# Georgia Air Quality Analysis

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# Summary

The goal of this project is to evaluate the stability, variation, and long-term behavior of air quality in four Georgia cities: Atlanta, Macon, Athens, and Americus over a 15 year time period (March 2007-March 2022). We analyzed this using historical Air Quality Index data and focusing specifically on data points in which ozone was the primary pollutant. As AQI directly affects public health risks and ozone levels are directly dependent on certain human activity, understanding the consistency and irregularity of AQI values provides insight into environmental conditions and air quality affecting residents across sample urban and rural regions of Georgia.

We applied several statistical process control methods to detect shifts, instability, or unusual events in the air quality data. We used X-bar charts to examine the stability of the average monthly AQI over time and R charts to observe the stability of AQI level variability from month to month. P charts were used to determine the proportion of unhealthy air quality scores recorded, using AQI $\geq$ 101 as the threshold. Finally, we used EWMA charts to detect gradual shifts in average AQI in the long-term to analyze trends in air quality across all four cities.

The results show a clear distinction between urban and rural air quality patterns over the 15 year time period. Atlanta and Macon consistently showed higher AQI averages and ranges which indicates more intense and regular ozone-related pollution output caused by factors such as high population density, heavy traffic, and industrial activity. Both cities show high variability, but overall, we saw that their variability was mostly predictable. Athens and Americus show lower average AQI levels and lower ranges of variability but had out-of-control points that drew attention to isolated environmental conditions such as droughts or wildfires that affected the air quality statewide. Long-term trends show that all four cities experienced a gradual decline in AQI levels, indicating improvement in statewide air quality overtime. This improvement is likely attributed to Georgia's implementation of policies in accordance with the Clean Air Act in the early 2000s which proved to contribute to more stable and generally lower average AQI levels as a result. Overall, the analysis highlights meaningful differences in stability, variability, and long-term trends across several Georgia cities and shows effectiveness in using statistical monitoring tools to understand air quality and other environmental patterns.

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# Introduction

Air quality plays a vital role in the health, wellbeing, and overall quality of life in communities across the globe. As urban centers expand and industrial activity continues to increase, the quality of the air we breathe has become a central public health issue in modern day. The Air Quality Index (AQI) was developed to provide a scale and help communicate the pollution levels in the air in an accessible way that the average person can consume and understand. The Air Quality Index takes the complexities of atmospheric pollutants and condenses the information into a numerical scale which is further broken down into a digestible scale ranging from “good” to “hazardous.” This simple and easy to understand system helps the average civilian understand the potential health impacts of spending time outdoors in their area. Today, checking the AQI has become as regular as checking the weather.

Monitoring air quality is important because it directly affects an individual’s health and wellbeing, and it also affects the environment as a whole. In human health, poor air quality has been linked to several health issues such as higher risk for cancer, respiratory disease, and cardiovascular disease, as well as various neurological, reproductive, and immune system disorders. In contrast, good air quality supports healthier communities and contributes to a better quality of life. Encouraging regular air quality monitoring also helps maintain environmental responsibility and leads to communities and local governments pushing for cleaner and more sustainable communities.

# Motivation

For the purpose of this analysis, we have narrowed down our scope to look at four cities in Georgia: Atlanta, Macon, Athens, and Americus. By narrowing the focus down to these particular cities, we seek to determine if these cities exhibit recognizable trends in air quality levels and examine the stability or irregularity of each city’s air pollution. Air quality is directly affected by many factors such as human activity, industry, and environment, and since a city’s AQI ultimately reflects public health risk for that area, it’s essential to understand its stability and variation.

In this analysis, we specifically focus on data where ozone was the dominant pollutant because ozone remains one of the most persistent air quality challenges. Ground-level ozone is directly influenced by factors such as traffic emissions, industrial activity, temperatures, and sunlight. Because AQI reflects pollution severity, higher values indicate worse air quality, so upward excursions in the charts represent months with more hazardous ozone levels. Targeting our analysis to ozone levels specifically allows us to analyze how each city is affected by and manages exposure to one of Georgia’s most prominent pollutants.

# Data

The data used in this analysis was originally accessed through Kaggle, an online source for accessing datasets, but the data itself originates from two sources: the US Environmental Protection Agency's Air Quality System, which tracks daily air quality measurements across the United States, and the SimpleMaps US Cities Database, which stores the geographic information needed for this dataset. The resulting dataset includes the daily AQI measurements and the associated pollutant type combined with the related attributes of the associated cities.

For the purpose of this project, we cleaned and condensed the data in two key ways. We first filtered the data to focus specifically on the data points where ozone was defined as the main pollutant, allowing us to focus specifically on ozone-driven trends without aggregating different pollutant types into our analysis that may behave differently based on seasonal and environmental factors. Second, we retained only the numerical AQI values rather than the categorical labels like "good" and "hazardous" because the numerical values provide a more precise basis for calculating descriptive statistics and creating control charts.

We also filtered to focus on the data from the four Georgia cities of interest: Atlanta, Macon, Athens, and Americus. The daily AQI values were cleaned to remove incomplete entries and then aggregated to compute the weekly averages of their AQI values. We chose a structure of using weekly averages to ensure smoother trends for the purposes of interpretation.

After cleaning the data, we generated some descriptive statistics to give an overview of the data in each city. Atlanta, the most urbanized of the four cities, has the highest ozone-related AQI levels, with a mean of 75.51, as well as the highest variability with a standard deviation of 38.64, and weekly averages ranging from 14.00 up to 220.00. Macon has a mean AQI of 55.85 and greater variability with a standard deviation of 25.61, with weekly averages between 15.80 and 174.33. Athens shows a mean of 49.92 and a standard deviation of 19.67, with weekly values from 13.00 to 126.83. Americus has an average weekly AQI of approximately 44.52 with a standard deviation of 16.94, ranging from 14.71 to 136.86.

