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Climate Change and Water Resources Management: An Integrated Assessment of Temporal Change in Population and Extreme Precipitation

Abstract: This research project involves the study of three counties within the Metro Atlanta Region in Georgia, USA with respect to two critical changes over the last six decades: extreme precipitation and population. The time-dependent changes in the extreme-rainfall return period were examined over the past 60-year span using the generalized extreme value (GEV) distribution for two 30-year blocks (1950-1979 and 1980-2009) of annual maximum daily precipitation. We found that across the state of Georgia, there was 16%, 22% and 28% increase in 25-year, 50-year and 100-year rainfall amounts respectively for the recent time period. All three counties have gone through population growth over the last 60 years - for one county the population has doubled, and for the other two counties the population has increased increased at least 5 times. Our findings have proven that as the population of an area increases, and we build upon natural resources, the use and necessity of water resource management tools (including the development of storm water infrastructures) increases with the urbanization of that area.

Keywords: extreme-rainfall, return period, generalized extreme value distribution, population growth, urbanization.

1 Introduction

Climate variability and change has the potential to cause significant impacts on our economic, ecological, social, and cultural resources. In a changing climate, civil infrastructures (such as dams, bridges, and culverts) are increasingly compromised during extreme precipitation events. However, much of our nation's infrastructure was developed assuming a non-varying climate [1,2]. As a result, we now see floods and infrastructure failure due to miscalculated design estimates. The increasing frequency and intensity of heavy rain events directly affect the efficiency and integrity of the stormwater infrastructure. For example, culverts (which carry water under the road) are engineered by studying the local hydrology (movement of water) and using intensity-duration-frequency curves, which calculate the likelihood of heavy rainfall

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events of varying amounts and durations. This simply means that culverts can only accommodate a certain amount of water before they become incapacitated. When this happens, the road above floods, and in extreme cases the surrounding area can become unstable as soil around the culvert erodes over time. So if extreme rainfall events are becoming more frequent and more intense, culverts designed decades ago are becoming less efficient; and if growing populations are creating more road-stream crossings, some areas in the metro Atlanta area may be more vulnerable than others, depending on the changes in population and precipitation. In this paper we used a combined approach to view the relationship between change/increase in population and extreme precipitation risk in an effort to better define human-natural environment relationships vulnerable to increasing climate variability.

2 Data and Methodology

Our work involves the study of three counties within the Metro Atlanta Region; Fulton, DeKalb and Clayton, with respect to two critical changes over the last five decades: extreme precipitation and population. The 1950-2010 population for each county was compiled using census data. Total population per decade was estimated to identify pattern in population change. Daily precipitation data over the period of 1950–2009 from 21 stations across the state of Georgia was obtained from the Historical Climatology Network (HCN) database [3]. The dataset at each site was checked to make sure that they do not contain a large percentage of missing values, are short in length, e.g., just a few years, or, contain suspicious values in terms of quality.

Generalized Extreme Value (GEV) distribution [4] is usually used to statistically describe extreme rainfall events [5,6]. The GEV distribution is a flexible model that combines the Gumbel, Fréchet, and Weibull maximum extreme value distributions (three popular distributions used in the extreme value analysis). The GEV distribution has three parameters: location (μ), scale (σ) and shape (ξ). The cumulative distribution function of GEV is given by [5]:

$$F(x) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \tag{1}$$

We used GEV distribution to estimate the magnitude of extreme rainfall events using “fgev” routine in the “evd” library of the R statistical package as done by DeGaetano [6]. The routine uses the maximum likelihood (ML) method in fitting the data.

“Return period” (T) based on extreme events is commonly used to assess the service level (or the level of risk) of drainage systems by engineers and water resource managers (for example, settlements, urban areas, important infrastructure are designed for 50-100 years return-periods of rainfall or floods). Return period is an estimate of the likelihood of an event, such as a flood or a river discharge flow to occur. With the changing climate, the probability of exceeding the original design criteria based on return period also increases [7]. Hence, study of the impact of non-stationarity of the extreme precipitation events on the return-periods is crucial. For accessing the time-dependent changes in the return periods of the extreme-rainfall, the annual maximum series of the 30 extreme precipitation events from 1950-1979 and 1980-2009 were obtained separately. GEV distribution was fit to each series and the precipitation amounts corresponding to 10-, 25-, 50- and 100- years return period were estimated for all the 21 stations. The ratio of the rainfall amount (**r**) estimated based on the recent time period to the corresponding rainfall amount based on the old time period was evaluated to assess the temporal change in the rainfall risk:

$$r_i = (R_i)_{recent}/(R_i)_{old,}$$

where, i = rainfall return period years (10, 25, 50, 100), Ri is the rainfall amount corresponding to the i-year return period

Bootstrap method [8] was used to assess the statistical significance of the change or uncertainty.

