An Assessment of Social and Physical Vulnerability to Hydroclimate Extremes in Appalachia

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Abstract

Appalachia is a cultural region in the southern and central Appalachian Mountains that lags behind the nation in several social vulnerability indicators. Climate projections over this region indicate that precipitation variability will increase in both severity and frequency in future decades, suggesting that the occurrence of natural hazards related to hydroclimate extremes will also increase. The objective of this study was to investigate the spatiotemporal patterns of drought and precipitation and determine how trends overlap with vulnerable communities across Appalachia. The study utilized trend analysis through Mann-Kendall calculations and a Social Vulnerability Index, resulting in a bivariate map that displays areas most susceptible to adverse effects from hydroclimate extremes. Results show the southwestern portion of the region as most vulnerable to increased precipitation, and the central-southeast most vulnerable to an increase in drought-precipitation variability. This study is among the first to utilize the boundaries defined by the Appalachian Regional Commission from a climatological perspective, allowing findings to reach audiences outside the scientific community and bring more effective mitigation strategies that span from the local to federal levels.

1. Introduction

Appalachia is a geographic region in the Appalachian Mountains with distinct cultural and economic characteristics. Appalachia receives ample precipitation throughout the year, with some areas receiving enough to be considered a temperate rainforest (Reinhardt and Smith 2007). Dozens of major rivers originate in the forests of Appalachia, making the region an essential water source for millions east of the Mississippi River. Although the region is considered to be 'water-rich', climate projections suggest that precipitation and drought variability is likely to increase in both severity and frequency in future decades (Carter et al. 2018; Dupigny-Giroux et al. 2018). Drought can destroy crops, reduce water yields, and elevate wildfire risk (Caldwell et al. 2016; Dale et al. 2001; Mitchell et al. 2014), while heavy precipitation can lead to dangerous hazards such as flooding, landslides, debris flows, and contaminated drinking water (CCES; NSSL; Trenberth 2008; Wooten et al. 2016). The impacts from both hydroclimate extremes are more likely to disproportionately impact underprivileged populations (Cutter et al. 2003), yet there is little research exploring how hydroclimatic extremes impact vulnerable communities in Appalachia.

The purpose of this study was to identify vulnerable populations that are most likely to see increases in drought and extreme precipitation. The study utilized the longest available record (1895–2016) of the Palmer Drought Severity Index (PDSI), a commonly used index that compiles precipitation, surface air temperature, soil moisture, and evapotranspiration rates to measure drought severity. We employed Mann-Kendall calculations to examine trends of PDSI values and a Social Vulnerability Index to identify clusters of at-risk communities. A bivariate mapping technique combined social and physical vulnerabilities to display areas that are most susceptible to the adverse effects from hydroclimate extremes. The findings from this study contribute to the literature on drought in Appalachia and highlight the need for tailored programs that better address the needs of isolated and underrepresented

 ian Regional Commission (ARC), the authors

anticipate that this study will attract the attention of government officials who work closely with ARC and impact legislation that spans from the local to federal levels.

2. Background

Vulnerability to natural hazards is inherently geographical, where the degree of loss varies over different social groups, time and space (Cutter, Boruff, and Shirley 2003; Fuchs et al. 2018). There is substantial literature that shows the risk of impact by a natural disaster disproportionately affects disadvantaged populations (e.g., Cutter et al. 2003; Fuchs et al. 2018; Rufat et al. 2015). Indicators that most strongly correlate with heightened vulnerability generally relate to a person's ability to have access to resources and information (SAMHSA 2017). Appalachia has a history of marginalization and extreme poverty as a result of geographical isolation (Yarnell 1998). Although conditions have improved in recent years, the region's struggled past is still evident: Appalachia exceeds the national average in poverty, unemployment, elderly populations and disability rates, and lags behind in educational attainment and having access to internet and phone services (Pollard and Jacobsen 2020a). Rural Appalachia is also more disadvantaged when compared to other parts of rural America (Pollard and Jacobsen 2020b), indicating that these areas may be more susceptible to impacts from natural hazards than other parts of the country.

The most common natural hazards in Appalachia are typically related to precipitation, or lack thereof. Heavy precipitation may lead to the destruction of crops, flooding, landslides, debris flows, and contaminated drinking water (CCES; NSSL; Trenberth 2008; Wooten et al. 2016). The Appalachian landscape harbors particular features that exacerbate these risks, such as: 1) frequent rainfall, 2) steep mountainous slopes that produce rapid runoff, 3) close proximity to rivers and low-lying areas, and 4) densely populated urban areas that experience increased runoff along impervious surfaces (NSSL; Wooten et al. 2016). Inversely, drought can destroy crops, reduce water yields, and elevate wildfire risk (Caldwell et al. 2016; Dale et al. 2001; Mitchell et al. 2014). However, few studies have examined the impacts of drought in Appalachia, despite the fact that it occurs regularly and can have disastrous consequences. According to the NOAA Storm Events Database (1950–2019), drought and related events (i.e., dust devils and wildfires) were responsible for $869.7 million in crop damages across the region (NCEI 2018). Recent studies have also shown that water yields are already declining in the Appalachians by as much as 18% (Caldwell et al. 2016), and more frequent drought could pose significant challenges with water availability. Unprecedented wildfires in 2016 were a direct result of severe drought in the southern Appalachians, causing millions in property damage and leading to 14 fatalities and hundreds of injuries (Andersen 2018; Boddy 2017; NCEI 2018). While this study does not directly examine the effects of these hazards, trends of hydroclimate extremes provide insights on what risks the region's vulnerable populations are more likely to experience.

The authors selected the Appalachian Regional Commission's boundaries as the study area to fill a literature gap that exists among examining climate impacts across the region. ARC is a federal

 poverty in Appalachia was the highest in the

nation, in an effort to spur economic growth (ARC). Though there have been a number of studies that utilize ARC boundaries, most of these are grounded in the political/social sciences and only examine socioeconomic demographics (e.g., Bradshaw 1992; Isserman and Rephann 1995; Ulack and Raitz 1981). To our knowledge, there are no studies that combine environmental and socioeconomic variables for the entire region. Given that adverse outcomes from extreme weather are highly correlated with economic status, utilizing ARC boundaries in this study directly aligns with ARC's missions, and will encourage legislative responses that better serve underrepresented communities.

3. Methods

3.1 Study Area

The Appalachian Regional Commission defines Appalachia as spanning across 13 states and 420 counties from northern Mississippi to southern New York. There are five subregions that will be used throughout this paper: Southern, South-Central, Central, North-Central, and Northern (Fig. 1).

3.2 Data

The Palmer Drought Severity Index (PDSI) was used to measure physical vulnerability to hydroclimate extremes. PDSI compiles precipitation, surface air temperature, soil moisture, and evapotranspiration rates, and is most commonly used to assess long-term drought (Alley 1984; Dai et al. 2019). The dataset contained the longest available record of monthly values from January 1895 to December 2016. PDSI values range from − 10 to 10, with values $>$ 4 indicating a severe moist spell and $cript >$ -4 representing intense drought.

To measure social vulnerability, the following socioeconomic variables were compiled using American Community Survey (ACS) 2015–2019 Census percentages: poverty status by age (under 18, 18–64, over 65); nonwhite minorities; aging population (over 65); individuals with high school or less education; single-parent households; low English proficiency; no vehicle access; no health insurance; no internet access; and no phone service (U.S. Census Bureau). These variables were chosen based on Cutter's (2003) foundational Social Vulnerability Index (SoVI). Although Cutter's index is more complex with 45 variables, we selected specific indicators that were based on the unique demographic characteristics of Appalachia (Pollard and Jacobsen 2020a). Some indicators from Cutter's SoVI were excluded to eliminate redundancy; for instance, median income variables were not included since poverty status more efficiently portrays a household's level of poverty.

