ASSOCIATIONS BETWEEN SOCIAL VULNERABILITY AND ENVIRONMENTAL QUALITY IN THE SOUTHEASTERN UNITED STATES

Gregory Bonilla[1], Leslie Conduff[2], Nathaniel L. Gibson[3], Sarah J. Love[3], Allison Rogers[1], Jillian Walton[4], Hyun Seok Yoon[3], and Paul R. Armsworth[3]

[1] Dept. of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996

[2] Dept. of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37996

[3] Dept. of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN 37996

[4] Dept. of Microbiology, University of Tennessee, Knoxville, TN 37996

Author emails:

gbonilla@vols.utk.edu

lconduf1@vols.utk.edu

ngibso11@vols.utk.edu

sjaynelove@gmail.com

aroger59@vols.utk.edu

jwalto12@vols.utk.edu

hyoon15@vols.utk.edu

p.armsworth@utk.edu

ABSTRACT

We lack a thorough understanding of correlations between sociodemographic factors and environmental quality. Though much work has been done on individual sociodemographic and environmental quality indicators, we still lack more comprehensive representations of how sociodemographic factors and different aspects of environmental quality relate to one another. Here, we utilized the Social Vulnerability Index (SVI) from the Center for Disease Control (CDC) and indicators of environmental quality from the Environmental Protection Agency (EPA) to examine spatial correlations between sociodemographic values and air quality, water quality and quantity, and recreational benefits across six states in the Southeastern United States. Counter to our initial hypothesis, we found only a weak negative correlation between social vulnerability and an aggregate measure of environmental quality, indicating that more socially vulnerable communities may live in areas with better overall environmental quality. This outcome may stem from a rural-urban pattern across the southeastern landscape. However, when SVI and environmental quality are separated into their parts, we observed a more nuanced relationship between the two. A thorough examination of the correlations between social vulnerability and environmental quality is necessary if environmental management measures are to reduce rather than exacerbate existing social inequities.

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1 INTRODUCTION

Environmental quality is often directly linked to human health and wellbeing, with poor environmental quality being a major contributing factor to death worldwide (27). While the effect of environmental quality on health has been extensively researched, studies that examine which sociodemographic communities are most negatively affected by poor environmental quality are relatively rare. Yet this is an essential factor to ensuring that environmental management actions alleviate rather than exacerbate societal inequities. While it is common to examine the impact of individual components of environmental quality on communities (e.g., the effect of air pollution on minority communities), more holistic analyses examining how multiple aspects of environmental quality impact communities are less common. As the environment and natural landscape continue to change, it is imperative to understand if more at-risk communities are adversely affected by these changes.

The Social Vulnerability Index (SVI), developed by the United States Center for Disease Control and Prevention (CDC) can be used to identify at-risk communities. Social vulnerability describes the potential for negative impacts on a community caused by external disasters, or stressors that impact human health. However, while many studies have used the SVI to assess health risk and hazard mitigation, there is a lack of studies that explore connections between the SVI and environmental quality (1,13). Our overarching goal is to explore the spatial relationship of environmental quality and socially vulnerable populations within the southeastern United States (Figure 1). Specifically, we consider (1) how the SVI correlates with environmental quality broadly, and (2) if there are correlations between individual indicators of socially vulnerable populations and environmental quality within the Southeast.

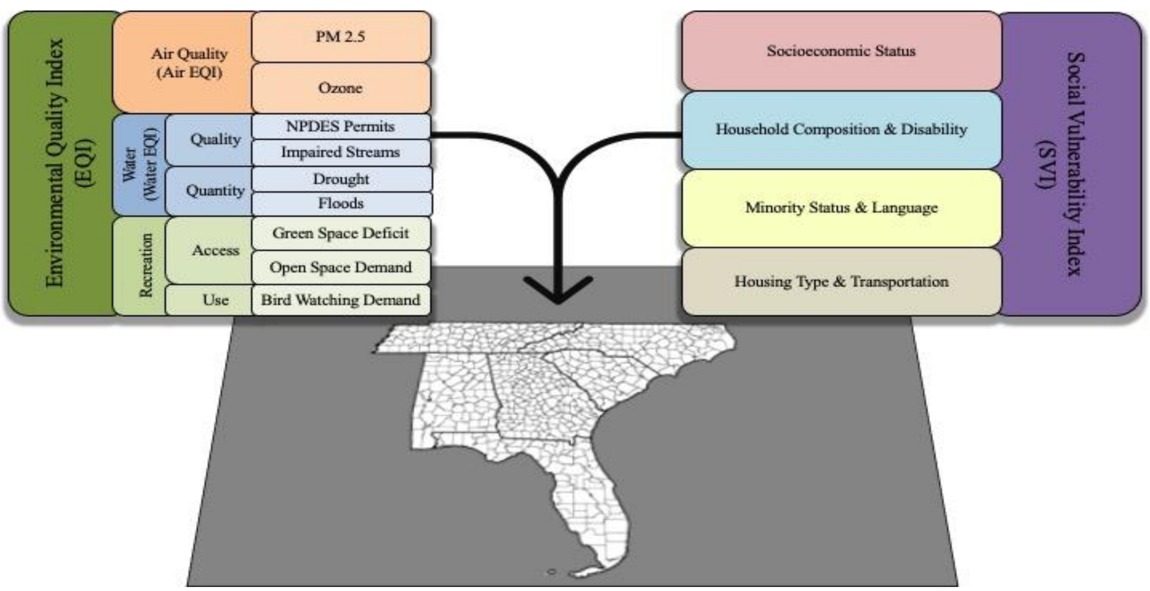

Figure 1: Framework for investigating associations between environmental quality and social vulnerability in the Southeastern United States.

2 METHODS

2.1 Data collection

Our analyses are based upon 16 indicators: The Social Vulnerability Index (SVI) and its 4 component variables, and 11 indicators of environmental quality and ecosystem services related to air, water, and recreation (Figure 1). Indicators for air, water, and recreation themes were selected after a literature review to determine common and important indicators for each theme. Sub-themes were also selected for water and recreation to acknowledge differences in indicator types (i.e., Water Quantity and Quality, Recreation Access and Use). Data were collected at the county level for six states in the southeastern United States: Alabama, Florida, Georgia, North Carolina, South Carolina, and Tennessee. The data were collected between February and April 2021 via online data repositories (Appendix 1-4). Data pertaining to social vulnerability were accessed via the Centers for Disease Control and Prevention Social Vulnerability Index 2018 Database (30). Data concerning environmental quality (overall quality, water quality and drought data, open space extent, and air quality) were obtained from the Environmental Protection Agency's Environmental Quality Index (EQI) (38); data on historical flood events were gathered from the National Oceanic and Atmospheric Administration Storm Events Database (18). Data regarding Open Space Access Demand and Bird Watching Demand were collected via ScienceBase (41) and EnviroAtlas (38), respectively.

Both SVI and EQI were constructed such that higher scores on these indices relay negative impacts. With respect to the SVI, scores range from 0 to 1 wherein scores closer to 1 are more socially vulnerable. Regarding EQI values (not individual variables used to calculate EQI, but the composite scores), larger positive values are indicative of poor environmental quality. As such, we transformed the data on green space availability using an inverse transformation to give a measure of green space deficit, thus maintaining a "higher is worse" interpretation of the indicator.

2.2 Statistical analysis

Correlation analyses were performed to investigate possible relationships between measures of social vulnerability and both environmental quality and ecosystem services. Spearman's rank-order correlations were used due to the failure to meet parametric assumptions. While we report significance levels to help organize our text, we did not yet adjust significance thresholds to account for multiple comparisons, nor did we fit and control for any spatial autocorrelation in the observed error structure. All statistical analyses were carried out in R version 4.04. Data visualizations were created using R (v4.0.4) and ArcGIS (v10.5) for maps.

3 RESULTS

Our analyses found that correlation between the SVI and EQI is -0.115, suggesting that counties with higher social vulnerability also have higher environmental quality (Figure 2), given the orientation of the two indices (see Methods). Counties exhibiting higher social vulnerability and better environmental quality can be observed in counties located in areas like southeastern of Georgia and northern Florida. Counties experiencing lower social vulnerability and poorer environmental quality can be seen in the urban centers across the Southeast, such as Nashville, Atlanta, Birmingham, and Charlotte. The negative correlation between the SVI and EQI can likely be attributed to the fact that there are many socially vulnerable, rural counties with higher environmental quality coupled with less socially vulnerable urban counties that have lower environmental quality.