# Analysis

### *X-bar Charts*

We first constructed X-bar charts to evaluate the stability of ozone-related air quality over time. Because our cleaned dataset contains pre-aggregated weekly AQI means, we constructed monthly subgroups composed of four weekly averages each. This allowed us to apply X-bar charts with a consistent subgroup size of 4 and evaluate stability of monthly average AQI over a 15 year time period (March 2007-March 2022).

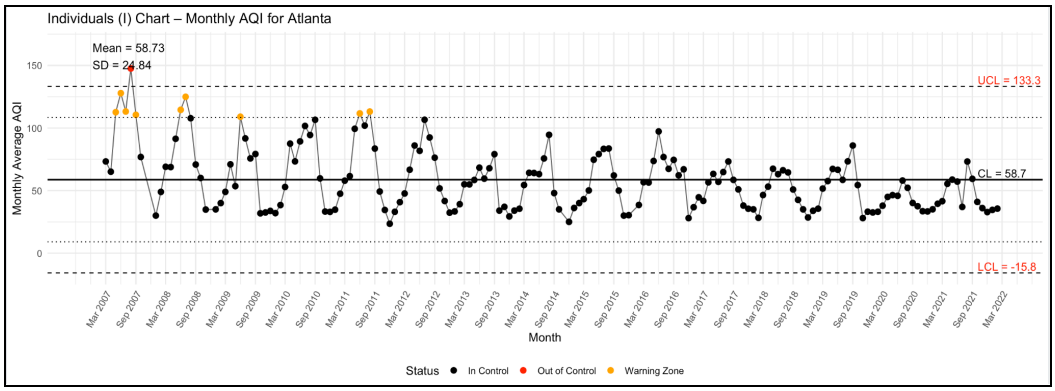


Figure 1. *I Chart - Monthly AQI for Atlanta* Atlanta's center line is 58.7 with limits at 15.8 and 133.3. Shows the highest variability and overall highest AQI levels among the four cities.

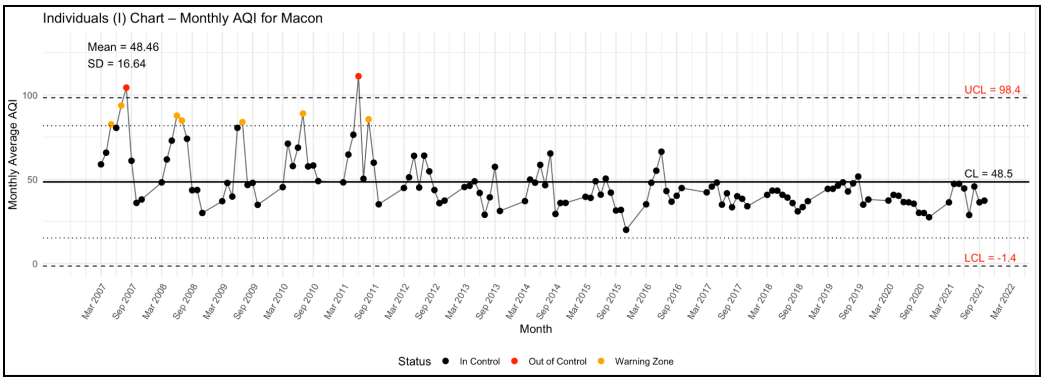


Figure 2. *I Chart - Monthly AQI for Macon* Macon's center line is 48.5 with limits at -1.4 and 98.4. AQI severity and variation are second to Atlanta's. Early years show high spikes and 2 out-of-control points.

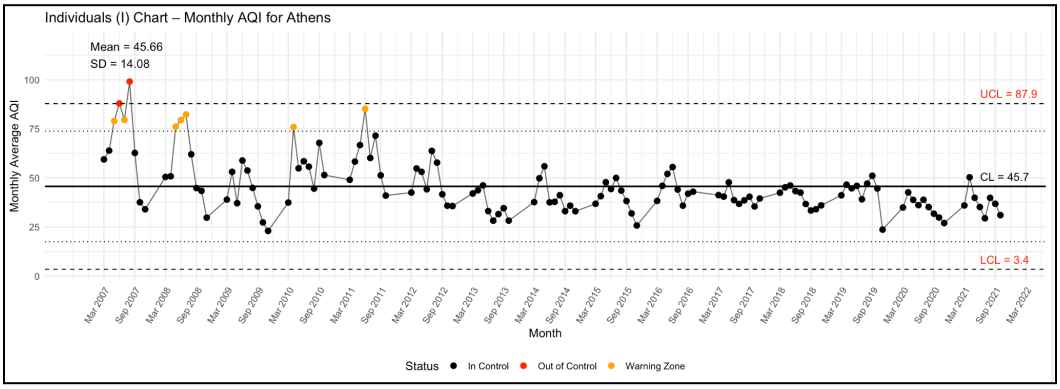


Figure 3. *I Chart - Monthly AQI for Athens* Athens' center line is 45.7 with limits at 3.4 and 87.9. Experiences moderate variation and 2 out-of-control points.

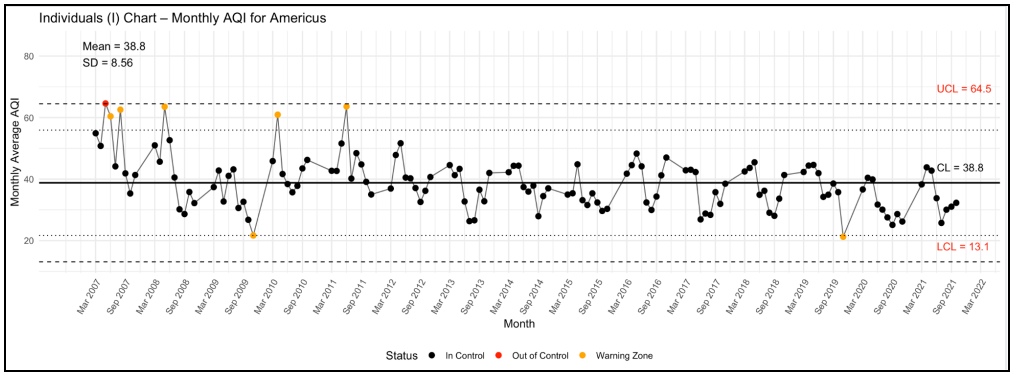


Figure 3. *I Chart - Monthly AQI for Athens* Americus' center line is 38.8 with limits at 13.1 and 64.5. Lowest and most stable AQI levels and 1 point out of control.