3.3 Statistical Analyses

Physical vulnerability was evaluated by calculating trends of PDSI values using the Mann-Kendall test (Hipel and McLeod 1994; Libiseller and Grimvall 2002). The Mann-Kendall calculates the *tau* value, which reveals the strength and direction ($+$ or $-$) of trends in each county. Negative *tau* values reveal trends of increased drought frequency and positive values indicate movement towards above-normal

 were deemed statistically significant. These tests

were conducted using the entire time period available (1895–2016) and also at 30-year intervals. Thirty-year intervals were chosen based on the established recommendations for Climate Normals by the World Meteorological Organization (WMO 1989). The objective was to examine long-term trends, as well as uncover patterns at shorter time scales.

A Social Vulnerability Index containing 15 variables based on Cutter's vulnerability indicators was constructed. These values were imported into IBM SPSS 27, then standardized and a Principal Component Analysis (PCA) was applied, resulting in a total of five components that met Kaiser's criterion (Kaiser 1960). The results from this process were totaled and mapped across the region using the standard deviation classification method to represent overall social vulnerability (Fig. 4). The five components were also examined individually to explore unique themes of each component (Fig. 5)

Hydroclimate trends and social vulnerability maps were combined using a bivariate mapping technique. This method used quantile classifications to reveal high, moderate, and low rankings of vulnerability (Table 5). The map displays the counties that are most susceptible to adverse effects of hydroclimate extremes (Fig. 6). The de-identified secondary data used for this analysis was publicly available and therefore, not reviewed by the Institutional Review Board (IRB) for human subject compliance.

4. Results

4.1 Physical Vulnerability

Long-term trends (Table 1, Fig. 2) revealed increased precipitation in the southwest, especially in Mississippi. Counties gradually grew drier moving east, with negative *tau* values peaking in the Carolinas. A total of 62.6% (263 of 420 counties) reported significant precipitation (positive) trends and 6.2% (*n*26) with significant drought (negative) trends, while the remaining 31.2% (*n*131) showed no significant movement in either direction. The strongest drought trends had a *tau* value of -0.08 (*p*value0.001) in Alexander and Davie counties in North Carolina, while the strongest precipitations trends had *tau*s that reached up to 0.19 in Tompkins and Schuyler counties in New York (*p*value0.001).

Trends at 30-year intervals (Table 2, Fig. 3) revealed patterns of alternating wet and dry periods. *Period A* (1895-1924) was a predominantly wet period, especially in the central and southern subregions, with 70.5% (*n*297) showing positive trends. Counties were drier in the north, though few of these (14 counties) were statistically significant. *Period B* (1925-1954) was notably drier, with negative *tau* values in 182 counties, though only 9.7% of these were statistically significant. We observed statistically significant positive trends in 22.5%, or 95 counties. Similarly, *Period C* (1955-1984) was an extremely wet period, with almost exclusively positive trends (e.g., less drought periods). Only 2 counties reported negative, but insignificant, *tau* values, while 85.2% of counties were statistically significant in the positive direction. *Period D* (1985-2016) follows with another dry period, though only 5 counties reported significant drought trends. The majority of the region displayed much weaker and insignificant *tau* values, with only 40.9% (or 172 counties) showing significantly positive trends.

4.2 Social Vulnerability

Our principal component analysis resulted in five components that explained a total of 72.5% of variance across social indicators. These components were totaled and mapped in ArcGIS Pro to visualize overall social vulnerability across the region (Fig. 4). This map did not reveal many obvious clusters of vulnerability, though Mississippi had the highest proportion of vulnerable counties than any other state (70.9%). The southern, south-central, and central subregions exceeded 30% when the three highest vulnerability classification were compiled (Extreme-High, High, Moderate-High) (Table 4). The northern and north-central subregions were deemed least vulnerable, as well as counties that surrounded metropolitan areas.

Component 1 contained 26.7% of explained variance, where most prominent variables included Disability, No Internet, Education Attainment, Poverty Status, and Unemployment (Table 3, Fig. 5). These were also variables which primarily affected rural Appalachia according to past demographic studies (e.g., Pollard and Jacobsen 2020b), demonstrating that this component most efficiently displayed vulnerability associated with rurality. There were two clusters with high vulnerability: 1) extremely high values in Kentucky, and parts of Virginia and West Virginia; and 2) the southernmost counties in Mississippi and western Alabama. The northern subregion and counties surrounding metropolitan areas showed low vulnerability. *Component 2* contained 12.4% of total explained variance, and most prominent social indicators were No Health Insurance and Low English Proficiency. While this component contained few counties in the highest vulnerability ranking, there were large clusters with high and moderately-high levels in the southern and south-central subregions. The remaining subregions had rather low vulnerability. *Component 3* reported 10.9% of explained variance, and contained the highest variance for Female Population, Single-Parent Households, and moderate variance for Nonwhite Minorities. There were two small clusters of elevated vulnerability in Mississippi/Alabama and in the Carolinas. Where New York and Pennsylvania had previously been presented as least vulnerable, this subregion notably shifted to having higher vulnerability. Metropolitan areas also exhibited higher rates of vulnerability. *Component 4* contained 10.2% of total explained variance, and served primarily as an indicator for Elder Populations. Most of Virginia was deemed moderately vulnerable, and there was also a small cluster of vulnerable counties along the North Carolina/Georgia border. Metropolitan areas, eastern Kentucky, and a small handful of counties in New York and Pennsylvania were least vulnerable. *Component 5* contained 9.373% of total explained variance, and highlighted variables for lacking access to phone services and vehicles. This component displayed clusters of elevated vulnerability in the central, north-central, and northern subregions, while the southern and south-central subregions were least vulnerable.

4.3 Bivariate Mapping

The bivariate map (Fig. 6) displayed counties that are most vulnerable to both hydroclimate extremes and socioeconomic factors. The map identified the central-southwestern portion of the study area as most

sippi, Alabama, Tennessee, and western

Kentucky. A handful of counties in northern Pennsylvania and New York also showed high increases in precipitation, but generally low social vulnerability. The central-eastern portion of the region (i.e., Ohio, West Virginia, Virginia, and North Carolina) had high socioeconomic vulnerability and low PDSI values, indicating that this area is most susceptible to increases in drought or drought-precipitation variability.

5. Discussion

Rural communities across Appalachia are increasingly vulnerable to changes in extreme weather. The aim of our study was to identify areas with both high social vulnerability and high physical vulnerability to increases in drought frequency or severe precipitation. To our knowledge, this is among the first studies to characterize both social and physical vulnerabilities to hydroclimate extremes across the Appalachian region. Results revealed that the southwestern portion of the study area (i.e., Mississippi, Alabama, Tennessee, and western Kentucky) was most vulnerable to increased precipitation, while the central-eastern portion (i.e., Ohio, West Virginia, Virginia, and North Carolina) was most susceptible to increased drought-precipitation variability. Both areas exhibited high socioeconomic vulnerability which will likely exacerbate the impacts from natural hazards related to both hydroclimate extremes. Our social vulnerability index revealed that the southern, south-central, and central subregions contained the highest rates of vulnerability, with *Components 1* (rural indicators), *4* (elder population), and *5* (access to phone services and vehicles) playing a strong role in highlighting the vulnerabilities of rural populations. Counties with the highest vulnerability classifications were consistently identified as rural based on the Urban Influence Codes (ERS 2013). This pattern corresponds with past literature that has shown rural areas are typically more vulnerable than their urban counterparts (e.g., Cutter, Boruff, and Shirley 2003). Findings highlight the need to improve outreach efforts directed to rural communities. Developing education programs that emphasize preparation and mitigation designed to reach even the most isolated populations would greatly increase resiliency in these areas.