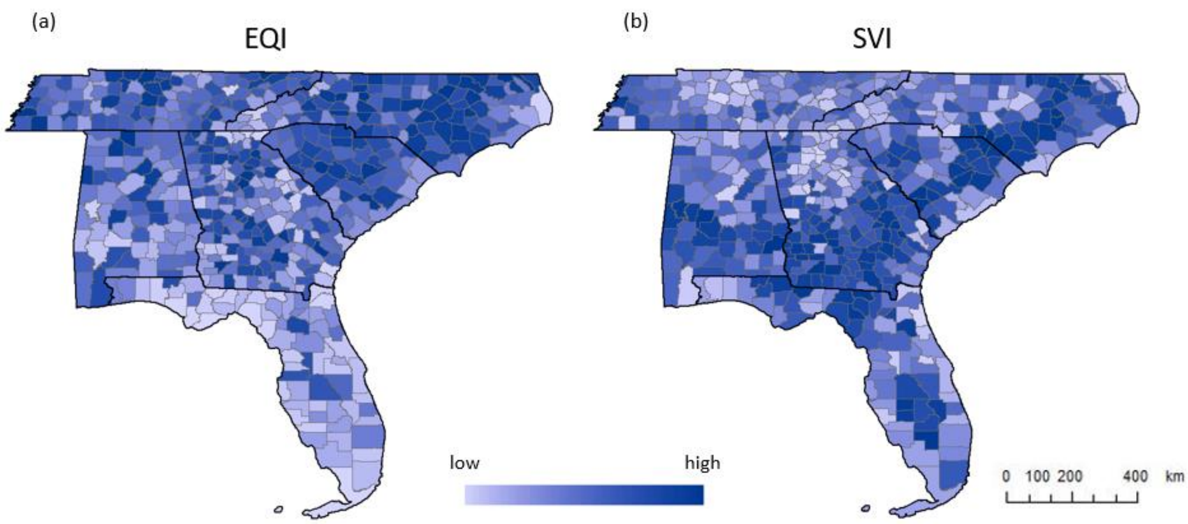

Figure 2. EQI (a) and SVI (b) values for each county in the Southeast region of the United States. Darker color indicates higher values of the respective variables. High EQI value indicates low environmental quality, whereas high SVI value indicates high vulnerability for the county.

Figure 2a shows aggregated EQI for each county with darker blue counties indicating areas where EQI values are higher, thus having poorer environmental quality. Aggregated environmental quality is higher in Florida, southern Alabama, and the Blue Ridge region, and lower in the Inner Coastal Plains and Piedmont in North Carolina and South Carolina and in major urban areas counties near Nashville, Atlanta, and Birmingham.

Figure 2b shows aggregated SVI for each county with darker blue counties indicating areas where SVI values are higher, thus having higher social vulnerability to natural or human-caused disasters that can negatively affect human health. SVI is particularly high compared to other areas in the Southeast in counties located within the Inner Coastal Plain ecoregion, central Florida, and several isolated counties in southwestern Tennessee.

VARIABLES	*EQI*	*Air EQI*	*PM2.5*	*Surface Ozone*	*Water EQI*	*Impaired Streams*	*NPDES Permits*	*Drought*	*Flood*	*Open Space Access Demand*	*Green Space Deficit*	*Bird Watching Demand*
SVI	-0.11 **	-0.07	-0.04	-0.29 ****	-0.06	-0.24 ****	-0.20 **	-0.23 ****	-0.26 ****	-0.12 **	0.05	-0.42 ****
Socioeconomic Status	-0.06	0.01	0.06	-0.17 ****	-0.12 **	-0.28 ****	-0.39 ****	-014 **	-0.33 ****	-0.21 ****	-0.09 *	-0.51 ****
Household Composition	-0.05	0.03	0	-0.11 **	-0.02	-0.22 ****	-0.22 ****	-0.08	-0.22 ****	-0.03	0.07	-0.37 ****
Minority Status	-0.02	-0.15 ***	-0.15 ***	-0.26 ****	0.09 *	-0.05	0.28 ****	-0.21 ****	-0.22 ****	-0.03	0.23 ****	0.15 ****
Housing and Transportation	-0.22 ****	-0.10 *	-0.14 *	-0.31 ****	-0.05	-0.04	0.03	-0.27 ****	-0.08	-0.12 **	0.01	-0.24 ****

Table 1. Spearman's Rank Sum Correlation values between social vulnerability indicators and environmental quality indicators. Significant positive correlations indicate that more socially vulnerable populations tend to have lower environmental quality with respect to the components that the indicators represent. Negative correlations indicate the opposite. Significance levels: **** $p<0.0001$, *** $p<0.001$, ** $p<0.01$, * $p<0.05$.

Table 1 shows the correlations between dis-aggregated EQI and SVI indicators. As with the composite scores, higher values of dis-aggregated EQI signify poorer environmental quality or reduced access to ecosystem services (except for birdwatching demand, which is an estimated number of days of bird watching). Higher values of dis-aggregated SVI signify greater social vulnerability for the indicator of interest. Therefore, a negative correlation between a social vulnerability indicator and an environmental quality indicator suggests that, in general, counties with higher social vulnerability also have higher environmental quality with respect to the represented indicators.

Generally, air quality indicators were negatively correlated with the social vulnerability indicators, indicating that many counties with socially vulnerable residents have better air quality (Table 1). For example, the negative correlation between the surface ozone pollution and housing type and transportation indicates counties with poor housing and transportation infrastructure have lower surface ozone pollution. Areas including Florida, the southeastern plains of Georgia, and the coastal plains of South Carolina had poor housing and transportation infrastructure and low surface ozone pollution (Appendix 2). There were also areas of high surface ozone pollution and good housing and transportation infrastructure which included counties in Tennessee, the Atlanta area, and the Piedmont region of North Carolina.

The negative correlations between water quality and quantity indicators and social vulnerability indicators demonstrate that socioeconomically disadvantaged counties have better water quality and quantity across the Southeast (Table 1). The number of impaired streams and household composition values show a particularly low negative correlation. This suggests that households composed of single parents or people with disabilities live in areas with, reportedly, less polluted streams. Low length of impaired streams and high household composition values are observed in Alabama, North Carolina, and the southeastern plains of Georgia. High length of impaired streams and low household composition value is also observed in areas such as Florida, Eastern Tennessee, and coastal North Carolina.

Green space deficit is an indicator of available opportunities, whereas bird watching demand is an indicator of the county-level demand for recreation opportunities. The correlation results between recreation-based indicators and social vulnerability indicators were ambiguous (Table 1). Green space deficit and social vulnerability indicators, especially minority status, were mostly positively correlated. The positive correlation suggests that there is a lack of green space access in areas with larger minority population. Areas such as the southeastern plains, central Florida, and urban areas of Nashville and Memphis showed high green space deficit as well as high minority population (Appendices 1 & 4). On the other hand, open space access demand and bird watching demand were mostly negatively correlated to social vulnerability indicators. This may be a result of rural counties with high social vulnerability showing less immediate demand for open space access and lower bird watching demand. Bird watching demand had especially low negative correlations with social vulnerability indicators in most of the high demand regions, such as southern Appalachians, Piedmont, coastal Alabama, and Florida, were also high vulnerability regions.

We also analyzed correlations between minority status and environmental quality indicators to determine the environmental quality in areas of higher minority populations. Notably, counties with larger minority populations had higher air quality, but less available green space (Table 1). However, this correlation requires further examination in future studies.

4 DISCUSSION

4.1 Connecting SVI and EQI

In this study, we investigated relationships between environmental quality, ecosystem services, and social vulnerability within the southeastern United States by analyzing correlations between indicators of each. At the spatial grain of counties, our analyses did not support our prediction that more socially vulnerable communities would correlate with areas of poorer environmental quality. As shown above, spatial distributions of SVI and EQI indices were largely mismatched (Figure 2), as the SVI was higher in impoverished rural counties while EQI values were higher in more urban counties (i.e., counties with large urban centers). As a result, our analyses suggested that socially vulnerable communities in the southeastern United States may be located in areas with better overall environmental quality.

There are some notable exceptions at finer spatial grains to the overall relationship we observed between social vulnerability and environmental quality in the Southeast. In North Carolina, for example, counties with high EQI values also appeared to have higher SVI scores, specifically in the eastern portion of the state. A similar relationship was observed in counties around the Orlando, Florida metropolitan area where EQI and SVI are both relatively high. There are also areas in the Southeast where there is high environmental quality and low social vulnerability: counties along the Georgia-North Carolina border appear to have lower EQI and SVI scores, as do specific counties such as Nassau, Florida and Dare, North Carolina. Altogether, while the broader trend across the Southeast remains that overall environmental quality appears better in counties associated with higher social vulnerability there are important exceptions that warrant further investigation.