Across all four cities, the X-bar charts show a common pattern of higher variability, higher spikes, and points exceeding the upper control limit in the early years followed by more stability around the center line in the later years. However, the magnitude of these trends varies. Atlanta's chart shows the least stable mean AQI level with the largest magnitude of spike toward and exceeding the upper control limit. Macon also shows notable instability, but its deviations are smaller than Atlanta's. Athens shows moderate stability, and Americus has the most stable mean, remaining closest to the center line for most of the time period.

These patterns imply that Atlanta and Macon's mean AQI levels are more frequently and heavily impacted by the surrounding activity and environment while Athens and Americus experience less of the factors that cause high and volatile AQI levels. The contrast suggests that larger urban centers experience a less stable AQI mean than rural, less populated areas.

### *R Charts*

Next, we constructed R charts to evaluate the stability of the variation in AQI levels month-to-month within the same 15-year period. We can use this method to focus on whether the amount of variation itself is stable over time. Large or out-of-control ranges indicate months where the AQI level fluctuated unusually sharply due to special-cause environmental events.

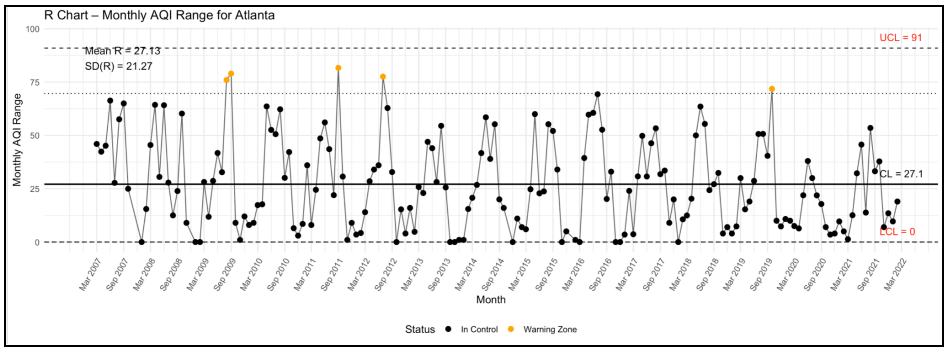


Figure 5. *R Chart - Monthly AQI Range for Atlanta* Atlanta has the highest average monthly range of 27.1 with limits from 0 to 91. Exhibits the greatest volatility in magnitude but has no points exceeding control limits.

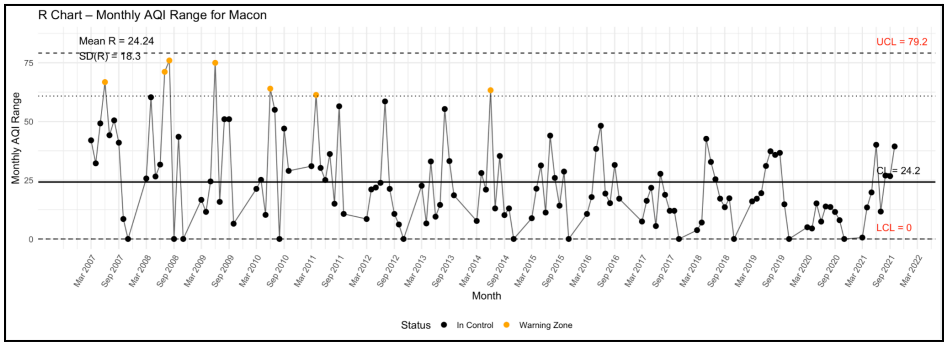


Figure 6. *R Chart - Monthly AQI Range for Macon* Macon's average range is 24.2 with limits from 0 to 79.2. Displays substantial variation, with several points approaching the upper control limit. Volatility is second to Atlanta's in magnitude but has no points exceeding control limits.

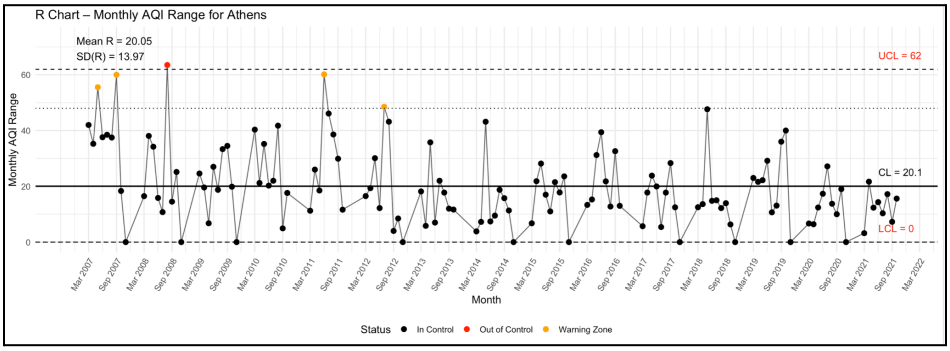


Figure 7. *R Chart - Monthly AQI Range for Athens* Athens' average monthly range is 20.1 with limits from 0 to 62. Shows moderate instability, including one 1 out-of-control point. Variability is lower but still elevated in the early years.