Notably, positive and negative trends for the entire 121-year period were rather weak, where *tau* values on either spectrum did not exceed ± 0.2. This indicates that trends in either direction are slow-moving, and that a fair amount of climate variability still persists in these areas. In general, we observed a lack of significant trends in neutral or negative directions, which may indicate increased variability of both hydroclimate extremes are expected to continue.

Calculating trends in 30-year intervals revealed an interesting pattern of alternating wet and dry periods. However, the strength of these trends were still rather weak, with a maximum *tau* value 0.303 in *Period A*. This suggests that Appalachia still exhibits high hydroclimate variability, even at shorter temporal scales. Drought trends in all four periods also reported much lower rates of statistical significance when compared with wetter precipitation trends. Counties showing drying trends contained less than 10% of statistical significance in each segment, while the rates of significant precipitation trends were consistently much higher, with a minimum rate of 22.5% in *Period B* and a maximum of 85.2% in *Period C*. This may be an indication of how drought functions across the region: drought events are inconsistent,

sence of drought. Wet periods may also be

increasing in severity, where trends of increased precipitation jump from 70.5% in *Period A* to 85.2% in *Period C.*

El Niño patterns may also be responsible for these wet/dry cycles. El Niño oscillations dictate precipitation patterns in the U.S. and are largely responsible for extreme weather events (Meehl et al. 2007). For instance, the 1982–1983 El Niño was the strongest of the century, and produced extremely heavy rain and flooding across the eastern U.S. (Quiroz 1983; Williams 2015). It is likely that this played a key role in explaining why we saw such strong positive trends during *Period C.*

Results from this study support the findings from climate projections across the region. In the southeast, precipitation is projected to increase, as well as the frequency of extreme events receiving at least 3 inches (Dow et al. 2018). The same is true in the northeast, which is expected to receive increased rainfall during the winter months (Lemcke-Stampone et al. 2018). Projections also indicate increased snowfall for counties surrounding the Great Lakes as a result of the lake effect snow (Hayhoe et al. 2007). Drought is also expected to increase, and severity may be exacerbated by higher temperatures and evapotranspiration rates, leading to rapid development of droughts or flash droughts (Otkin et al. 2018).

5.1 Limitations & Implications

There were some limitations with this study. Precipitation data from weather stations was omitted due to its complexity and inconsistent records across the region. Future studies could create a clearer climatological picture by incorporating these records across the region. Additionally, examining social vulnerability at the county level over-simplifies the complex distribution of vulnerable communities. For instance, a county that may have overall low vulnerability may have vulnerable populations that are clustered within specific census-tracts. A more effective study should examine these facets at a finer scale (Simpson and Human 2008). Moreover, drought is a difficult phenomenon to adequately quantify using a single drought index such as PDSI. Future studies should consider using composite indicators of multiple drought indices to more fully evaluate dryness across the hydrological cycle. Nevertheless, a major takeaway for this study is that, while Appalachia's weather still exhibits high variability, precipitation occurs at a more consistent level than drought. Current trends may point to a future of increased precipitation and extreme events in the southwest portion of the study area, while areas with weaker trends may indicate higher drought-precipitation variability.

Despite these limitations, this study also provides several valuable contributions. The study adds to the literature focusing on drought variability in precipitation-abundant ecosystems like Appalachia. Drought is highly complex and difficult to assess, but it is crucial to understand how it functions in such climates. Acknowledging how drought uniquely impacts Appalachia will help water managers better prepare for future challenges surrounding water quality and distribution. Moreover, this study is among the first to examine the intersection of physical and social vulnerabilities to hydroclimate extremes across the Appalachian region. By visualizing vulnerability across ARC boundaries, our study has the potential to

attract the attention from a wide range of audiences to identify and target areas that may be most severely impacted by extreme weather events.

6. Conclusion

Our study offers a unique perspective examining the intersection of physical and social vulnerabilities to hydroclimate extremes across the Appalachian region. This study is among the first to consider Appalachia as defined by the ARC from a climatological perspective. As a federal economic partnership, the Commission's mission is to tailor policies that address Applachian-specific issues and work towards building more resilient communities. By utilizing these boundaries, our study provides a comprehensive examination on how climate hazards affect Appalachian populations, which is directly relevant to ARC's missions. We anticipate our findings will attract the attention of government officials who work closely with ARC and impact legislation that spans from the local to federal levels. The results from this study highlight the need to address rural needs by developing stronger outreach and education programs that will assist residents in isolated areas to prepare for the effects of hydroclimate extremes.

Declarations

CONFLICT OF INTEREST: None

FUNDING: None

HUMAN SUBJECT: The de-identified secondary data used for this analysis was publicly available and therefore, not reviewed by the Institutional Review Board (IRB) for human subject compliance. All authors have undergone Research, Ethics and Compliance Training. This statement is also found within the manuscript.

References

1. Alley WM (1984) The Palmer Drought Severity Index: Limitations and Assumptions. Journal of Applied Meteorology and Climatology 23(7):1100–1109. https://doi.org/10.1175/1520-0450(1984)023<1100:TPDSIL>2.0.CO;2
2. Andersen LM (2018) A Vulnerability Assessment of Extreme Drought and Unprecedented Wildfire in the Southern Appalachian Mountains. Appalachian State University
3. Appalachian Regional Commission (ARC) About the Appalachian Region. https://www.arc.gov/about-the-appalachian-region/ (last accessed 6 April 2021)
4. Boddy J (2017) As record Appalachian wildfires fizzle out, scientists look to learn from the destruction. https://www.sciencemag.org/news/2016/12/record-appalachian-wildfires-fizzle-out-scientists-look-learn-destruction (last accessed 6 April 2021)
5. Bradshaw M (1992) The Appalachian Regional Commission: Twenty-Five Years of Government