Relying only on aggregated values for EQI and SVI masks some relationships between the individual variables used to create those aggregated values. For instance, while the water EQI is not significantly correlated with total SVI, indicators for water quality and quantity were all negatively correlated with overall SVI while the number of NPDES permits was positively correlated with minority status. Aggregated values such as SVI and EQI are commonly used in decision-making processes, which can make information readily interpretable, but can mask significant indicator correlations. Thus, caution should be taken when using aggregated values as the sole factor in any study or decision-making process (6) or, conversely, when seeking to draw general lessons but only examining particular aspects of environmental quality or social vulnerability.

4.2 Applications and Broader Impacts

In this section we expand on some of the ways our results and approach could be applied. Environmental monitoring is ubiquitous across the United States, as evidenced by the availability of data from agencies such as the EPA (i.e., EnviroAtlas and EQI data used in this report) and early national accounts of environmental quality (11). Organizations like the Southeast Conservation Adaptation Strategy (SECAS) have brought together stakeholders from a broad swathe of institutions (federal agencies, non-governmental organizations and universities, tribal leaders and private businesses) to perform monitoring related to climate change and urbanization. SECAS, like other organizations involved in environmental reporting, has developed a suite of indicators to quantify the trends in environmental quality over time in the Southeast (31). Our results highlight how environmental monitoring could benefit from incorporating indicators describing impacts on different human communities, such as the SVI indicators. Doing so would allow decision-makers and practitioners to explicitly consider who benefits most from improved environmental quality and how they benefit, in addition to broadening future environmental monitoring efforts. This information would also likely aid in targeting restoration and conservation efforts into areas that have the highest need – both environmentally and societally.

As well as being relevant to recurrent environmental monitoring efforts, efforts to understand environmental impacts on different sectors of society are also important when examining one-off policy initiatives. For example, the Biden administration has outlined a climate and conservation agenda colloquially referred to as the "30 by 30" plan (34). The Biden administration's plan promotes ambitious conservation goals that, in part, aim to triple protected areas by 2030; the 30 by 30 initiative is likewise promoted within the scientific community (7). As actions are taken in advocating for environmental improvements at national and/or global scales, there remains a need to focus on the support of the public at local scales. Questions pertaining to where protected areas are to be located, as well as who will benefit most from these protected areas and how, will need to be addressed. From the understanding that socioeconomic status is a primary driver of social vulnerability, particularly in the Southeast (Appendix 1), expanding protected areas may lead to increased income in local communities that can reduce vulnerability while maintaining or improving environmental quality. For example, National Parks in the United States generated $41.7 billion in economic output for the national economy in 2019; states included in this report generated nearly $5 billion of that total output (5). As such, careful consideration of which communities bear costs or reap benefits are critical aspects that need careful consideration in the environmental management decision-making process across the Southeast. In this respect, practitioners that work to meet conservation goals and environmental benchmarks set by federal policy could concurrently work to reduce social vulnerability.

Apart from policy-related applications, the work presented here fits into a broader discussion of environmental justice concerns. Early work in environmental justice focused on issues in the Southeast, specifically the locations of industrial and hazardous waste facilities near minority and low-income populations (26). Since that time, modern environmental justice movement have tended to focus on single issues as means to influence changes in policy (18,33). At the same time, our analyses demonstrate how the heterogeneous distribution of environmental quality indicators can result in contrasts of environmental injustice. For example, our results showed broadly that across the Southeast more socially vulnerable populations tended to live in rural areas with better environmental quality. However, if we consider only the racial demographic component (SVI "Minority Status") in our analyses we see conflicting results: while areas with a higher proportion of minorities had better air quality and experienced fewer natural disasters like floods and droughts, there was a higher number of NPDES permits and less available green space. Regardless, people in areas that may appear to have better environmental quality may still struggle and remain vulnerable, so practitioners in the Southeast should remain cognizant of how populations may both suffer and benefit from varying aspects of the environment.

4.3 Future Directions

While the analyses performed here are critical first steps in investigating connections between social vulnerability and environmental quality, future studies should expand the examined indicators to gain a more-comprehensive view into the geographic patterns. In particular, including ecosystem services more directly could aid in mapping services that overlap with environmental quality and the Social Vulnerability Index. This could, in part, demonstrate more clearly which populations derive the most benefits from ecosystem services and if the presence or absence of ecosystem services contributes to social vulnerability. Since we did not see the anticipated positive correlation between EQI and SVI, further exploration is also needed to elucidate the relationship between SVI and environmental quality in the Southeast, and if that relationship differs from other areas in the United States. In addition, a stronger emphasis on differences in rural and urban areas and other covariates in future analyses is necessary, given that many of our indicators could be associated with population density. Finally, further investigation of the relationship between ecosystem services, environmental quality and SVI could include ecosystem accounting for the Southeast, wherein the economic value of ecosystem services and environmental quality are explicitly considered in the context of human wellbeing (8). An ecosystem accounting approach could convey how the economic benefits of higher environmental quality and ecosystem services vary based on socioeconomic status, household composition and disability, minority status and language, and housing type and transportation as well as the aggregated SVI value.

5 APPENDICES

Appendix 1 SOCIAL VULNERABILITY INDEX (SVI)

Here, we used the SVI to represent the total vulnerability across single and multi-dimensional indicators for the Southeastern United States. The SVI was developed from the Geospatial Research, Analysis and Services Program to determine where resources should be allocated during hazardous events across vulnerable communities in the United States (30). Covering over 3,000 counties, the most recent 2014-2018 SVI ranking percentiles are the summation of 15 U.S Census variables compiled into 4 themes: Socioeconomic Status, Household Composition and Disability, Minority Status and Language, and Housing Type and Transportation.

A1.1 Indicators

Socioeconomic Status is determined by factors such as being below or above the poverty line, employment status, income level, and education (i.e., obtaining a high school diploma). Living below the poverty line, being unemployed, as well as having a lower income and/or education level contribute to higher vulnerability. **Household Composition and Disability** considers age of residents (65 and older or 17 and younger), those with disabilities, and single parent households as factors contributing to social vulnerability. **Minority Status** is a broad measure within the SVI, as it captures whether people belong to a minority population as well as ability to speak English "less than well". Finally, **Housing Type and Transportation** characterizes types of homes (multi-unit structure, mobile home), crowding levels and group quarters, and access to a vehicle.

A1.2 Methods

The SVI uses 15 indicators that were retrieved from the United States Census Bureau's American Community Survey. This is a questionnaire that includes questions related to demographic, social, and financial statuses and is repeated every 5 years for analysis. Indicators for each theme were ranked from highest to lowest apart from per capita income which was inversely ranked due to the inverse vulnerability values. Each variable was then assigned a percentile rank using the formula *Percentile Rank = (Rank-1) / (N-1).* These ranks were then summed and analyzed across county- and census tract-levels for each state. To identify those that were most vulnerable, counts or flags were used to indicate tracts or counties that have multiple individual variables above the 90th percentile ranking. These summation rankings and flags show the rates of vulnerability from respective categories from least vulnerable denoting a 0 to most vulnerable at a range of up to 1 (30). For our study, we limited the range of values to those contained within county levels of states within the Southeast region: Alabama (AL), Florida (FL), Georgia (GA), North Carolina (NC), South Carolina (SC), and Tennessee (TN).

A1.3 Results

VARIABLES	SVI	Socioeconomic Status	Household Composition	Minority Status
Socioeconomic Status	0.85 ****	-	-	-
Household Composition	0.65 ****	0.59 *****	-	-
Minority Status	0.37 ****	0.01	-0.03	-
Housing and Transportation	0.76 ****	0.50 ****	0.21 ****	0.37 ****

Table A1: Correlations between SVI and its component variables in the southeastern United States.

Across the Southeast, social vulnerability appears to be largely a reflection of poverty, housing conditions and lack of transportation, but household composition and minority populations play significant roles as well (Table A1). All indicators are significantly correlated with total SVI, with most indicators likewise being significantly correlated with one another. For example, socioeconomic status is correlated with both household composition as well as housing and transportation. This is largely unsurprising, as the indicators which contribute to more vulnerable socioeconomic status (poverty, unemployment) would likely be connected to indicators contributing to household composition (age and disability) and housing and transportation (housing type, access to a vehicle). However, minority status is not correlated with either socioeconomic status or household composition, though it is significantly correlated with housing and transportation.