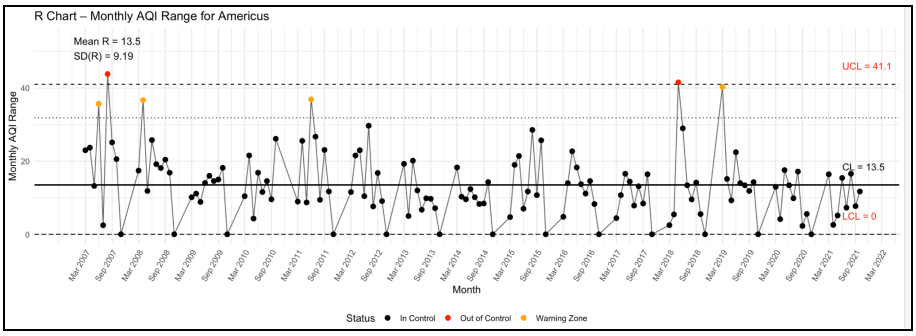


Figure 8. *R Chart - Monthly AQI Range for Americus* Americus has the smallest average range at 13.5 with limits from 0 to 41.1. Shows the most stable month-to-month variation overall, but has 2 points exceeding the upper limit.

Atlanta and Macon exhibit the largest overall ranges and highest volatility, but neither city shows out-of-control points, suggesting their AQI variability is high but also fairly consistent and predictable within their upper and lower limits. This is likely because urban centers experience more regular and stable sources of fluctuation such as high traffic and industry. In contrast, Athens and Americus show out-of-control points, indicating the presence of atypical events that temporarily disrupted their usual variability patterns such as weather anomalies or other isolated environmental events. Since these areas have lower and more stable variation, these occurrences stand out more clearly as special-case events. In summary, urban areas have higher but more routine variability while rural areas have lower volatility but are more susceptible to one-off events that cause out-of-control spikes.

### *p Charts*

To evaluate the stability of how often each city experiences unhealthy air quality, we constructed p charts, which monitor the proportion of nonconformity per month where air quality fails to meet health standards. We define a nonconformity as any day with AQI ≥ 101, which represents air quality that does not meet established standards. The p chart allows us to assess whether the frequency of poor air quality days is fairly stable over the 15 year time period, or if there are trends that may be linked to specific causes for unusual spikes.

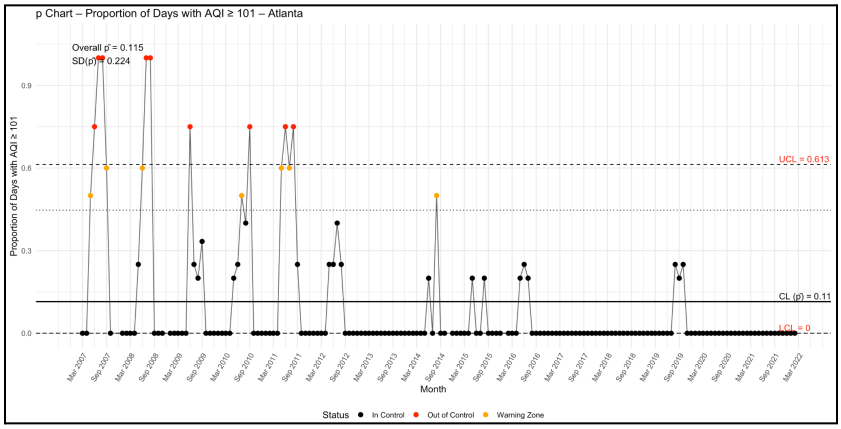


Figure 9. *p Chart - Proportion of Days with AQI ≥ 101- Atlanta* Atlanta shows a nonconformity rate of 0.115 with

substantial variation. Several points fall beyond the upper limit, reflecting periods with unusually high proportions of unhealthy days.

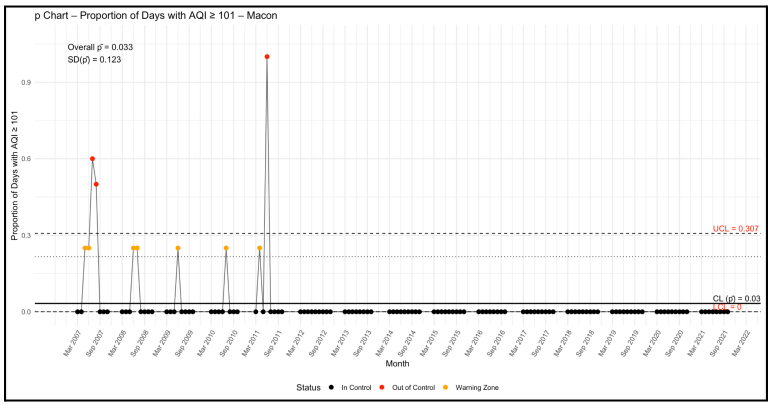


Figure 10. *p Chart - Proportion of Days with AQI ≥ 101- Macon* Macon's nonconformity rate is 0.033. Several earlier months exceed the upper control limit, and the later months show zero nonconformity.

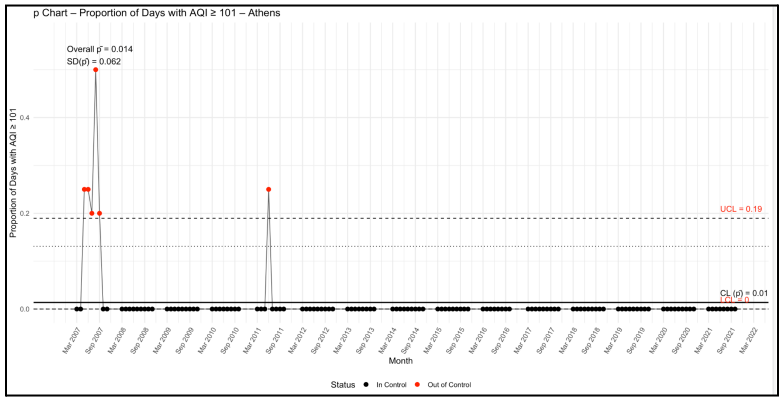


Figure 11. *p Chart - Proportion of Days with AQI ≥ 101- Athens* Athens' nonconformity rate is 0.014. Only 6 months show any unhealthy days at all, but all of them exceed the upper control limit.