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6. Caldwell PV, Brantley ST, Elliott KJ, Laseter SG, Miniat CF, Swank WT (2016) Declining water yield from forested mountain watersheds in response to climate change and forest mesophication. Glob Change Biol 22(9):2997–3012. https://doi.org/10.1111/gcb.13309
7. Center for Climate and Energy Solutions (CCES) Extreme Precipitation and Climate Change. https://www.c2es.org/content/extreme-precipitation-and-climate-change/(last accessed 6 April 2021)
8. Cutter SL, Boruff BJ, Shirley WL (2003) Social Vulnerability to Environmental Hazards. Soc Sci Q 84(2):242–261. https://doi.org/10.1111/1540-6237.8402002
9. Dai A and National Center for Atmospheric Research Staff (Eds). Last modified 12 Dec 2019. The Climate Data Guide: Palmer Drought Severity Index (PDSI). Retrieved from https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi
10. Dale VH, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Joyce LA, Lugo CJ, McNulty S, Neilson RP, Peterson CJ, Simberloff D, Swanson FJ, Stocks BJ, Wotton M (2001) Climate Change and Forest Disturbances: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms. or landslides BioScience 51(9):723–734. https://doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2
11. Carter L, Dow K, Hiers K, Kunkel A, Lascurain D, Marcy M, Osland P, Schramm (2018) Fourth national Climate assessment. Chapter 19. In: Fourth National Climate Assessment. U.S. Government Publishing Office, Washington, DC
12. Economic Research Service (ERS) (2013) Urban Influence Codes. https://www.ers.usda.gov/data-products/urban-influence-codes/documentation.aspx
13. Elliott KJ, Miniat CF, Pederson N, Laseter SH (2015) Forest tree growth response to hydroclimate variability in the southern Appalachians. Glob Change Biol 21(12):4627–4641. https://doi.org/10.1111/gcb.13045
14. Fuchs S, Thaler T (2018) Vulnerability and resilience to natural hazards. Cambridge University Press
15. Gaffin DM, Hotz DG (2000) A precipitation and flood climatology with synoptic features of heavy rainfall across the Southern Appalachian Mountains. National Weather Service Weather Forecast Office, Morristown, TN. Digest, NOAA, Morristown, Tennessee. https://www.weather.gov/mrx/heavyrainclimo
16. Hayhoe K, Wake CP, Huntington TG, Luo L, Schwartz MD, Sheffield D, Wood E, Anderson B, Bradbury J, DeGaetano A, Troy TJ, Wolfe D (2007) Past and future changes in climate and hydrological indicators in the US Northeast. Clim Dyn 28:381–407. https://doi.org/10.1007/s00382-006-0187-8
17. Hipel KW, McLeod AI (1994) Time Series Modelling of Water Resources and Environmental Systems. Elsevier Science, New York
18. Isserman A, Rephann T (1995) The Economic Effects of the Appalachian Regional Commission: An Empirical Assessment of 26 Years of Regional Development Planning. Journal of the American [illegible]1944369508975647

19. Kaiser HF (1960) The application of electronic computers to factor analysis. Educ Psychol Measur 20:141–151. https://doi.org/10.1177/001316446002000116
20. Dupigny-Giroux LL, Caldwell C, Hodgkins GA, Hollinger DY, Lane E, Lemcke-Stampone MD, Lentz ED, MacDonald AB, Miller R, Mills KE, Sheffield PE, Solecki WD, Wellenius GA (2018) Fourth national Climate assessment. Chapter 19. In Fourth National Climate Assessment. Washington, DC: U.S. Government Publishing Office. Retrieved from https://nca2018.globalchange.gov/chapter/18/ (last accessed 6 April 2021)
21. Libiseller C, Grimval A (2002) Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. Environmetrics 13:71–84. http://dx.doi.org/10.1002/env.507
22. Meehl GA, Tebaldi C, Teng H, Peterson TC (2007) Current and future U.S. weather extremes and El Niño. Geophys Res Lett 34(20) https://doi.org/10.1029/2007GL031027
23. Mitchell RJ, Elliott KJ, Hiers JK, Liu Y, Miniat CF, O'Brien JJ, Starr G (2014) Future climate and fire interactions in the southeastern region of the United States. For Ecol Manage 327:316–326. http://dx.doi.org/10.1016/j.foreco.2013.12.003
24. Monthly PDSI data, 1895–2016. North Carolina Institute for Climate Studies, NOAA's National Centers for Environmental Information. Last accessed 6 April 2021
25. National Centers for Environmental Information (NCEI) (2018) Storm Data. 60(11). https://www.ncei.noaa.gov/pub/orders/IPS/IPS-EF895D3A-194C-47D9-BD20-148C298649E2.pdf
26. NOAA National Centers for Environmental Information (NCEI). n.d. Definition of Drought. https://www.ncdc.noaa.gov/monitoring-references/dyk/drought-definition (last accessed 6 April 2021)
27. Otkin JA, Anderson MC, Basara JB, Ford TW, Hain C, Svoboda M (2018) Flash droughts: a review and assessment of the challenges imposed by rapid-onset droughts in the United States. Bull Am Meteor Soc 99(5):911–919. https://doi.org/10.1175/BAMS-D-17-0149.1
28. Pollard K, Jacobsen LA (2020a) The Appalachian Region: A Data Overview from the 2014–2018 American Community Survey. Population Reference Bureau. Retrieved from https://www.arc.gov/report/the-appalachian-region-a-data-overview-from-the-2014-2018-american-community-survey/ (last accessed 6 April 2021)
29. Pollard K, Jacobsen LA (2020b) New Report Explores Appalachia's Current Strengths and Vulnerabilities. Population Reference Bureau. https://www.prb.org/appalachias-current-strengths-and-vulnerabilities/ (last accessed 10 March 2021)
30. Quiroz RS (1983) The Climate of the "El Niño" Winter of 1982-83 - A Season of Extraordinary Climatic Anomalies. Monthly Weather Review 111(8):1685–1706. doi:10.1175/1520-0493(1983)111<1685:TCOTNW>2.0.CO;2
31. Reinhardt K, Smith WK (2007) Leaf Gas Exchange of Understory Spruce–fir Saplings in Relict Cloud Forests, Southern Appalachian Mountains, USA. Tree Physiol 28:113–122. https://doi.org/10.1093/treephys/28.1.113

32. Rufat S, Burton CG, Maroof AS, Tate E (2015) Social vulnerability to floods: Review of case studies and implications for measurement. International Journal of Disaster Risk Reduction 14(4):470–486. https://doi.org/10.1016/j.ijdrr.2015.09.013
33. Simpson DM, Human RJ (2008) Large-scale vulnerability assessments for natural hazards. Nat Hazards 47:143–155. doi:10.1007/s11069-007-9202-6
34. Smith AB (2020) 2010–2019: A landmark decade of U.S. billion-dollar weather and climate disasters. Retrieved from https://www.climate.gov/news-features/blogs/beyond-data/2010-2019-landmark-decade-us-billion-dollar-weather-and-climate (last accessed 6 April 2021)
35. Substance Abuse and Mental Health Services Administration (SAMHSA) (2017) Disaster Technical Assistance Center Supplemental Research Bulletin Greater Impact: How Disasters Affect People of Low Socioeconomic Status. Retrieved from https://www.samhsa.gov/sites/default/files/dtac/srb-low-ses_2.pdf (last accessed 6 April 2021)
36. The National Severe Storms Laboratory (NSSL). n.d. Severe Weather 101- Floods. https://www.nssl.noaa.gov/education/svrwx101/floods/ (last accessed 10 March 2021)
37. Trenberth KE (2008) The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts. Encyclopedia of Hydrological Sciences.https://doi.org/10.1002/0470848944.hsa211.
38. Ulack R, Raitz K (1981) Appalachia: A Comparison of the Cognitive and Appalachian Regional Commission Regions. Southeastern Geographer 21(1):40–53. https://doi.org/10.1177/0013916582146005
39. U.S. Census Bureau; American Community Survey (2019) American Community Survey 5-Year Estimates, generated by Leah Hart Handwerger; using Social Explorer; https://www.socialexplorer.com/explore-tables
40. Williams J (2015) How the super El Nino of 1982-83 kept itself a secret. Washington Post. https://www.washingtonpost.com/news/capital-weather-gang/wp/2015/06/12/how-the-super-el-nino-of-1982-83-kept-itself-a-secret/ (last accessed 6 April 2021)
41. World Meteorological Organization (WMO) (1989) Calculation of Monthly and Annual 30-Year Standard Normals. WCDP-No. 10, WMO-TD/No. 341. World Meteorological Organization
42. Wooten RM, Aldred JL, Hales TC, Miniat CF, Witt AC (2016) Frequency and Magnitude of Selected Historical Landslide Events in the Southern Appalachian Highlands of North Carolina and Virginia: Relationships to Rainfall, Geological and Ecohydrological Controls, and Effects. In: Greenberg CH, Collins BS (eds) Natural Disturbances and Historic Range of Variation. Managing Forest Ecosystems, vol 32. Springer, Cham. doi:10.1007/978-3-319-21527-3_9
43. Yarnell SL (1998) The southern Appalachians: A history of the landscape. United States Forest Service, Southern Research Center. Retrieved from https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs018.pdf (last accessed 6 April 2021)
44. Yoon KD (2012) Assessment of social vulnerability to natural disasters: a comparative study. Nat Hazards 63:823–843. https://doi.org/10.5194/nhess-17-2313-2017