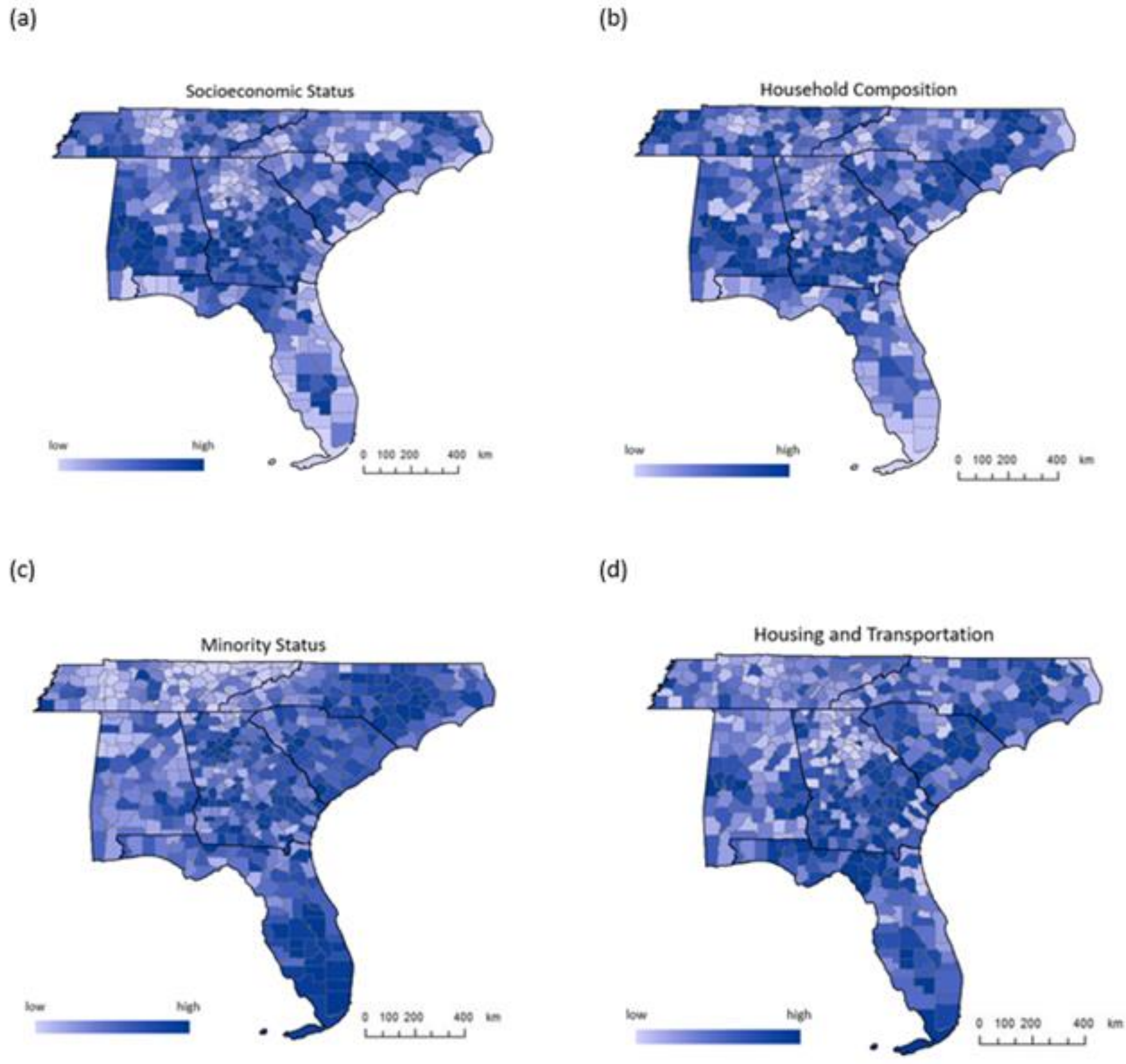

Figure A1: Trends of social vulnerability across the southeastern United States. Darker shaded counties represent areas of higher vulnerability.

Figure A1 shows how indicators of social vulnerability are distributed across the Southeast. Both the socioeconomic status and housing and transportation indicators exhibit nearly the same spatial pattern as the overall SVI, with higher vulnerability along the Inner Coastal Plain (Figure A1a & d). Notably, poverty appears to be acute in the Southeast: as of 2019, all states in our study have an estimated poverty rate of at least an 12% with Alabama (15.6%), Georgia (13.9%), and South Carolina (13.9%) among national leaders in poverty (36).

Household composition also had a similar distribution of increased vulnerability in the Inner Coastal Plain, though at a lesser degree than the either socioeconomic status and housing and transportation (Figure A1b). Specifically, we see slightly different patterns in Tennessee and Alabama than the previous two indicators. Scores for household composition were higher in East Tennessee and counties along the southern border with Alabama and Georgia, while Alabama had higher household composition scores in Alabama were located more in the central area of the state. This could in part be explained by the higher prevalence of disabilities among working age people (i.e., age 21-64) in these states, as Alabama (14.9%) and Tennessee (14.0%) are both well above the national average for disability prevalence (10.4%) (9).

Lastly, minority status in the Southeast does not appear to follow similar patterns as SVI and its related indicators. Instead, minority populations appear to be clustered in certain urbanized areas such as southern Florida, eastern North Carolina, the Atlanta metropolitan area in Georgia, and around Memphis, Tennessee (Figure A1c). There are notably large minority populations in Florida and Georgia, with both states having non-white populations (46.1% and 47.3%, respectively) much higher than the national demographic profile (34.5%) (35).

Appendix 2 AIR QUALITY

Associations between adverse health outcomes and resident proximity to air pollution drivers like factories and automobiles have been well documented (16, 26). Exposure to air pollution is known to increase the risks for cardiovascular morbidity and mortality (4). In order to combat air pollution, regulatory legislation like the Clean Air Act and its subsequent amendments have targeted the emissions of hazardous air pollutants to promote human wellbeing (12,20). Despite such measures, air pollution remains a serious environmental hazard in the United States (3,19,25). This particularly true for low-income and minority populations, as air pollution has been demonstrated to affect mortality more adversely in those populations (15). Altogether, tracking air quality and levels of pollution is critical to understanding overall environmental quality and its impact on humans.

A2.1 Indicators

To explore air quality in the southeastern United States, we used two indicators that capture air quality, as well as an aggregated air quality indicator value. We first considered overall air quality using the composite air quality score contained in the EQI, which captures a wide range of air pollutants and toxins (38). We also included two specific pollutants, fine particulate matter (PM2.5) and surface ozone (O3), as these are often viewed as primary drivers of reduced air quality and increased human health hazards (2). PM2.5 refers to particulate matter that has a diameter smaller than 2.5 microns that are either solid or liquid, while surface ozone is a measure of ground-level ozone gas. Though the health-related hazards of both pollutants are understood (14, 25), recent work has demonstrated that particularly vulnerable communities may be at greater risk of health issues related to PM2.5 and surface ozone exposure (28).

A2.2 Methods

We examined the headline air quality indicator as well as two critical components of the overall Air EQI value, PM2.5, and O3 from the EQI database. The indicators were extracted at the county-level from the EPA's EQI (38). Both indicators were originally sourced from the Air Quality System for the EPA EQI (38). Annual averages for both pollutants were calculated from 2006 to 2010 and annual county estimates were made at the center point of each county (38).

A2.3 Results

VARIABLES	*EQI*	*Air EQI*	*PM2.5*
Air EQI	0.62 ****	-	-
PM2.5	0.24 ****	0.16 ***	-
Surface Ozone	0.35 ****	0.25 ****	0.58 ****

Table A2: Correlations between air quality indicators and total environmental quality in the southeastern United States.

In the southeastern United States, we found that all indicators of air quality (Air EQI, PM2.5, and surface ozone) are positively correlated to overall environmental quality (Table A2). While Air EQI was more strongly correlated to overall EQI than either individual pollutant, PM2.5 and surface ozone were closely associated (Table A2).