3 Results

Population change results are presented in Fig. 1. We can see that all the three counties have gone through population increase per each decade. Over the last 60 years (between 1950 and 2010) the population of Fulton county has almost doubled, population of DeKalb county has increased by 5 times, and population of Clayton county has increased by 11 times.

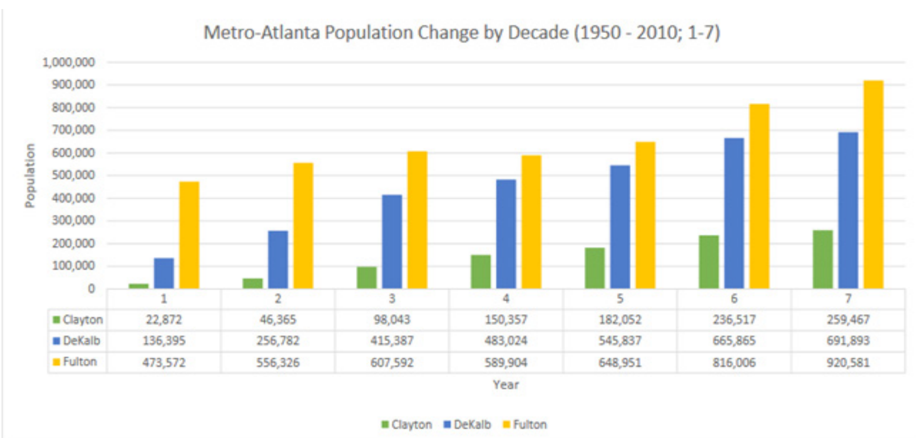

Figure 1: Population per decade for each of the counties from 1950-2010; 1950-1959 is represented by 1, 1960- 1969 by 2 and so on.

To assess the relationship of change in population with the change in precipitation risk, r_{10}, r_{25}, r_{50} and r_{100} are obtained and presented in Table 1, and Fig. 2 and 3.

Table 1: Statistical summary of temporal change in extreme rainfall risk in GA

	10-year	25-year	50-year	100-year
Maximum	1.06	1.96	2.22	2.54
Minimum	0.88	0.78	0.70	0.62
Average	1.11	1.16	1.22	1.28
75% Quartile	1.18	1.30	1.35	1.41
Median	1.14	1.11	1.11	1.08
25% Quartile	0.96	0.99	1.02	1.03

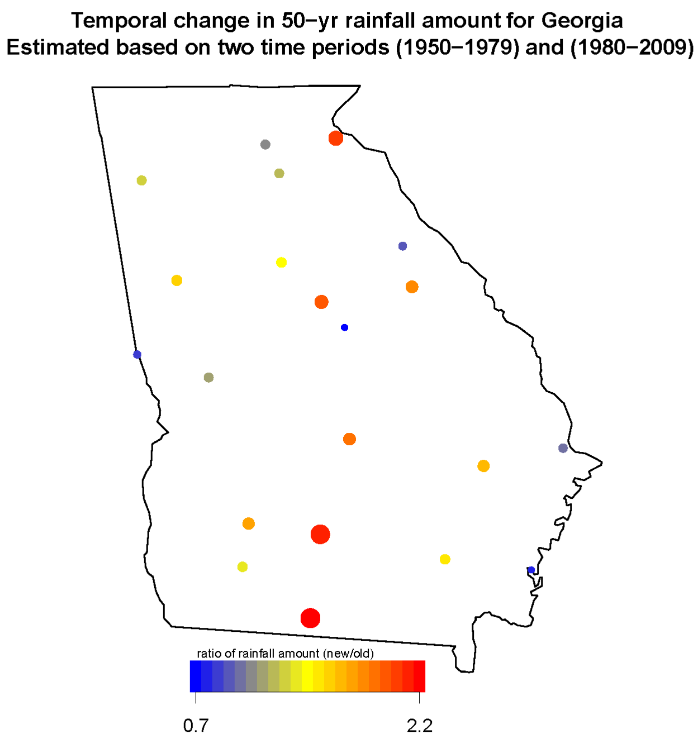

Figure 2: Ratio of 50-yr rainfall amount (new/old)