Tables

Table 1. PDSI trends by subregion for 1895-2016

	1895-2016		
Subregion	**Increasing**	**Decreasing**	**Insignificant Trend**
Southern	69.3%	13.4%	17.3%
South-Central	44.8%	14.1%	41.1%
Central	89.1%	0.0%	10.9%
North-Central	39.7%	0.0%	60.3%
Northern	64.0%	0.0%	36.0%
Total	62.6%	6.2%	31.2%

Table 2. PDSI trends at 30-year intervals by subregion

	Period A: 1895-1924			Period B: 1925-1954		
Subregion	**Increasing**	**Decreasing**	**Insignificant Trend**	**Increasing**	**Decreasing**	**Insignificant Trend**
Southern	96.2%	0.0%	3.8%	55.2%	0.0%	44.2%
South-Central	56.5%	0.0%	43.5%	29.4%	0.0%	71.6%
Central	100.0%	0.0%	0.0%	0.0%	6.0%	94.0%
North-Central	87.3%	0.0%	12.7%	9.5%	44.5%	46.0%
Northern	15.1%	16.3%	68.6%	8.1%	9.3%	82.6%
Total	70.5%	3.3%	26.2%	22.5%	9.7%	67.8%
	Period C: 1955-1984			**Period D: 1985-2016**		
	Increasing	**Decreasing**	**Insignificant Trend**	**Increasing**	**Decreasing**	**Insignificant Trend**
Southern	96.2%	0.0%	3.8%	0.0%	4.8%	95.2%
South-Central	86.5%	0.0%	13.5%	31.8%	0.0%	68.2%
Central	48.8%	0.0%	51.2%	82.9%	0.0%	17.1%
North-Central	100.0%	0.0%	0.0%	47.6%	0.0%	52.4%
Northern	100.0%	0.0%	0.0%	55.8%	0.0%	44.2%
Total	85.2%	0.0%	14.8%	40.9%	1.2%	57.9%

Table 3. Social vulnerability components preserved by Principal Component Analysis

	Component				
Variable	**1**	**2**	**3**	**4**	**5**
% Female	-0.23	0.078	**0.73**	0.223	0.228
% Nonwhite Minorities	-0.05	0.309	**0.583**	-0.496	-0.303
% Disability	**0.777**	-0.278	-0.126	0.239	0.048
% Aging (65+)	0.011	-0.048	0.01	**0.869**	-0.112
Educational Attainment (High School or less)	**0.746**	0.063	-0.328	0.203	0.158
Unemployment Rate	**0.608**	-0.384	0.193	-0.185	0.111
Poverty Status (<18 years)	**0.832**	-0.034	0.224	-0.057	0.125
Poverty Status (18-64 years)	**0.773**	-0.245	0.082	-0.196	0.19
Poverty Status (65+ years)	**0.762**	0.033	0.034	-0.098	0.112
Single-Parent Households	0.365	-0.127	**0.713**	-0.133	-0.069
Low English Proficiency	-0.326	**0.623**	-0.053	-0.428	0.191
No Health Insurance	0.026	**0.907**	0.079	-0.017	-0.016
No Vehicle Access	0.308	-0.255	0.119	-0.153	**0.729**
No Internet	**0.776**	0.277	0.044	0.265	0.164
No Phone Services	0.246	0.315	-0.063	0.006	**0.738**
Total Variance Explained:	29.694%	12.417%	10.854%	10.2%	9.373%

Table 4. Social vulnerability classifications by subregion

	Classification						
Subregion	**Extreme-Low**	**Low**	**Moderate-Low**	**Moderate**	**Moderate-High**	**High**	**Extreme-High**
Southern	1.0%	3.8%	20.2%	36.5%	28.8%	8.7%	1.0%
South-Central	1.2%	1.2%	16.5%	47.0%	30.6%	2.3%	1.2%
Central	0.0%	2.4%	15.9%	46.3%	29.3%	4.9%	1.2%
North-Central	3.2%	11.1%	15.9%	47.6%	20.6%	1.6%	0.0%
Northern	2.3%	7.0%	33.7%	51.2%	4.6%	0.0%	1.2%
Total %	1.4%	4.8%	20.7%	45.2%	23.1%	3.8%	1.0%

Table 5. Combined physical and social vulnerability classifications by subregion

Classification	Total %	Subregion				
		Southern	South-Cental	Central	North-Central	Northern
Low Social-Low Physical	10.5%	5.8%	11.8%	1.2%	19.0%	17.4%
Moderate Social-Low Physical	11.4%	3.8%	18.8%	2.4%	22.2%	14.0%
High Social-Low Physical	11.9%	7.7%	24.7%	7.3%	17.5%	4.6%
Low Social-Moderate Physical	12.6%	14.4%	5.9%	12.2%	7.9%	20.9%
Moderate Social-Moderate Physical	12.6%	12.5%	12.9%	19.5%	15.9%	3.5%
High Social-Moderate Physical	11.0%	10.6%	7.1%	24.4%	9.5%	3.5%
Low Social-High Physical	10.2%	6.7%	3.5%	12.2%	6.3%	22.1%
Moderate Social-High Physical	9.3%	11.5%	9.4%	9.8%	0.0%	12.8%
High Social-High Physical	10.5%	26.9%	5.9%	11.0%	1.6%	1.2%