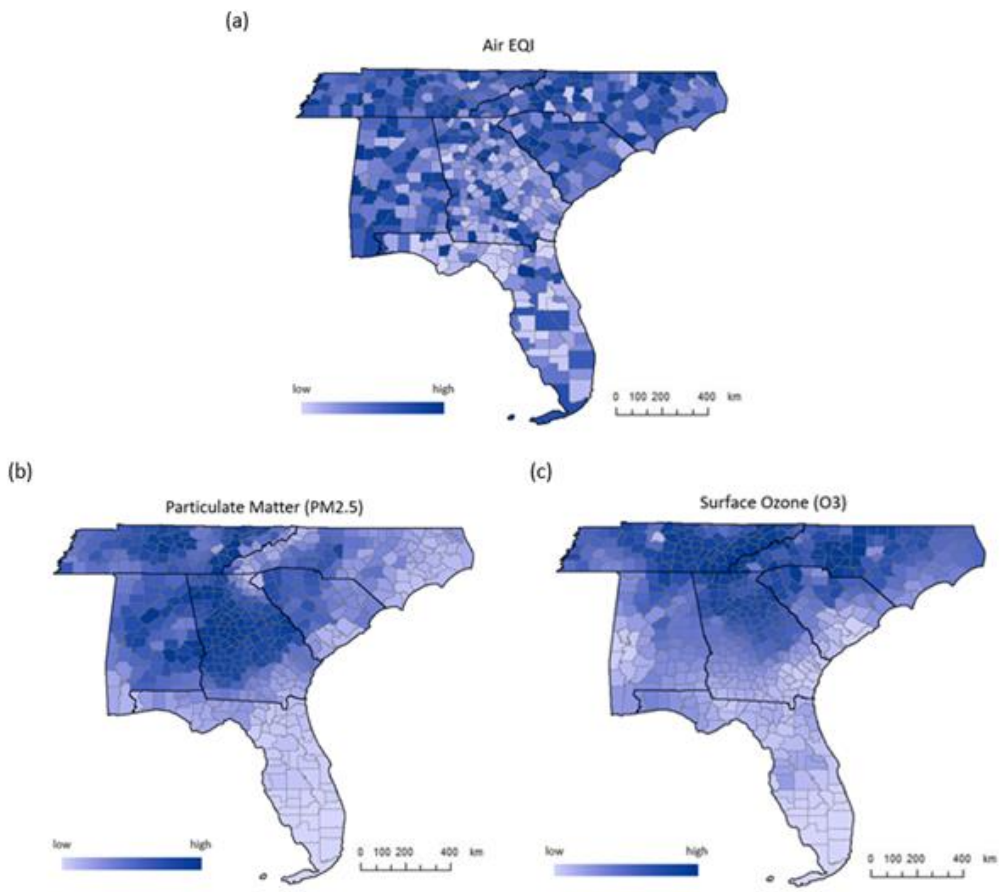

Figure A2: Indicators of air quality across the southeastern United States. Darker shaded counties represent lower air quality (a) and higher concentrations of pollutants (b, c), respectively.

Figure A2 shows the distribution of air quality indicators within the Southeast. Notably, Air EQI had a patchy distribution with counties of higher and lower air quality interspersed throughout the Southeast (Figure A2a). However, both PM2.5 and surface ozone have smoother gradients of concentrations across the region; PM2.5 concentrations are higher in Tennessee, Georgia, and Alabama with levels dropping towards both coastlines, while surface ozone is highest in Tennessee and North Carolina with concentrations reducing as one moves south (Figure A2b & c). Tennessee appears to have lower air quality than other states in the Southeast, with both PM2.5 and surface ozone having relatively concentrations throughout the state. In contrast, there are several counties in Florida that have lower overall air quality while PM2.5 and surface ozone concentrations are lower than many other counties in the region. As a result, it would appear that other pollutants are driving reduced air quality in some counties in Florida while indicators from this study appear to be major contributors to reduced air quality throughout Tennessee.

Appendix 3 WATER QUALITY AND QUANTITY

We examined both water quality and water quantity to explore overall water trends in the Southeast. Water quality affects human health, environmental health, and our ability to utilize ecosystem services related to water (6). The importance of water quality was underscored by the Clean Water Act of 1972 that was enacted to regulate water pollution (41). Although water regulatory policies were created at the national level and improvements have been made, over half of the streams and rivers in the U.S. nonetheless still violate the Clean Water Act (17). Whereas water quality mapping relies on the chemical, physical, and biological composition of water, water quantity is a measure of the availability of water and corresponding water quantity-related disasters, such as droughts and flooding (38).

A3.1 Indicators

Water Quality: Two indicators for water quality, the number of National Pollutant Discharge Elimination System (NPDES) permits and percentage of impaired stream length, were considered. Additionally, an aggregated water quality and quantity value (Water EQI) is used. NPDES permits originated in conjunction with the Clean Water Act and allow a limited, monitored amount of pollutant discharge from major point sources. The pollutant discharges covered by NPDES permits include several different pollutants such as biological contaminants, chemical waste, and industrial, municipal, and agricultural waste (39). Whereas NPDES permits highlight where potential pollution from major point sources is occurring, impaired streams are streams that do not currently meet water quality standards outlined in the Clean Water Act (38). The Clean Water Act requires that states must create Total Maximum Daily Load standards for pollutants, above which a stream is considered impaired (40). This indicator covers both drinking water quality and recreational water quality.

Water Quantity: In this section we also address two water quantity indicators: historical instances of droughts and flood. These indicators address water shortages and excesses that lead to water quantity emergencies. The drought indicator is included in the aggregated Water EQI value, while the flood indicator is not included in the aggregated Water EQI value. First we consider the percentage of extreme droughts in counties across the Southeast. This indicator includes both D3 droughts, extreme droughts, and D4 droughts, exceptional droughts (24). D3 droughts occur when there is crop and pasture loss, high fire risk, and widespread water shortages, whereas D4 droughts occur when there is high and widespread crop and pasture loss, higher fire risk than in D3, and a water shortage emergency (24). Data for the drought indicator was retrieved from the Drought Monitor Data and weekly drought data was averaged to an annual estimate of D3 and D4 drought percentage in each county for the years 2006 to 2010 (38). In addition to droughts, we also considered how the prevalence of flooding in counties across the Southeast. Data concerning flood records was collected from the National Oceanic and Atmospheric Administration Storm Events Database (23), and the indicator accounts for all floods that have occurred from 2000 to 2020. The Storm Events Database provides information on location of the flood (county or National Weather Service forecast zone), date of the flood, flood cause (estimated or observed), and severity of flood (in terms of damage caused and possible deaths). Flood severity was not included in our indicator for these analyses.

A3.2 Methods

To map these indicators, NPDES permits per 1000 km and impaired stream percent at the county level were extracted from the EPA's EQI (38). NPDES permit data was originally retrieved from the Watershed Assessment, Tracking and Environmental Results Program Database (WATERS) for the EPA's EQI. The EPA EQI estimated impaired stream length using impairment and water quality standards also retrieved from WATERS and RAD was used to designate streams and county-level cut offs for stream length. These indicators were averaged at the county-level from 2006 to 2010 for each county (38).

The drought indicator was retrieved from the Drought Monitor Data and weekly drought data was averaged to an annual estimate of D3 and D4 drought percentage in each county (38). Then the annual averages were averaged for 2006 to 2010 to create the drought indicator (38). Data on floods was collected from the National Oceanic and Atmospheric Administration Storm Events Database (23), and the indicator accounts for all floods that have occurred from 2000 to 2020. The Storm Events Database provides information on location of the flood (county or National Weather Service forecast zone), date of the flood, flood cause (estimated or observed), and severity of flood (in terms of damage caused and possible deaths). Flood severity was not included in our indicator for these analyses.

A3.3 Results

VARIABLES	*EQI*	*Water EQI*	*Impaired Streams*	*NPDES Permits*	*Drought*
Water EQI	0.40 ****	-	-	-	-
Impaired Streams	-0.04	-0.04	-	-	-
NPDES Permits	-0.08	-0.01	0.39 ****	-	-
Drought	0.18 ****	0.18 ****	0.01	-0.19 ****	-
Flood	0.00	0.05	0.35 ****	0.36 ****	0.11 *

Table A3: Correlations between water quality and quantity indicators and total environmental quality in the southeastern United States. Asterisks indicate significance levels.

Water EQI showed a significant positive correlation with the total EQI value as well as with drought (Table A3). Flood and NPDES permits both also showed a significant positive correlation with impaired streams. Flood and NPDES permits were positively correlated, which suggests that counties that have higher NPDES permits per 1000 km of stream experience more flooding. The counties with increased flooding and higher numbers of NPDES permits also have more impaired streams. Drought and NPDES permits showed a significant negative correlation, suggesting that counties prone to extreme droughts have fewer NPDES permits per 100 km of stream.