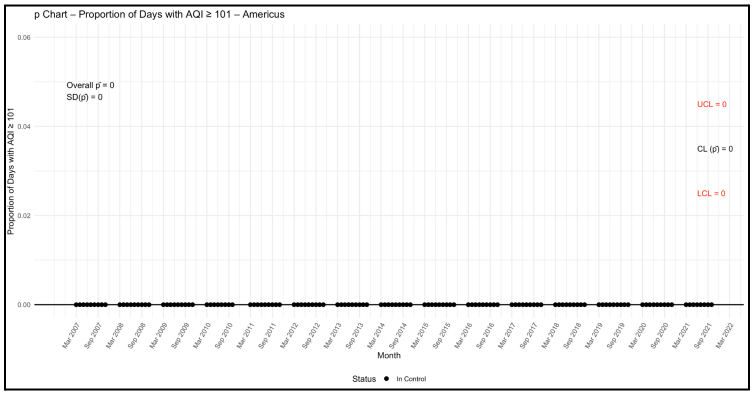


Figure 12. *p Chart - Proportion of Days with AQI ≥ 101- Americus* Americus' nonconformity rate is 0. No recorded points with AQI above 101 in any month.

The results highlight how the frequency of unhealthy air quality days differ greatly across the four cities. Atlanta experiences the highest proportion of nonconforming days, reflecting the

presence of consistent factors that cause variability in air quality such as large population and heavy traffic. Macon shows occasional spikes, though far fewer than Atlanta. Athens has less spikes overall than Macon but all spikes are out-of-control. Finally, Americus has no spikes and a rate of zero. This supports that cities experience unhealthy AQI levels more regularly while smaller rural areas tend to have few occurrences that are caused by special-cause events.

### *EWMA Charts*

Finally, we constructed EWMA charts to assess long-term shifts in AQI levels for each city with parameters $\lambda = 0.2$ and $L = 3$. EWMA charts smooth short-term fluctuations and place more weight on recent observations, so the charts are particularly effective for detecting subtle and sustained shifts rather than isolated spikes. The center line represents the overall mean monthly AQI and the control limits are calculated using the steady state EWMA standard deviation. Points that exceed the limits indicate potential long-term departures from typical air quality patterns.

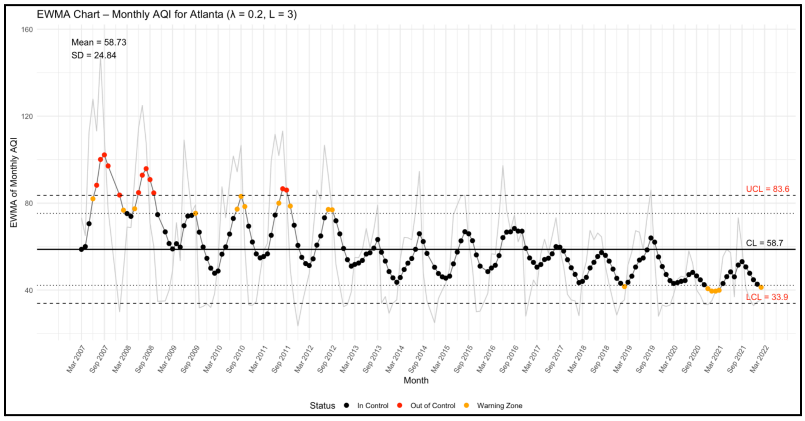


Figure 13. *EWMA Chart - Monthly AQI for Atlanta* Atlanta has a mean of 59.7 with limits at 19.5 and 99.9. The early years show several points exceeding the upper limit, followed by a gradual decline and stabilization in later years. In later years, points seem to begin to shift below the mean.

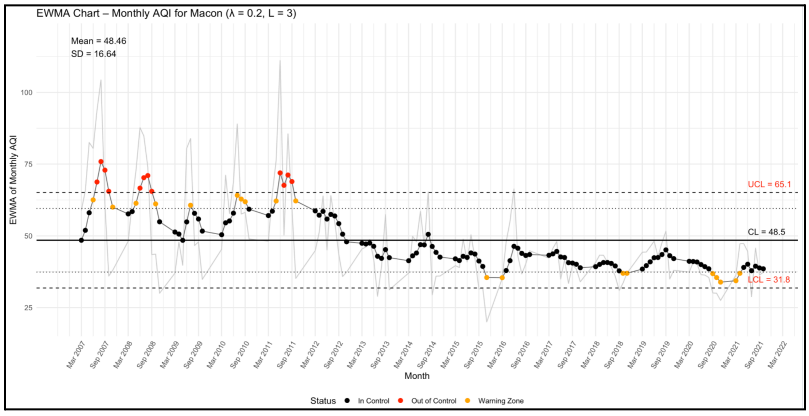


Figure 14. *EWMA Chart - Monthly AQI for Macon* Macon has a mean of 50.1 with limits at 17.4 and 82.8. Early

years show several points exceeding the upper limit, followed by a gradual decline and stabilization in later years slightly below the mean.

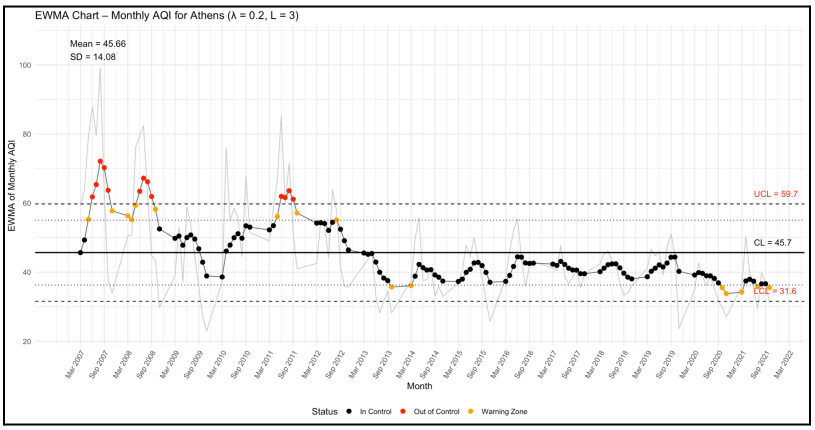


Figure 15. *EWMA Chart - Monthly AQI for Athens* Athens has a mean of 50.1 with limits at 17.4 and 82.8. Early years show a consistent trend near the upper limit, while later years show a gradual decline and stabilization slightly below the mean.