Figures

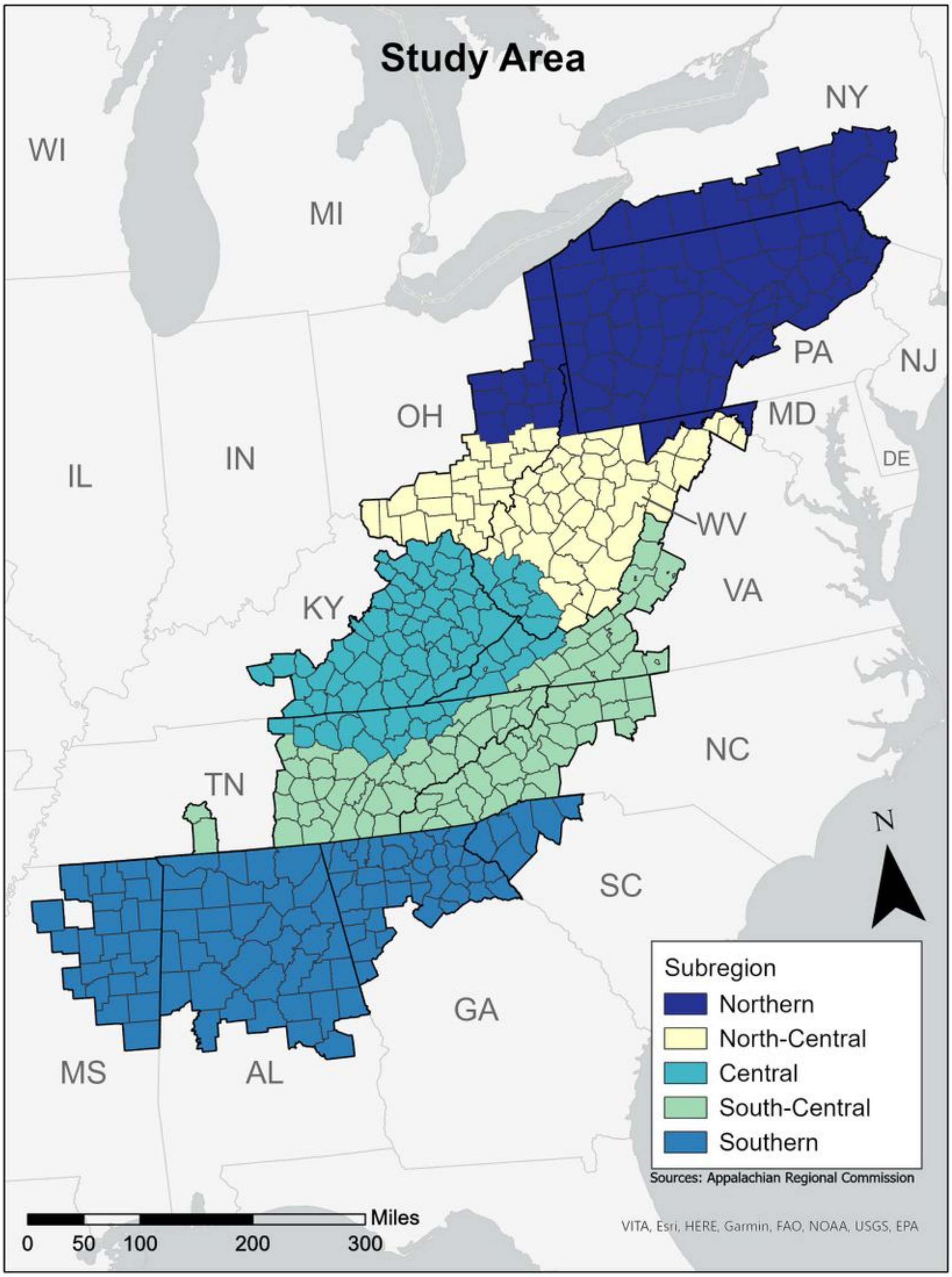

Figure 1

Study area as defined by the Appalachian Regional Commission with defined subregions. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This

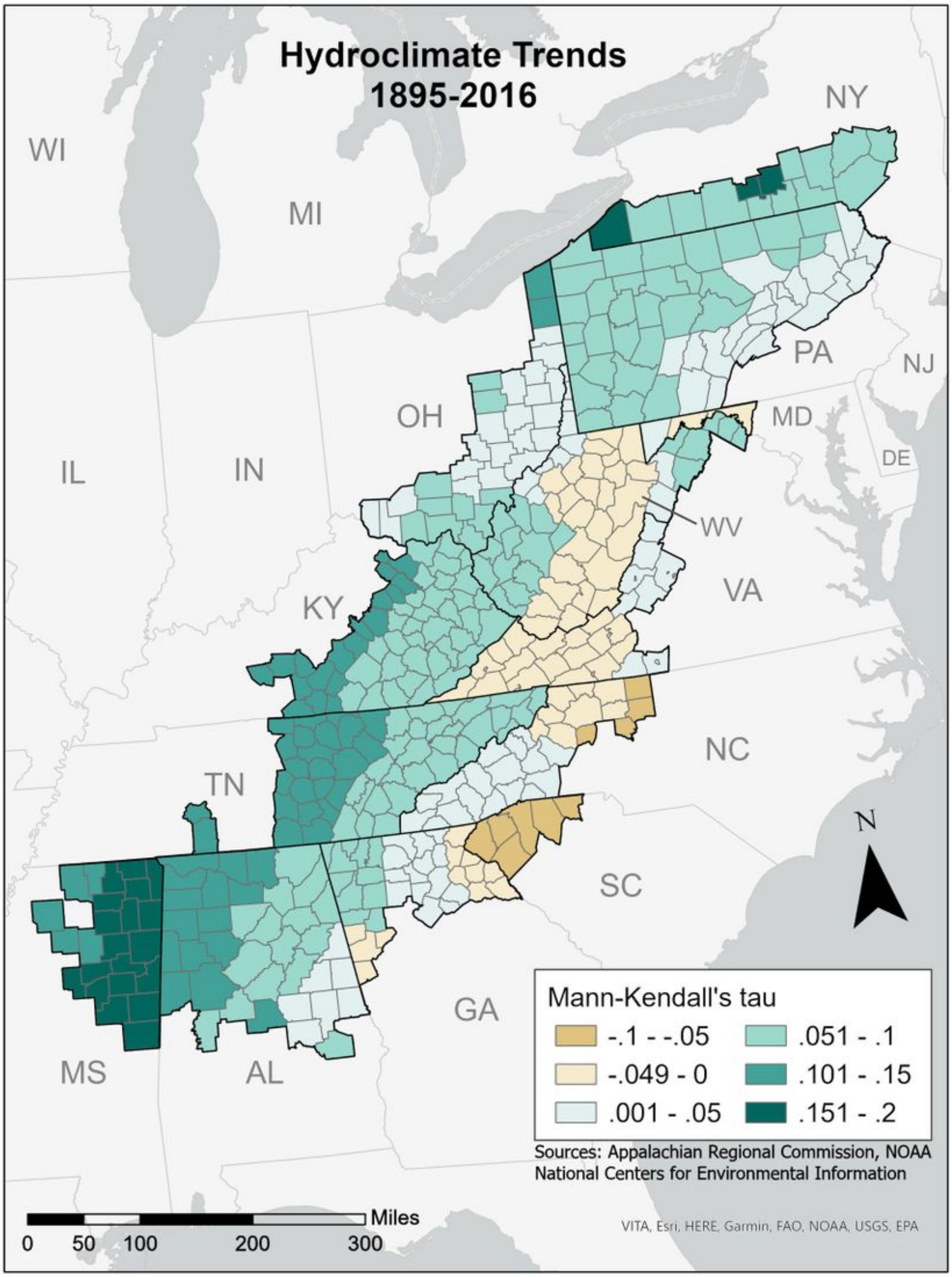

Figure 2

Mann-Kendall's tau values mapped using Palmer Drought Severity Index (PDSI) from 1895 to 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This