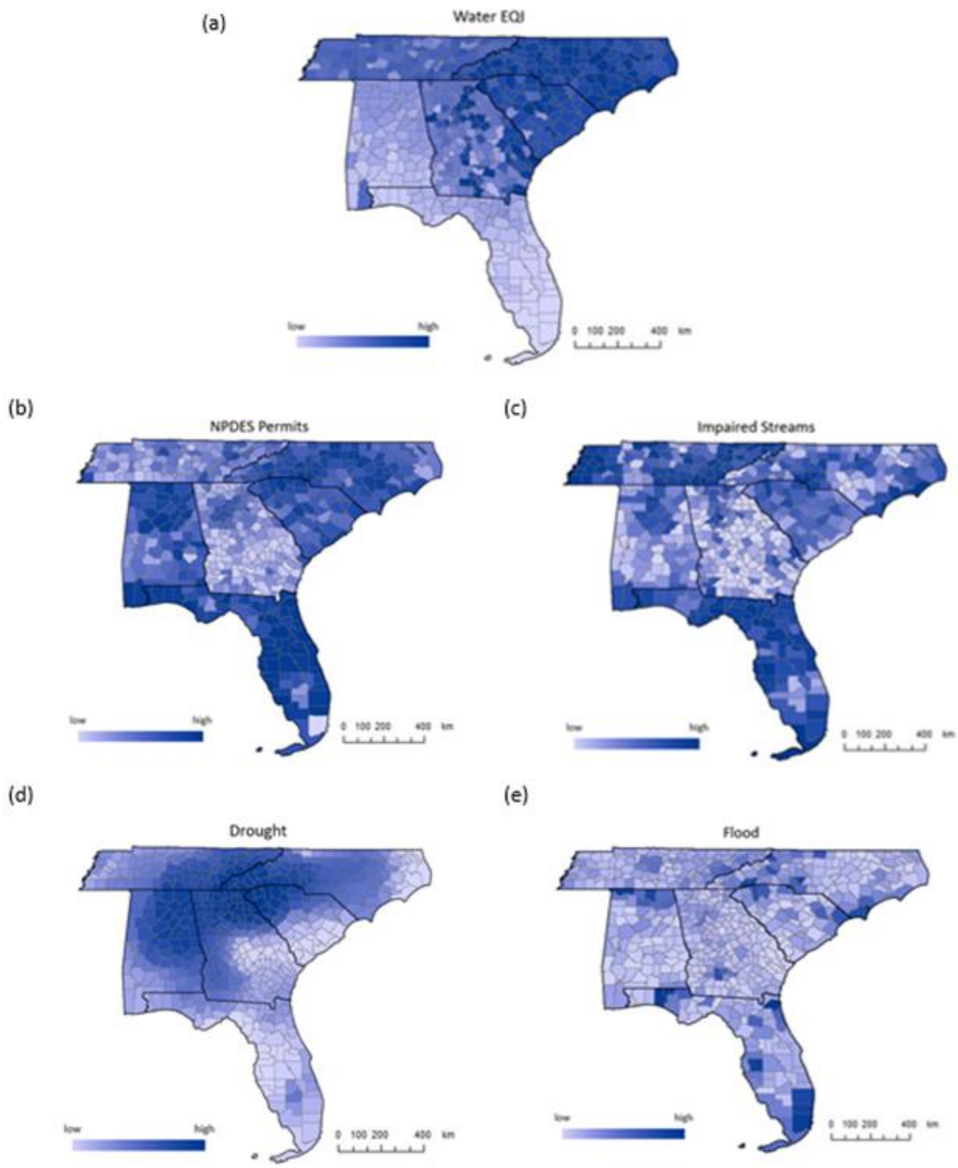

Figure A3: Distribution of water quality and quantity indicators across the southeastern United States. Darker shading represents counties with lower water quality (a), higher amounts of NPDES Permits and Impaired Streams (b & c), and more instances of droughts and floods (d & e).

Overall, Alabama and Florida both had low Water EQI scores while South Carolina and North Carolina had higher Water EQI scores (Figure A3a). The individual drought, impaired streams, and NPDES permit indicators did not directly explain the Water EQI scores. This reveals that aggregated Water EQI values may help reduce misunderstanding or misinterpretation of water quality as well as water quantity information. As expected, the Water EQI scores had a significant positive correlation with the total EQI score, suggesting that areas with a high total EQI scores also exhibit high Water EQI scores.

Figure A3b shows that Tennessee and Georgia had fewer NPDES permits than other states in the region, with Georgia with the fewest NPDES permits out of the states included in this analysis. These differences could be explained by the states that independently enforce and regulate the NPDES permits. Since states issue and monitor NPDES permits, there are no uniform standards for the permitting process, thus there may be inconsistency in pollution control (10). Additionally, Georgia has reported greater flexibility with NPDES permit enforcement and regulations, which may explain the lower ratio of NPDES permits there (10). NPDES permits had a significant positive correlation with flood and impaired streams and a significant negative correlation with drought.

As seen in Figure A3c, impaired stream percentages exhibited a similar pattern to NPDES permits. Georgia had a lower percentage of streams reported as impaired in many of its counties compared to other states, which may exemplify states setting their own standards for water quality as dictated by the Clean Water Act. Alabama also had a lower percentage of impaired streams, as seen by the lighter shading, but they had a higher amount of NPDES permits. Tennessee exhibited an opposite trend to Alabama, with a lower number of NPDES permits but a higher percentage of impaired streams.

Whereas the water quality indicators are similar in distribution, water quantity indicators show a markedly different pattern. Figure A3d shows a dark blue area where the drought in the Southeast is concentrated. As expected, coastal counties do not have as many extreme droughts as inland counties. There are many counties that had extreme droughts along the shared borders of Tennessee, Alabama, Georgia, and the Carolinas.

Lastly, Figure A3e demonstrates that few counties had high flood risk, even in counties located on the coastlines. Overall, increased flood risk clusters around coastal counties, but there are several inland outliers with increased flood risk. While the other indicators had great variation in their counties, mapping of the flood risk indicator showed that most counties experience low levels of flood risk. Floods were positively correlated with impaired streams and NPDES permits, meaning that in areas with higher rates of flooding, there are more NPDES permits and a greater quantity of impaired streams. This could be particularly problematic for residents, as there could be public health hazards related to flood water aside from the risk posed by the flood itself.

Appendix 4 RECREATION

Outdoor recreation promotes improved physical and mental health (32). The importance of recreational benefits was recently highlighted by the Great American Outdoors Act (GAOA), which provides for upkeep of amenities and infrastructure in national parks, recreational areas, and forests (22). Understanding the distribution of open space access demand and use is crucial to the creation of local infrastructures that supply recreational benefits for their communities (29). Bird watching is an example of a popular recreational activity nationwide. As a recreational demand, bird watching aids in the continued conservation of open space which in turn benefits communities via increased public land access (37).

A4.1 Indicators

Three recreational indicators were used: open space access demand, green space deficit, and bird watching demand. These indicators represent both *use* of recreation areas, as well as *access* to such spaces. Specifically, open space access demand and green space availability deficit represent access to recreational benefits, whereas bird watching demand exemplifies the use of recreation benefits. Prior work has shown that people are more willing to use a publicly accessible space if it is closer to their home (42). Furthermore, access to recreational land is important in providing opportunities for physical activity and community socialization (32). Bird watching demand represents the use of recreational land, and aids in management decisions regarding the conservation of lands for hunting and fishing (37).

A4.2 Methods

Open space access demand represents a mean standardized score based on the number of people that have access to open space within a given range of distances whether it be walking (within 0.5 mile), a short drive (within 3 miles), and or a longer drive (within 10 miles) (42). This indicator was retrieved from the 2018 "Conservation Priorities for Open Space Recreation Access" dataset developed by researchers at Duke University. Open space access demand is a measure of the availability of open spaces in comparison to the number of people living in the area. As such, larger values for open space access demand convey that the area is both densely populated while lacking in open space. With respect to green space deficit, green space availability represents the percent cover of land considered as natural and/or open space developed land cover (37). For this study, we inverted the green space availability values for consistency with other variables in which higher values represented poorer environmental quality. Bird watching demand was measured by the number of days that people were expected to partake in bird watching (trips/day) (37). Data for bird watching demand, measured via the USFWS Fishing, Hunting, and Wildlife Associated Recreation survey, was retrieved from the EPA EnviroAtlas (37). Larger values correspond with higher demand for bird watching recreation.