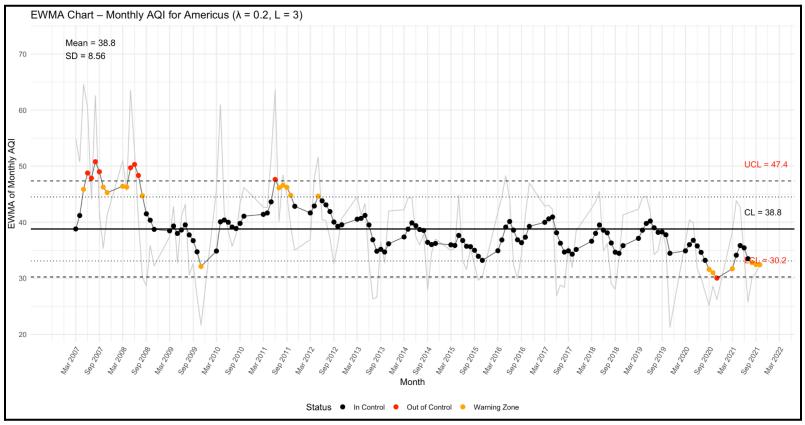


Figure 16. *EWMA Chart - Monthly AQI for Americus* Americus has a mean of 38.8 with limits at 20.0 and 57.6. Shows an overall downward trend with lower magnitude and variation in values.

Across all four cities, we see a consistent long-term downward trend in AQI levels, displaying substantially higher levels in the early years before gradually decreasing and stabilizing over time. These charts reinforce the conclusion that air quality across all locations has improved steadily over the observed 15 year period.

# Results

Across all four cities, the results show clear patterns in both mean ozone-related AQI levels and the stability of air quality over time (March 2007-March 2022). First, urbanization strongly influences average air quality and variability. Atlanta consistently exhibits the highest mean ozone levels, largest ranges, and the most extreme early-period spikes. Macon follows closely with similar but less intense patterns. These results align with what we know about urban air

pollution patterns caused by regular factors such as high traffic and population density, high industrial activity, and overall greater emissions sources. On the other hand, Athens and Americus which are smaller and less industrial towns show much lower average AQI and more stable levels. Second, the special-cause out-of-control points detected likely correspond to identifiable environmental events. For example, the higher than average values in early months align with the 2007 drought in the Southeastern United States, since droughts are known to exacerbate pollution. There is also another consistent spike in 2011 which aligns with the Honey Prairie Fire, a widespread wildfire in south Georgia. Events such as these help explain why there is a trend across all four cities of higher pollution levels in the early months of the time range we studied.

The p charts reinforce which cities experience unhealthy air most often, with Atlanta leading with the highest nonconformity rate, consistent with sustained urban emissions. Macon and Athens both show occasional early spikes consistent with the timeframes of the environmental events which then disappear and stabilize in later years. Americus, the smallest and least industrial town, shows zero nonconforming months, confirming it as having the most consistently healthy air quality.

Finally, the EWMA charts reveal a consistent downward trend in monthly AQI over the twenty year period. This improvement corresponds to policy and technology changes in relation to pollution control, such as Georgia's policies in accordance with the Clean Air Act including controls on industrial NOx emissions and mobile-source reduction programs aimed at lowering pollutants that form ground-level ozone beginning in the early 2000s.

Together, the control charts tell a consistent story. Urban centers experience higher and more variable ozone levels overall, but all four cities have seen consistent spikes due to events that affected the air quality of all of Georgia, and all cities have seen a consistent improvement in air quality. These results validate the influence of human activity and population density on ozone emissions while also highlighting the effectiveness of long-term emissions reduction policies.

***Next Steps***

For the purposes of further analysis, the study could be expanded to include additional pollutants such as PM2.5 and PM10. This could provide a more comprehensive profile of each city's air quality changes and compare patterns across pollutant types. Additionally, this study could be combined with local meteorological variables such as temperature, humidity, and wind patterns to determine more precise root-cause analysis of fluctuations in air quality in varying regions of Georgia. Finally, a valuable next step would be to conduct forecasting and use predictive models or machine learning methods in combination with the control charts used in this study to more effectively anticipate unhealthy air levels in the future.