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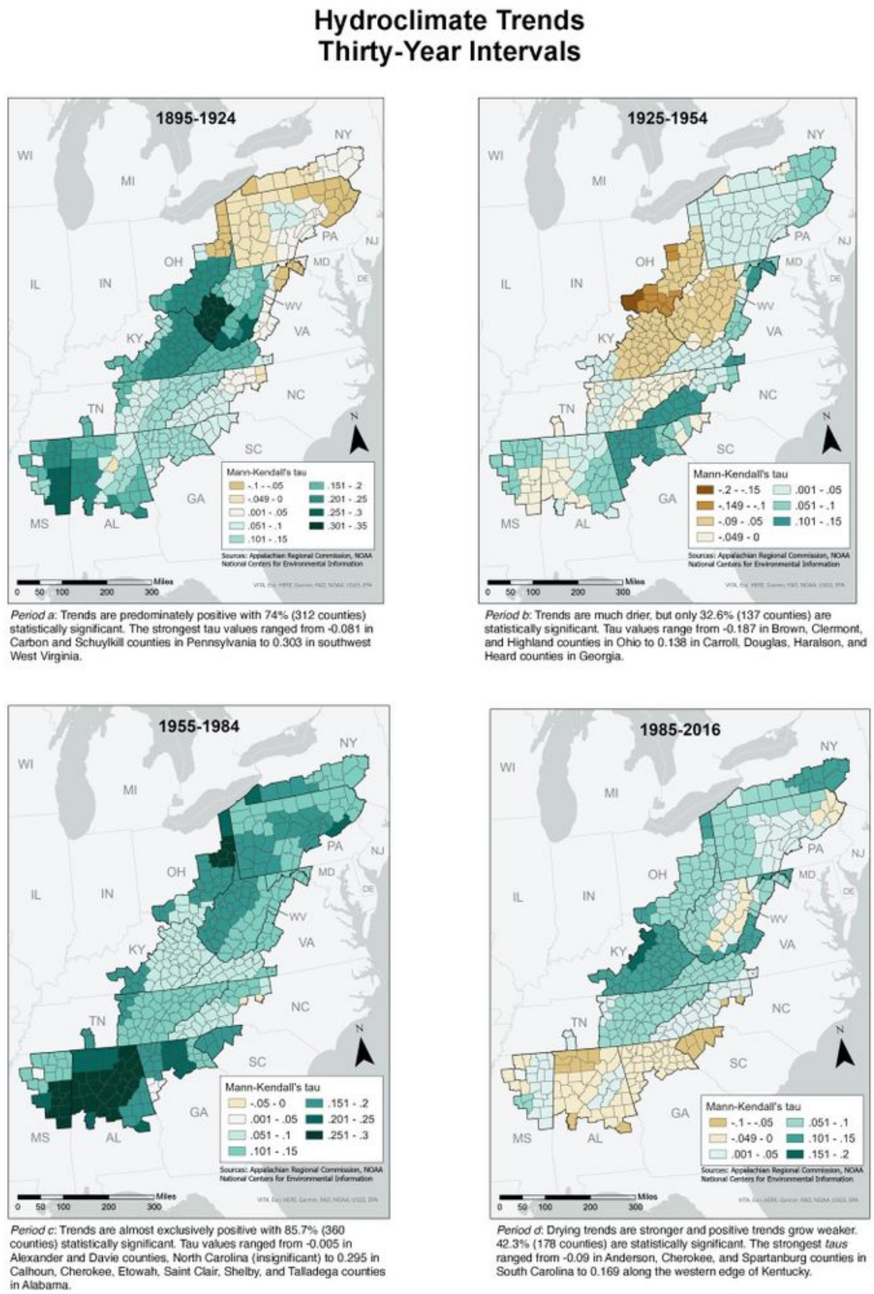

Figure 3

Mann-Kendall’s tau mapped using Palmer Drought Severity Index (PDSI) from 1895 to 2016 in 30-year intervals. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or

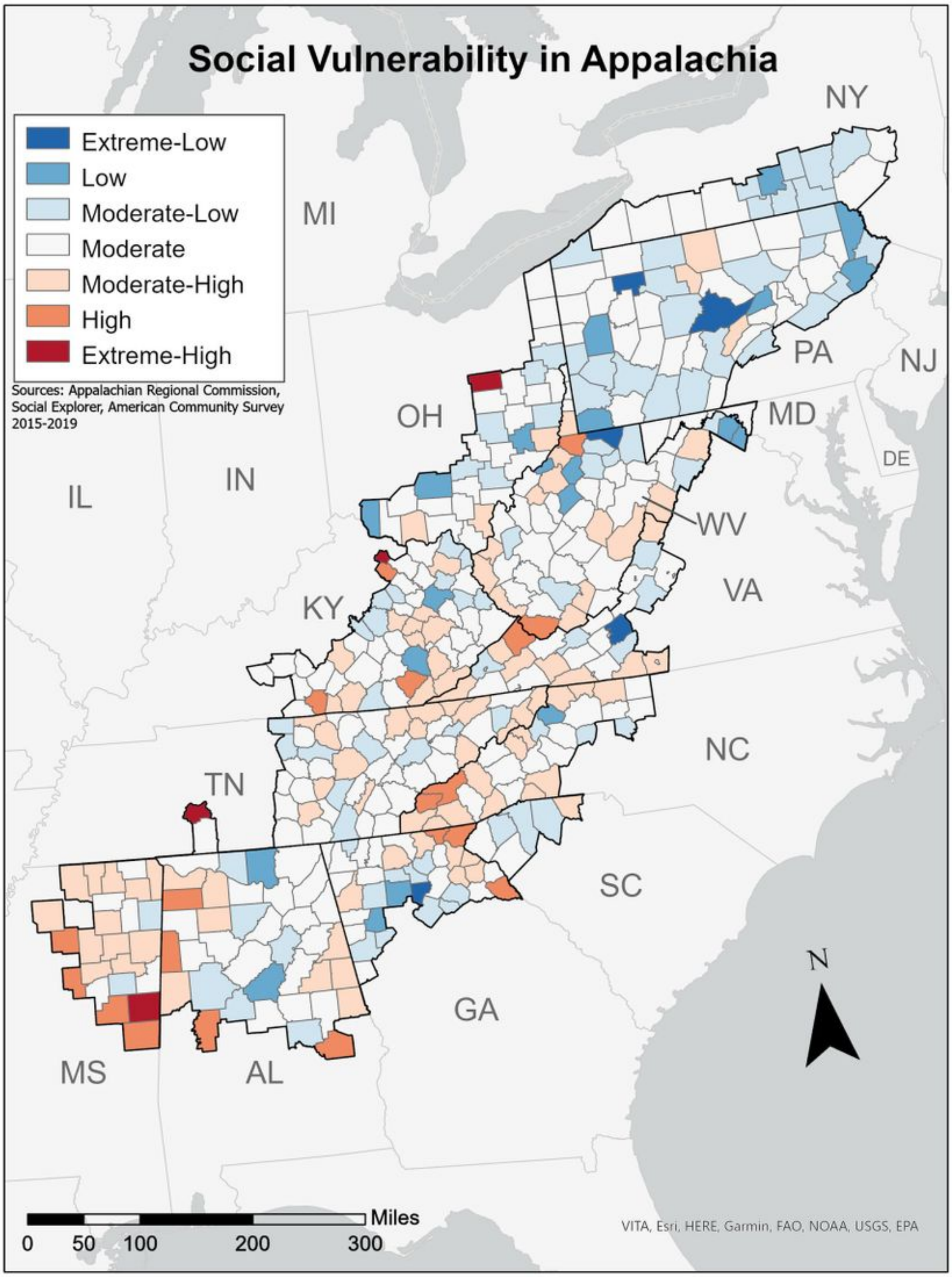

Figure 4

Social vulnerability determined by combined principal component. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by