Statistical summary of the ratios (r) for 21 stations are listed in Table 1. The range of change across the stations is from 0. 6 to 2.5 times of the original value or the old value (Table 1). For 16 stations out of 21 (or for 76% of stations), an increase in both 50-yr and 100-yr rainfall amount was observed for the recent time period. For 8 stations, at least 25% increase in both 50-yr and 100-yr rainfall amount was observed for the recent time period. An increase of 50% or more was observed for 3 stations in the 50-yr and 4 stations in the100-yr rainfall amount. Although spatial pattern of the change is not discernible, however increase is more distinct in eastern and southern regions of the state (Fig. 2 and 3).

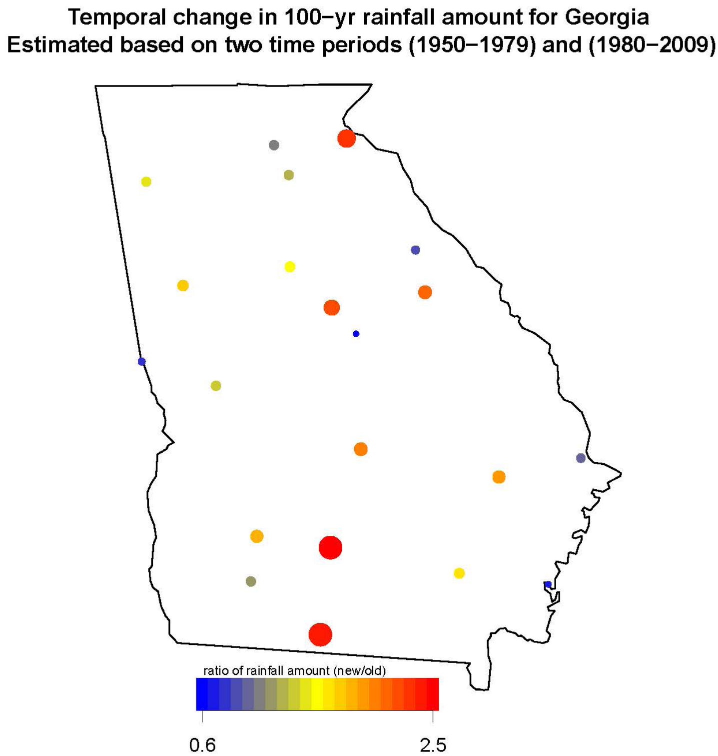

Figure 3: Ratio of 100-yr rainfall amount (new/old)

4 Discussion and Conclusions

This research project involves study of three counties within the Metro Atlanta Region in USA with respect to two critical changes over the last six decades: extreme precipitation and population. The time-dependent changes in the extreme-rainfall return period are examined over the past 60-year-span using the generalized extreme value (GEV) distribution for two 30 year blocks (1950-1979 and 1980-2009) of annual maximum daily precipitation. There has been in average 16%, 22% and 28% increase in 25-year, 50-year and 100-year rainfall amounts respectively for the recent time period. All three counties have gone through population growth over the last 60 years.

The purpose of this work was to illustrate the relationship between population change and the extreme precipitation risk. A large population easily suggests the presence of more roads, buildings, rooftops and other impervious land area. As sewage drains, pipes, culverts and bridges are implemented to manage storm water, the data used in the development and design of these structures must be based off of relevant and current rainfall data. Our findings of this work have proven that as the population of an area increases, and we build upon natural resources, the use and necessity of water resource management tools (including the development of storm water infrastructures) increases with the urbanization of that area. This information illustrates a key challenge for any community that wants to grow and develop while maintaining or improving their resilience to extreme rain events.

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