A4.3 Results

VARIABLES	*EQI*	*Open Space Access Demand*	*Green space Deficit*
Open Space Access Demand	0.33 ****	-	-
Green space Deficit	0.26 ****	0.43 ****	-
Bird Watching Demand	0.09 *	0.27 ****	0.14 **

Table A4: Correlations between recreational use (bird watching demand) and access (open space access demand & green space deficit) indicators and total environmental quality in the southeastern United States. Asterisks indicate significance levels.

As seen in Table A4, open space access demand and green space deficit are positively correlated; with increasing green space deficit, the demand for open space access also increases. Open space access demand also shows a significant positive correlation with bird watching demand; as demand for open space access increases, bird watching demand also increases. Lastly, there is a positive correlation between green space availability deficit and bird watching demand; as green space availability decreases, deficit values increase. This suggests that as the green space deficit increases, the demand for bird watching also increases.

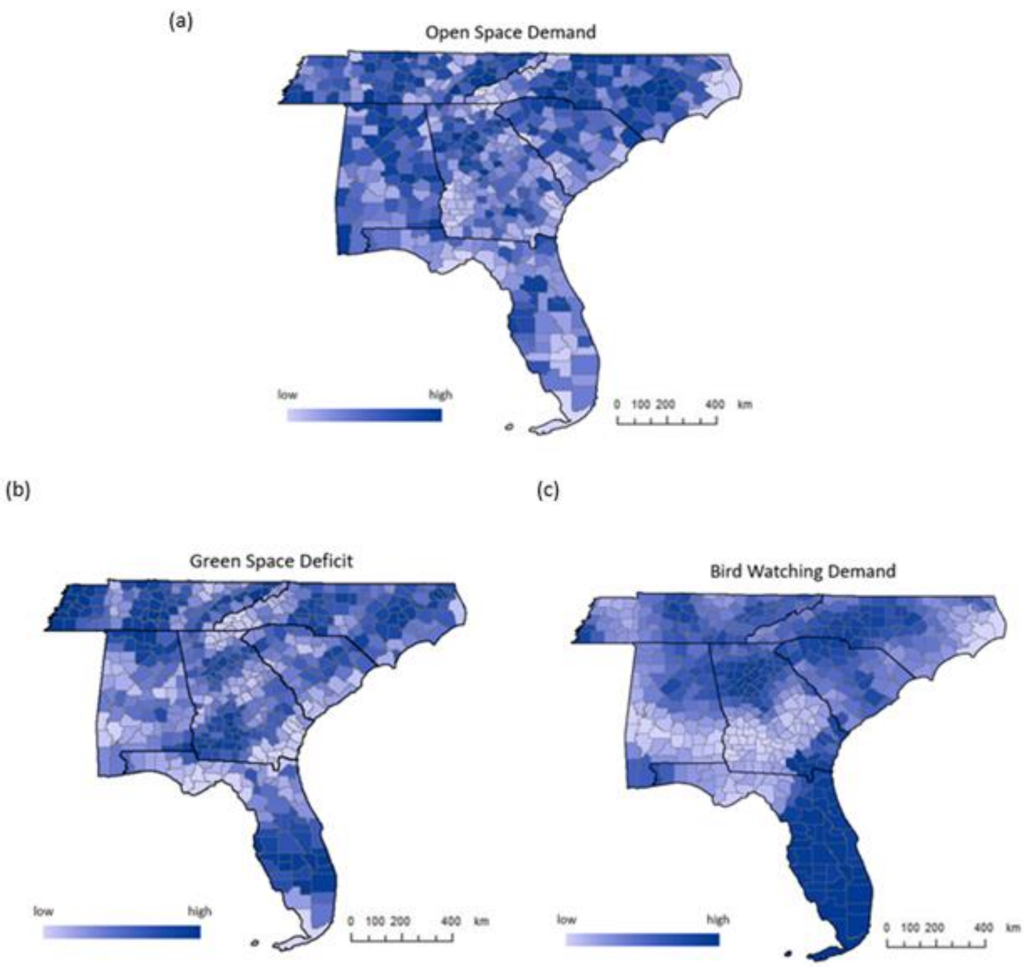

Figure A4: Trends in recreation across the southeastern United States. (a) Open Space Demand, (b) Green Space Deficit, and (c) Bird Watching Demand.

Figure A4a shows dark coloration representative of areas in the Southeast with high open space access demand and light coloration representative of areas with low demand for open space access. Areas surrounding Nashville, Tennessee and Raleigh, North Carolina had the darkest coloration, indicating a high demand for open space access. Portions of North Carolina (Boone and Franklin counties) and areas within Georgia (Blakely and Dawson counties) had the lightest coloration, suggesting a relatively low demand for open space access. This points to a trend where areas closer to urban centers tend to have a higher demand for open space access than more rural counties.

Figure A4b shows a greater green space deficit in counties with a darker coloration. Lighter coloration on the map shows lower deficit values of green space availability across the Southeast region, therefore more available green space. Central and western Tennessee, central Florida, and Raleigh, North Carolina show large deficits in green space availability. The largest green space deficits are concentrated near major urbanized cities of these Southeastern states, specifically around Nashville, Tampa, and Raleigh. This reflects a similar pattern to that observed in open space access demand, where urbanized areas have higher greenspace deficits while rural areas have lower deficits.

Figure A4c shows dark coloration where the demand for bird watching is high; lighter coloration illustrates where the demand is low. We should note that with this metric, the delineation of what should be considered higher or lower environmental quality is less clear. The majority of Florida had the highest demand for bird watching, followed by Charlotte, North Carolina; Spartanburg, South Carolina; Goose Creek, South Carolina; Nashville, Tennessee; Memphis, Tennessee; and Knoxville, Tennessee. Atlanta and Waycross, Georgia and Mobile and Birmingham, Alabama also show a higher demand for bird watching. Areas with a higher demand are centered around densely populated cities such as Charlotte, Nashville, Charleston, and Atlanta. Bird watching demand is lower in southern Alabama, Georgia, and northwestern Florida.

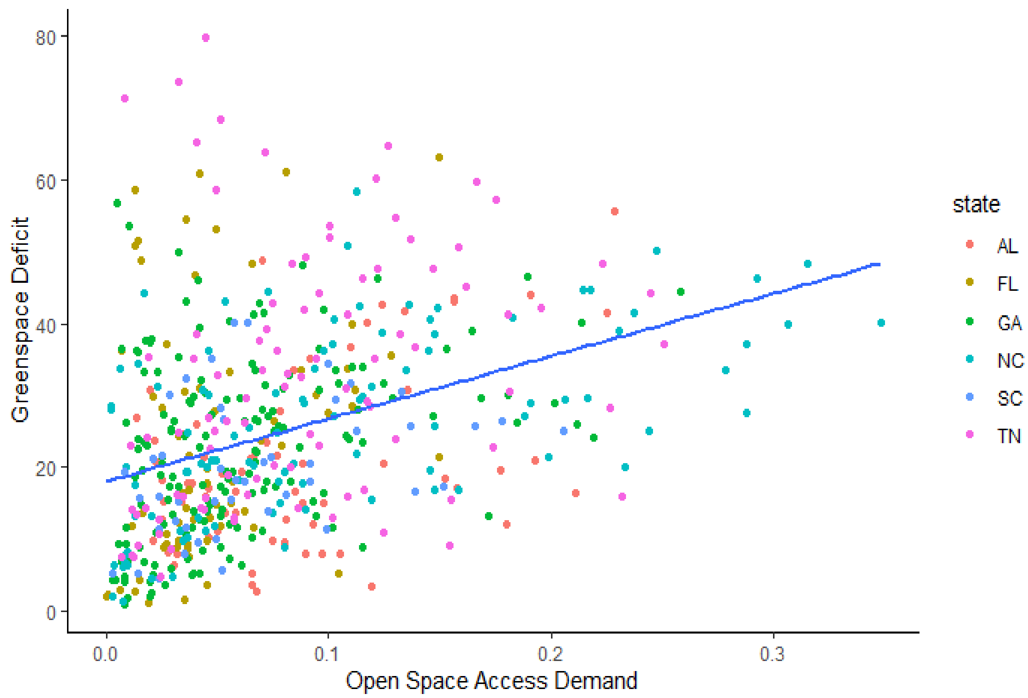

Figure A5: Trends between green space access deficit and open space access demand across the Southeastern United States.

Figure A5 shows a positive linear relationship between green space deficit and the demand for open space access amongst the states. This supports our findings that reduced green space correlates to higher open space access demand.

