with high MHI displayed moderate to high TIC. Areas with high MHI tended to be suburban, particularly clustered around the City of Richmond, Roanoke, and Charlottesville. The relationship between MHI and TIC demonstrates that areas with similar land disturbance characteristics in the lower and upper parts section of Figure 1 display geographical clustering of localities with similar economic profiles that influences their TIC.

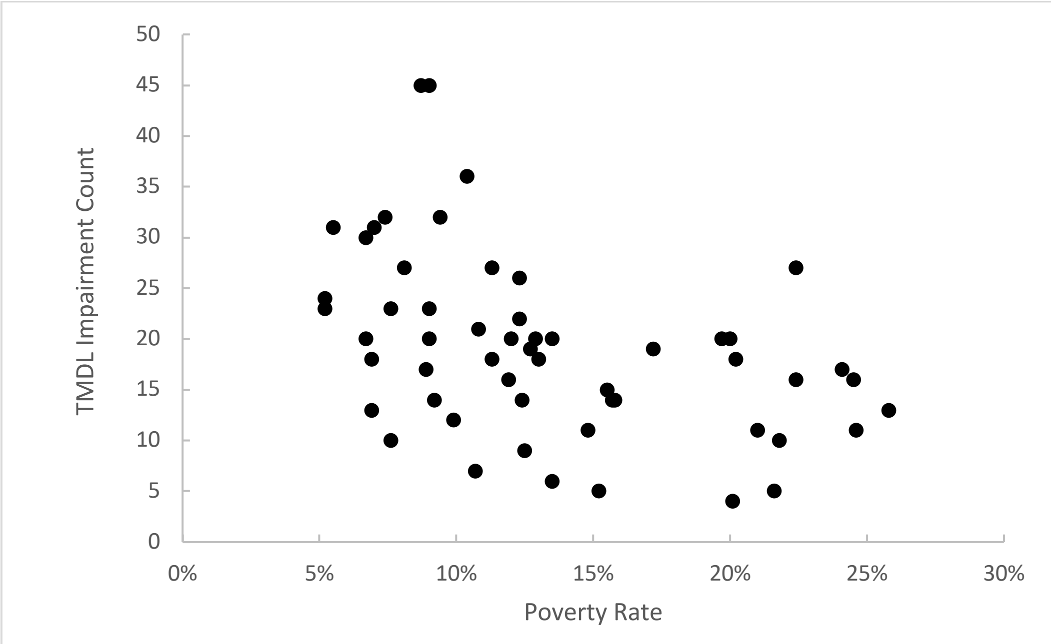

Figure 2- Relationship between Poverty Rate and TMDL Impairment Count (2018) in the James River Watershed. (n=55, y=-68.8x+28.309, r^2=0.196, p<0.001)

A negative linear relationship was observed between Poverty Rate (PR) and TIC (Figure 2). The average poverty rate within the JRW is 13%, is slightly above the national poverty rate of 12% (Semega et al., 2020). Areas with lower poverty rates tended to have higher TIC than compared to areas with higher poverty rates. Areas with low poverty rates tended to be more affluent located near urban areas such as Roanoke, Charlottesville, and Richmond. Areas with intermediate (i.e., 15 to 20%) poverty rates varied within their location within the state and tracked moderate TMDL impairment levels. Jurisdictions with a high poverty level were mostly located within the lower portion of the watershed near the confluence with the Chesapeake Bay in the Hampton Roads area. These areas tended to be more developed and urban.

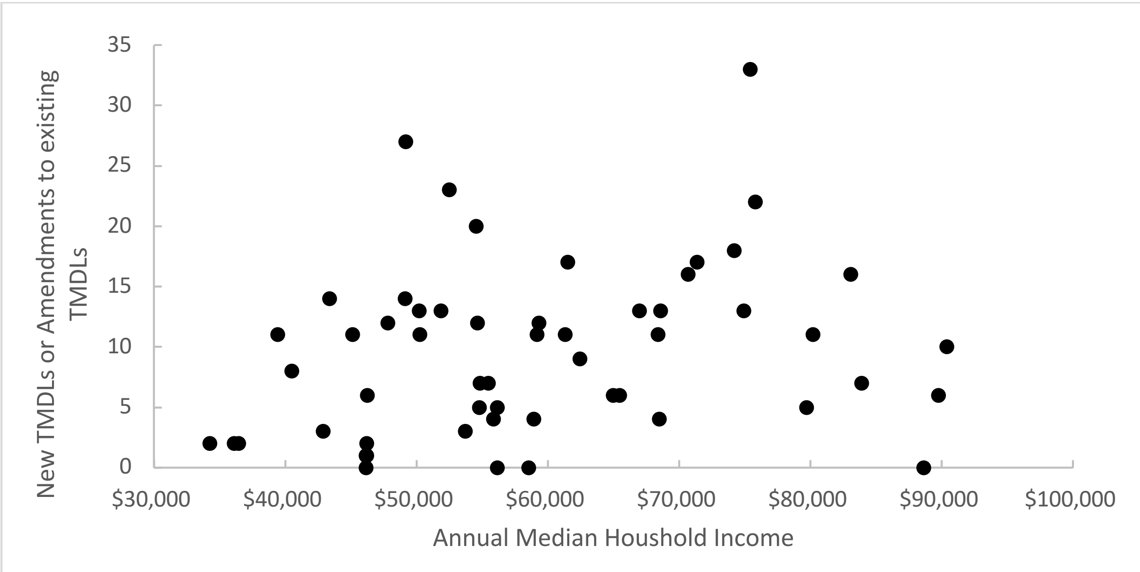

Figure 3-Relationship between Annual Mean Household Income and New or Amended TMDLs. (n=55, r^2=0.0549, α=0.05, p=0.0851)