# Appendix

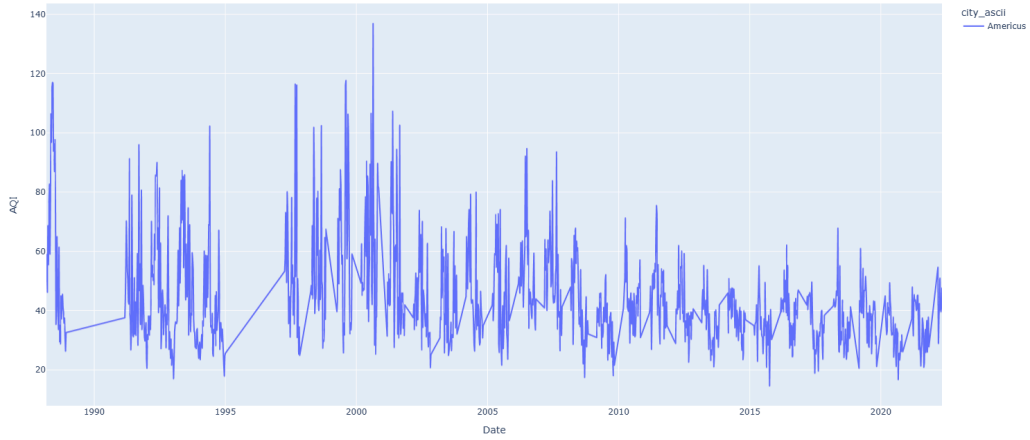


Figure 17: Americus Times Series Plot

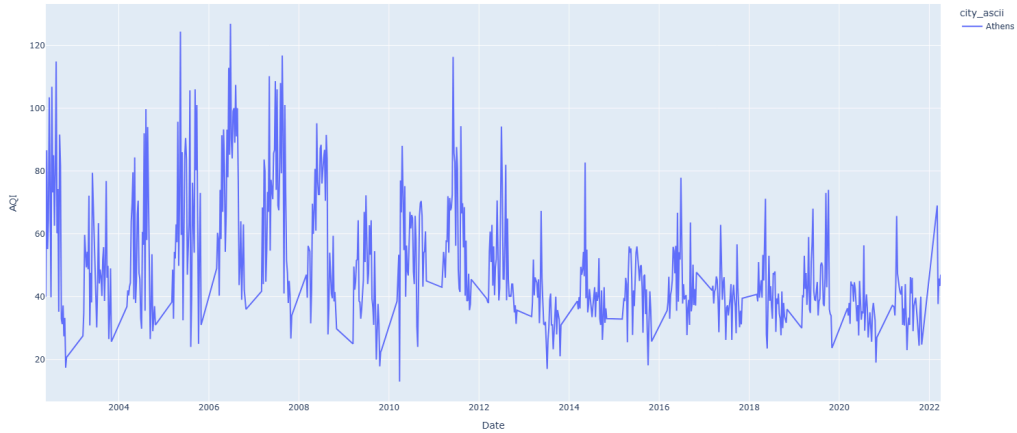


Figure 18: Athens Times Series Plot

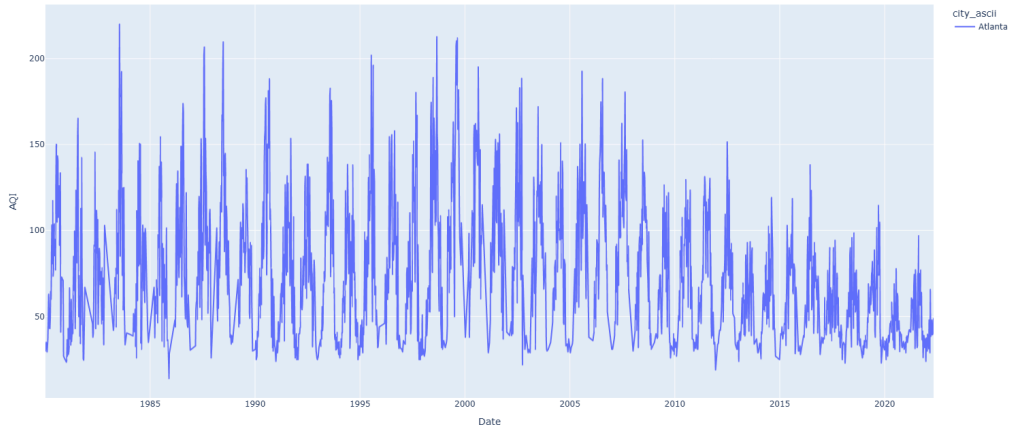


Figure 19: Atlanta Times Series Plot

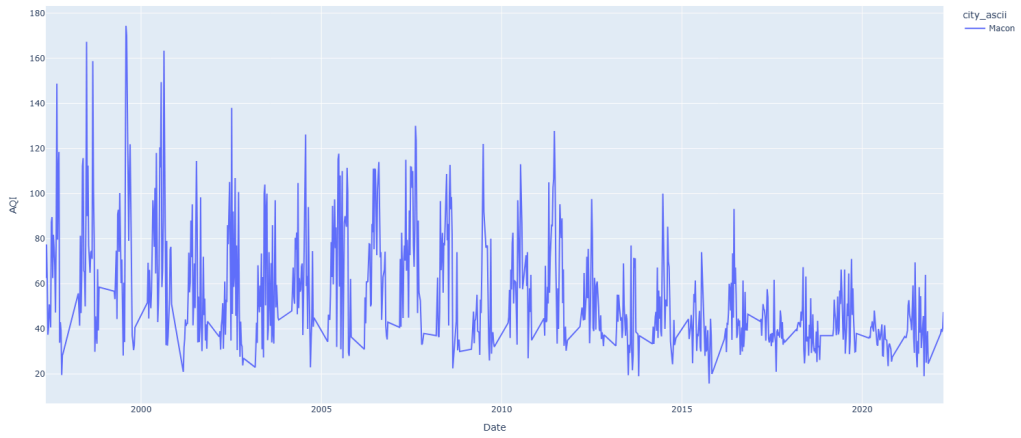


Figure 20: Macon Times Series Plot

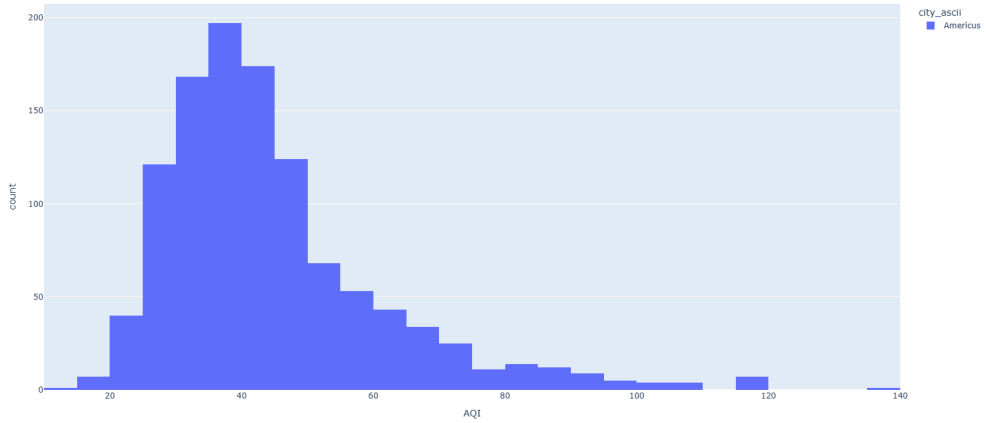


Figure 21: Americus Histogram Plot

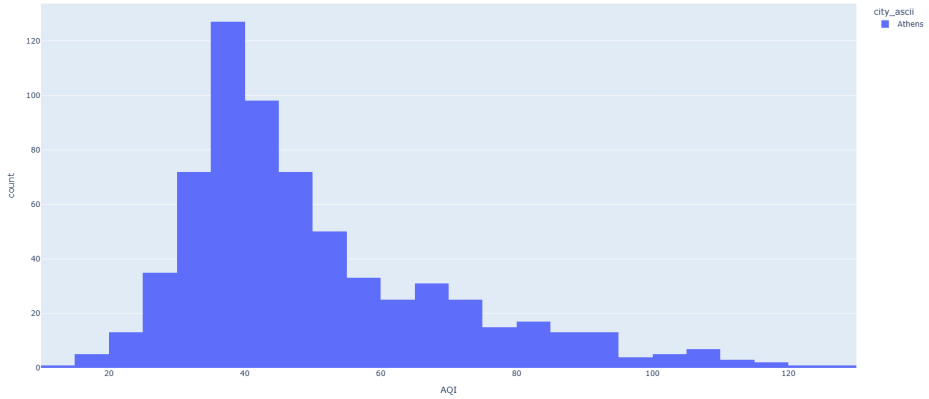


Figure 22: Athens Histogram Plot

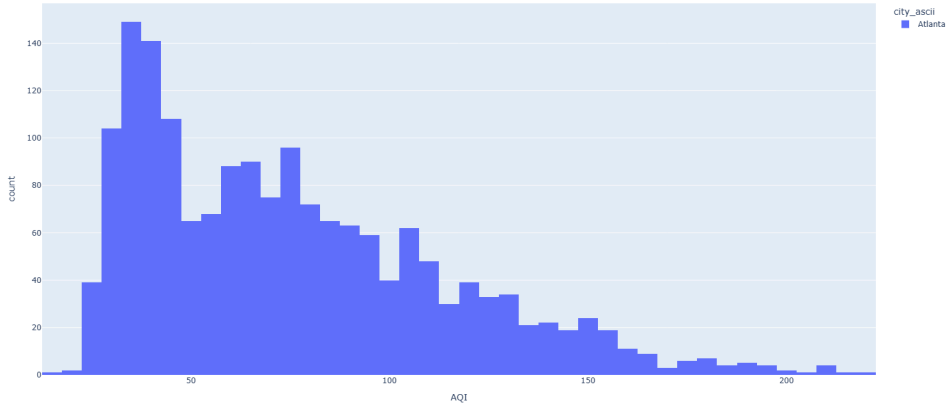


Figure 23: Atlanta Histogram Plot

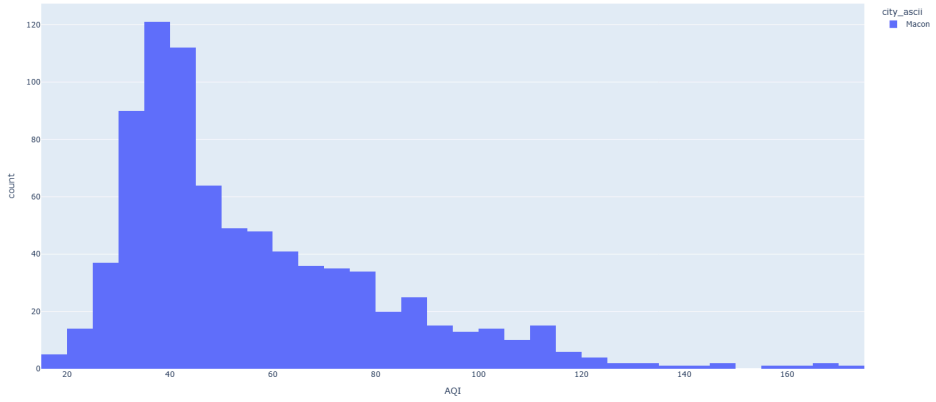


Figure 24: Macon Histogram Plot

Summary Statistics:

Americus's AQI Mean is: 44.52278669043375

Americus's AQI STD is: 16.93724588196906

Americus's AQI Min. is: 14.714285714285714

Americus's AQI Max. is: 136.85714285714286

Athens's AQI Mean is: 49.916873396065014

Athens's AQI STD is: 19.665606737616223

Athens's AQI Min. is: 13.0

Athens's AQI Max. is: 126.83333333333331

Atlanta's AQI Mean is: 75.5079433734278

Atlanta's AQI STD is: 38.64164764195501

Atlanta's AQI Min. is: 14.0

Atlanta's AQI Max. is: 220.0

Macon's AQI Mean is: 55.850681514993326

Macon's AQI STD is: 25.606003073391776

Macon's AQI Min. is: 15.8

Macon's AQI Max. is: 174.33333333333334

References:

Dataset - https://www.kaggle.com/code/calebreigada/us-air-quality-analysis
https://www.airnow.gov/aqi/aqi-basics/
https://www.epa.gov/ozone-pollution-and-your-patients-health/what-ozone?utm_source=chatgpt.com
https://www.niehs.nih.gov/health/topics/agents/air-pollution
https://epd.georgia.gov/ozone-state-implementation-plans-sips
https://www.georgiaencyclopedia.org/articles/geography-environment/human-history-of-the-okefenokee-swamp/m-11278/
https://www.weather.gov/ohx/2007drought