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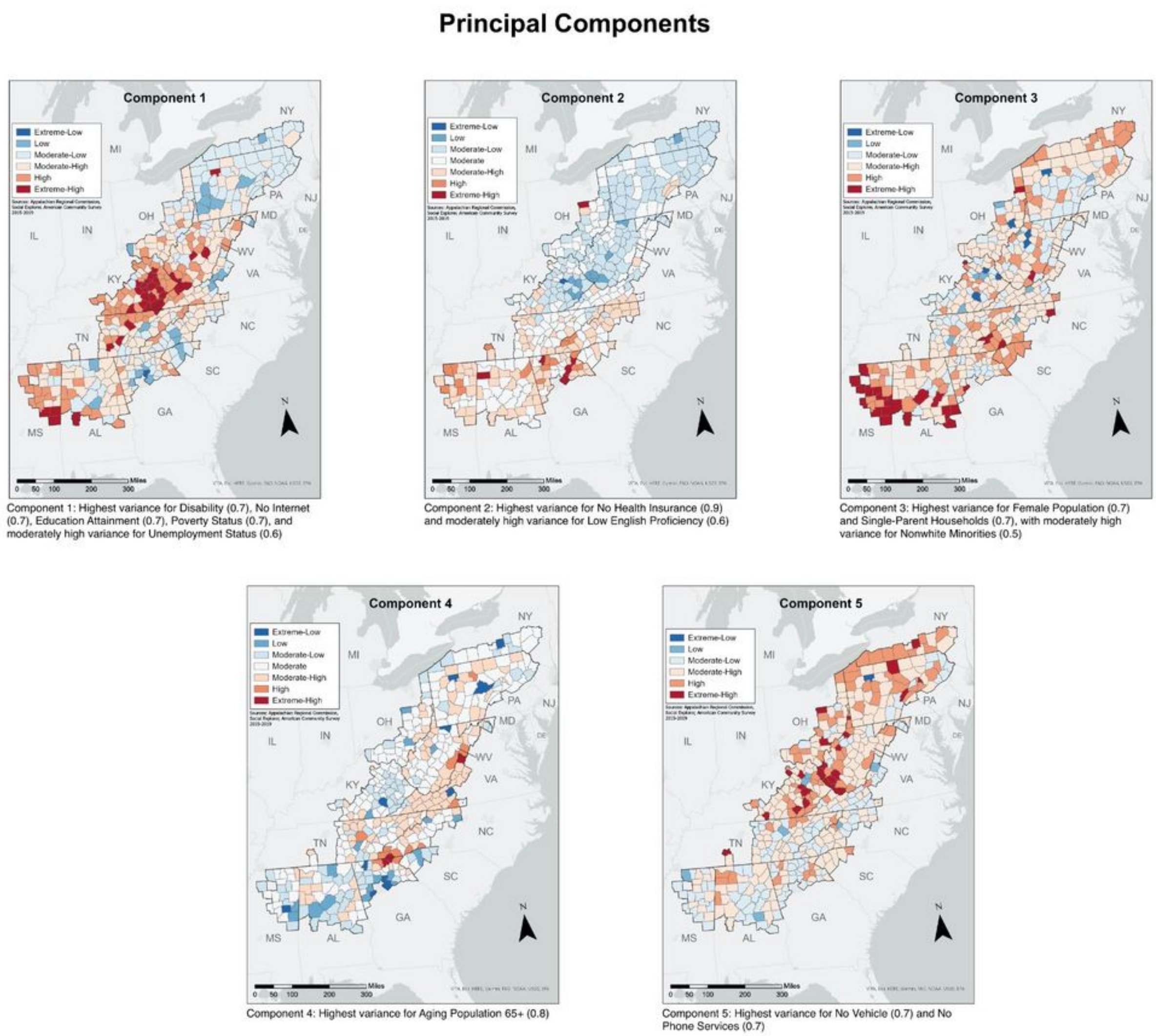

Figure 5

Social vulnerability represented by each principal component. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

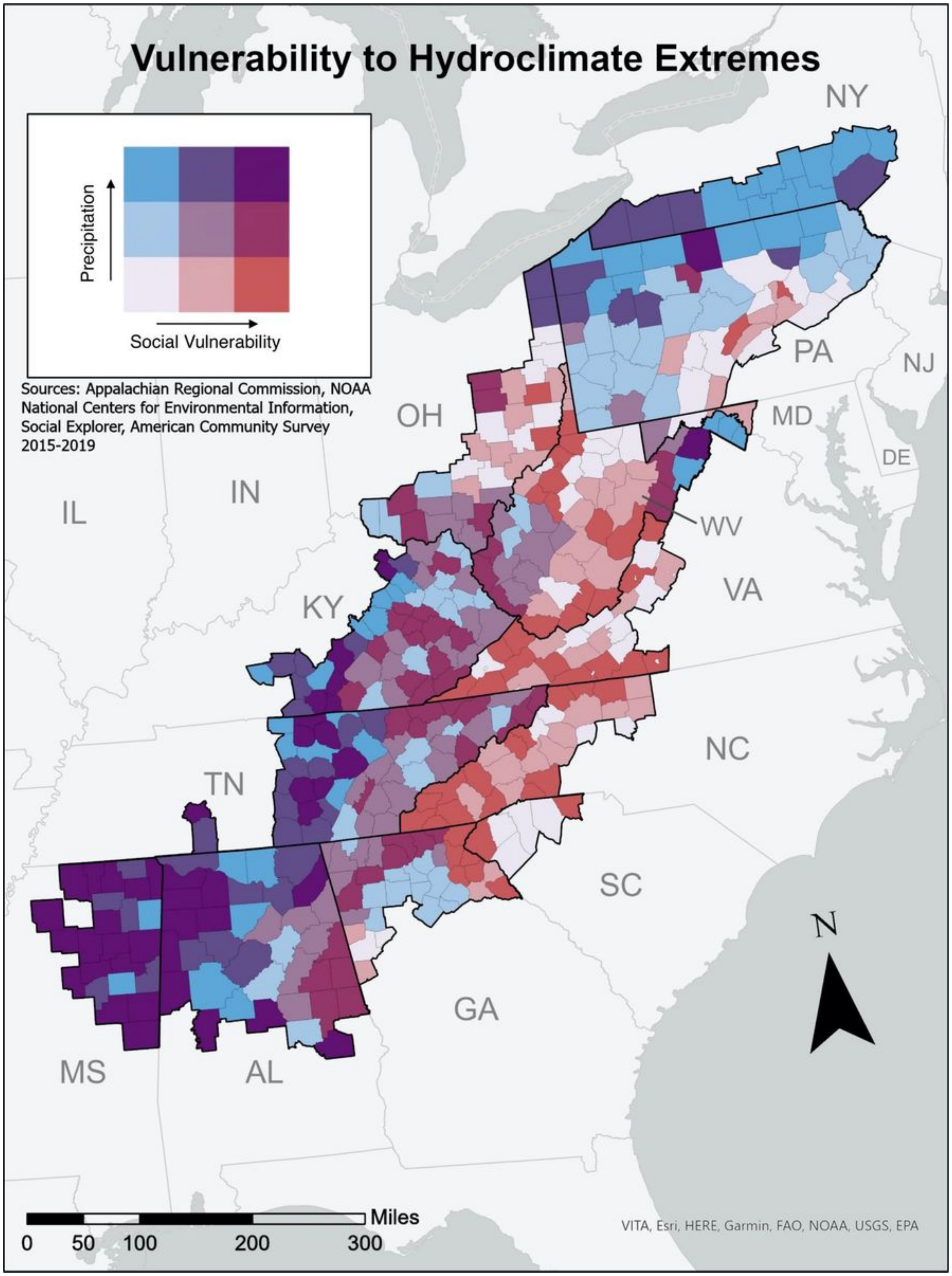

Figure 6

Bivariate map representing vulnerability to hydroclimate extremes in Appalachia. High tau values represent increased precipitation and low tau values represent increased drought. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or

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