To examine possible inequalities within the distribution of efforts to ameliorate water quality, the relationship between MHI and New + Amendments of TMDLs (NATMDL) was also evaluated. Regression analysis indicated no statistically significant relationship between these two factors (Figure 3). Within the distribution of NATMDL, some localities had NMTMDL value of zero, meaning that no streams are to be assessed for TMDL by VADEQ from 2016-2022. However, many of the localities with low values for NATMDL were either small cities or rural counties, and areas with higher NATMDL were more populated and located in the lower part of the JRW.

Discussion

This exploratory analysis was developed to investigate the relationship of TMDLs and selected socioeconomic factors within the JRW. Such analysis confirmed a significant relationship between TIC and two of the three tested socioeconomic factors. A positive linear relationship was observed between MHI and TIC and a negative linear relationship between the poverty rate and TIC. From a socioeconomic perspective, these results suggest that amelioration efforts in 2016-2022 were not concentrated in specific areas based on wealth. Instead, other factors that were not included in this analysis could provide additional insight into the cause of these relationships.

The two localities with the highest TIC were Albemarle and Augusta counties, both with above-average MHI, moderately low poverty, but high TIC. These counties, located in the middle portion of the JRW, are communities with prevalent agricultural and pastoral land use. As animals graze this land and produce excreta, this may contribute to elevated TIC within those localities (Scott et al. 2017).

The lowest TIC localities were small cities located within the upper JRW with low MHI and high poverty rates. Concurrently, these cities have high TIC proportional to their area. This intensity of TIC in such a small area could suggest poor water quality despite the low TIC. This presents a limitation of the methodology as density effects are not directly measured. However, the TMDLs in these areas are mostly of basin-wide TMDLs, not TMDLs that were explicitly developed because of impairment that was completely specific to the locality. Lack of assessment in these small cities could indicate a lack of assessment in these areas due to the fine spatial scales required to develop TMDLs in these areas, specifically in Lexington and Buena Vista. Alternatively, TIC in these areas relative to density may suggest intense pollution location of these cities in the upper JRW.

Areas with low PR but high TIC were majority low-density rural to suburban localities as these areas contained high TIC and overall high incomes. Jurisdictions with poverty under 9% often surrounded more urbanized communities within the JRW. Counties with both urban and rural land use surrounding larger cities in Virginia have sprawling low-density development. Compared to urban areas, suburban and rural areas display the highest water quality changes than pre-disturbance conditions (Tu et al., 2007). This phenomenon may explain the elevated amounts of TIC in these localities as suburban and exurban sprawl made their way to these areas. An alternate explanation for high TIC in these areas may result from economic privilege where wealth in these areas with low PR and high MHI resulted in higher TMDLs established.

Previous studies suggested stream restoration efforts with high pollution intensity co-occurred in areas with more wealth were more white and more educated (Stanford et al., 2018). Stanford et al. explained that these whiter, more affluent, and more educated areas were better at securing funding for restoration projects and providing matching funding for restoration. The overall whiteness of the environmental conservation workforce is also a contributing factor of inequality. This occurs by environmental professionals advocating for improved environmental quality in their communities, which tend to be not diverse and not economically disadvantaged (Stanford et al., 2018). As environmental professionals often advocate for due diligence in their communities, this may create a positive feedback loop of disregarding environmental issues in more impoverished communities. This presents an environmental justice dilemma as communities of color and more impoverished communities often have lower overall environmental quality (Bullard, 1993). Though race was not included within this analysis, this study's findings would be appropriate for this further analysis relating specifically to TMDLs.

Due to the simplicity of analysis, many sources of bias could have caused uncertainty within the findings. As there was no differentiation between tributaries and the James River's main stem, cumulative effects likely increase the TIC in downstream localities. These cumulative factors, such as population distribution in the JRW, are possible sources of bias. Additionally, the JRW is more populated in downstream areas, particularly surrounding the Richmond and Hampton

Roads areas, which are more affluent and have higher MHI. These factors also could have skewed the data toward higher TIC levels in areas with high MHI. Density effects of population and overall population are possible sources of error as each locality has different land areas that may have warranted bias in the distribution. Since the localities included were limited to the city and county levels, small cities possibly had elevated TIC relative to land area, population, and population density.

Conclusion

The results of this study indicated that multiple statistically significant relationships exist between socioeconomic factors and TMDLs in a locality within the James River Watershed. As non-point source pollution regulation in the United States is nebulous, government frequently overlooks how different populations see environmental regulation enactment within their communities. This study demonstrated that wealthier localities, by count, tend to have more TMDLs than poorer localities. Similarly, the study also demonstrated that areas with low poverty tended to have higher counts of TMDLs than areas with higher poverty. As more affluent areas are more likely to have adequate funding and political desire for environmental regulation, it is suggested that this is a possible reason for wealthier localities having more TMDLs. Though analysis methods were simplified, this study demonstrated the connection between socioeconomic factors and TMDL impairment, which warrant further investigation within another context such as Environmental Justice.

Bibliography

Note: to access data used in the project, please contact Liz Sharp (lizsharp@vt.edu) or Kevin McGuire (kevin.mcguire@vt.edu).

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