6 REFERENCES

1. An, R., & Xiang, X. (2015). Social vulnerability and obesity among US adults. *International Journal of Health Sciences*, *3*(3), 7-21.
2. Anenberg, S. C., Horowitz, L. W., Tong, D. Q., & West, J. J. (2010). An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. *Environmental health perspectives*, *118*(9), 1189-1195.
3. Bowe, B., Xie, Y., Yan, Y., & Al-Aly, Z. (2019). Burden of cause-specific mortality associated with PM2. 5 air pollution in the United States. *JAMA network open*, *2*(11), e1915834-e1915834.
4. Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *The lancet,* 360(9341), 1233-1242.
5. Cullinane Thomas, C., and L. Koontz. 2020. 2019 national park visitor spending effects: Economic contributions to local communities, states, and the nation. Natural Resource Report NPS/NRSS/EQD/NRR—2020/2110. National Park Service, Fort Collins, Colorado.
6. de Paul Obade, V., & Moore, R. (2018). Synthesizing water quality indicators from standardized geospatial information to remedy water security challenges: a review. *Environment international*, *119*, 220-231.
7. Dinerstein, E., Vynne, C., Sala, E., Joshi, A. R., Fernando, S., Lovejoy, T. E., ... & Wikramanayake, E. (2019). A global deal for nature: guiding principles, milestones, and targets. *Science advances*, *5*(4), eaaw2869.
8. Edens, B., & Hein, L. (2013). Towards a consistent approach for ecosystem accounting. *Ecological Economics*, *90*, 41-52.
9. Erickson, W., Lee, C., & von Schrader, S. (2020). 2018 Disability Status Report: United States. Ithaca, NY: Cornell University Yang-Tan Institute on Employment and Disability(YTI).
10. Flatt, V. B. (1997). A Dirty River Runs Through It (the Failure of Enforcement in the Clean Water Act). *Boston College Environmental Affairs Law Review*, *25*(1), 1–46.
11. H John Heinz III Center for Science, Economics and the Environment. (2008). The State of the Nation's Ecosystems 2008. Retrieved from: http://cfinsights.issuelab.org/resources/11234/11234.pdf
12. Henneman, L. R., Liu, C., Chang, H., Mulholland, J., Tolbert, P., & Russell, A. (2019). Air quality accountability: Developing long-term daily time series of pollutant changes and uncertainties in Atlanta, Georgia resulting from the 1990 Clean Air Act Amendments. *Environment international,* 123, 522-534.
13. Horney, J., Nguyen, M., Salvesen, D., Dwyer, C., Cooper, J., & Berke, P. (2017). Assessing the quality of rural hazard mitigation plans in the southeastern United States. *Journal of Planning Education and Research*, *37*(1), 56-65.
14. Jerrett, M., Burnett, R. T., Pope III, C. A., Ito, K., Thurston, G., Krewski, D., ... & Thun, M. (2009). Long-term ozone exposure and mortality. *New England Journal of Medicine*, *360*(11), 1085-1095.

15. Jorgenson, A. K., Hill, T. D., Clark, B., Thombs, R. P., Ore, P., Balistreri, K. S., & Givens, J. E. (2020). Power, proximity, and physiology: does income inequality and racial composition amplify the impacts of air pollution on life expectancy in the United States?. *Environmental Research Letters*, *15*(2), 024013.
16. Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental pollution*, *151*(2), 362-367.
17. Keiser, D. A., & Shapiro, J. S. (2019). Consequences of the Clean Water Act and the demand for water quality. *The Quarterly Journal of Economics*, *134*(1), 349-396.
18. Kelly-Reif, K., & Wing, S. (2016). Urban-rural exploitation: An underappreciated dimension of environmental injustice. *Journal of Rural Studies*, 47, 350-358.
19. Kravitz-Wirtz, N., Teixeira, S., Hajat, A., Woo, B., Crowder, K., & Takeuchi, D. (2018). Early-life air pollution exposure, neighborhood poverty, and childhood asthma in the United States, 1990–2014. *International journal of environmental research and public health*, *15*(6), 1114.
20. Miranda, M., Edwards, S., Keating, M., and Paul, C. (2011). Making the environmental justice grade: the relative burdens of air pollution exposure in the United States. *International Journal of Environmental research and Public Health.*
21. Mohai, P., Pellow, D., & Roberts, J. T. (2009). Environmental justice. *Annual review of environment and resources*, *34*, 405-430.
22. National Park Service (2021). *Great American Outdoors Act.* Retrieved from https://www.nps.gov/subjects/legal/great-american-outdoors-act.htm
23. National Centers for Environmental Information NOAA (2021). *Storm Events Database*. Retrieved from https://www.ncdc.noaa.gov/stormevents/
24. National Centers for Environmental Information NOAA (NA). *DROUGHT: Degrees of Drought Reveal the True Picture.* https://www.ncdc.noaa.gov/news/drought-degrees-drought-reveal-true-picture
25. Pope III, C. A., Coleman, N., Pond, Z. A., & Burnett, R. T. (2020). Fine particulate air pollution and human mortality: 25+ years of cohort studies. *Environmental research*, *183*, 108924.
26. Pope III, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: lines that connect. *Journal of the air & waste management association, 56*(6), 709-742.
27. Pruss-Ustun, A., Corvalán, C. F., & World Health Organization. (2006). *Preventing disease through healthy environments: towards an estimate of the environmental burden of disease*. World Health Organization.
28. Rhee, J., Dominici, F., Zanobetti, A., Schwartz, J., Wang, Y., Di, Q., ... & Christiani, D. C. (2019). Impact of long-term exposures to ambient PM2. 5 and ozone on ARDS risk for older adults in the United States. *Chest*, *156*(1), 71-79.
29. Scholte, S. S., Daams, M., Farjon, H., Sijtsma, F. J., van Teeffelen, A. J., & Verburg, P. H. (2018). Mapping recreation as an ecosystem service: Considering scale, interregional differences and the influence of physical attributes. *Landscape and Urban Planning,* 175, 149-160.

30. Social Vulnerability INDEX (SVI). (2020, September 15). Retrieved March 24, 2021, from https://www.atsdr.cdc.gov/placeandhealth/svi/index.html
31. Southeast Conservation Adaptation Strategy. 2020. Recent Trends in Southeastern Ecosystems (2020): Measuring Progress toward the SECAS Goal. Retrieved from http://secassoutheast.org/pdf/SECAS-goal-report-2020.pdf
32. Stålhammar, S., & Pedersen, E. (2017). Recreational cultural ecosystem services: How do people describe the value?. *Ecosystem Services*, *26*, 1-9.
33. Sze, J., & London, J. K. (2008). Environmental justice at the crossroads. *Sociology Compass*, *2*(4), 1331-1354.
34. The White House. 2021. *President Biden Takes Executive Actions to Tackle the Climate Crisis at Home and Abroad, Create Jobs, and Restore Scientific Integrity Across Federal Government* [Fact Sheet]. Retrieved from https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/
35. U.S. Census Bureau (2019). *Selected Demographic Characteristics, 2015-2019 American Community Survey 5-year estimates.* Retrieved from https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/
36. USDA Economic Research Service (2021). *Percent of total population in Poverty, 2019.* Retrieved from https://data.ers.usda.gov/reports.aspx?ID=17826
37. U.S. EPA (2016). *Bird Watching Recreation Demand, EnviroAtlas National Data Fact Sheet.* Retrieved from https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/BirdWatchingRecreationDemand.pdf
38. U.S. EPA (2020). *Environmental Quality Index - Technical Report (2006-2010) (Final, 2020)*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/305.
39. U.S. EPA (2020). *National Pollutant Discharge Elimination System (NPDES), NPDES Permit Basics.* Retrieved from https://www.epa.gov/npdes/npdes-permit-basics
40. U.S. EPA (NA). *Impaired Waters and TMDLS, Overview of Identifying and Restoring Impaired Waters under Section 303(d) of the CWA.* Retrieved from https://www.epa.gov/tmdl/overview-identifying-and-restoring-impaired-waters-under-section-303d-cwa
41. Van Houtven, G., Powers, J., & Pattanayak, S. K. (2007). Valuing water quality improvements in the United States using meta-analysis: Is the glass half-full or half-empty for national policy analysis? *Resource and Energy Economics*, *29*(3), 206–228.
42. Warnell, K., 2020, Conservation Priorities for Open Space Recreation Access: U.S. Geological Survey ScienceBase, https://doi.org/10.21429/k9k5-fz91.