Kara: An Analysis of Temperature and Rainfall

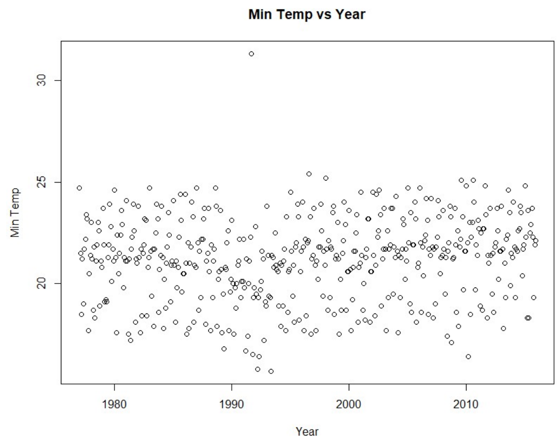
By: Alyssa Farmer and Jacob Koors

Introduction

Togo is a small West-African nation of just 21, 925 square miles and is bordered by three very distinct nations: Benin to the east, Burkina Faso to the north, Ghana to the west, and the Gulf of Guinea to the south. Togo's geography consists of tropical oceanic coasts, woodland hills, and vast northern savannahs. With large and direct access to the ocean, trade is a vital component to Togo's economy which is sustained by exporting primary goods such as agricultural and mining products. In a current trade deficit, Togo is importing more from its largest trade partners-France, the Netherlands, and Côte d'Ivoire- and exporting less to Burkina Faso, China, and the Netherlands. The nation's largest exports consist of cocoa, cotton, and phosphates. This is very intensive on the land it is produced as faming and mining requires extensive amounts of land and water resources. Being a colony that has changed hands multiple times, Togo has struggled politically and continues to face difficulties in power vacuums and transitions of power. Recent times have seen a decrease in volatility even as reliance on the International Monetary Fund has persisted. This need for additional funding is caused by very different levels of growth and infrastructure within the nation. Togo is divided into five very unique districts: Savanes in the north, Kara below, then Centrale, Plateaux, and the southernmost is Maritime. All of the regions comprise of the entire width of the nation, but are split as one travels from north to south. This study will focus on one city in the region of Kara.

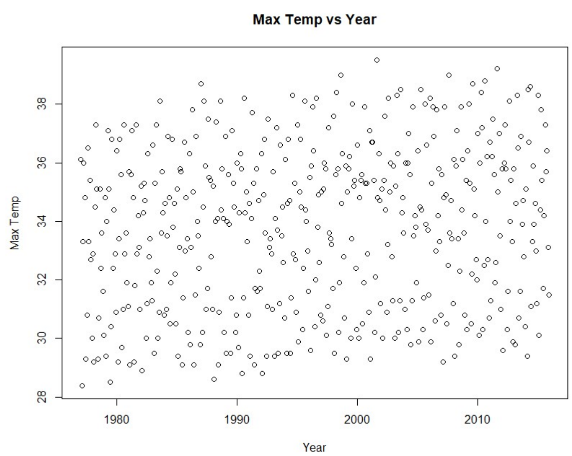
The city of Kara is the capital of the Kara region and fittingly is divided by the Kara River. The city has grown to a population of just a little under 95, 000 people. Kara is one of the nation's economic hubs and its economy comprises of almost entirely agricultural products. Most people in the city are forced to work for their own survival and trade is less of a priority for many. In this study, we will be analyzing the surface temperature maximum and minimums as well as rainfall levels. This is in an attempt to determine if there is some kind of trend that can be deciphered over time.

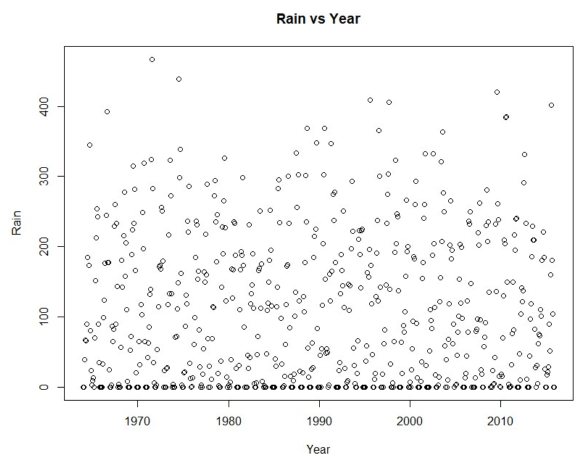
Two groups have analyzed trends in the city of Kara in the past. The group of Nielsen and Frink found that both minimum and maximum surface temperatures in the city of Kara were increasing, but two distinct models explained the two. Both contained a cyclical sine and cosine term, but the group found that maximum temperature only called for a linear model while minimum temperature called for a quadratic model. In this report, our aim is to focus on rainfall and how both time and temperature impact the amount of rainfall in Kara (assumed to be in units of mm).

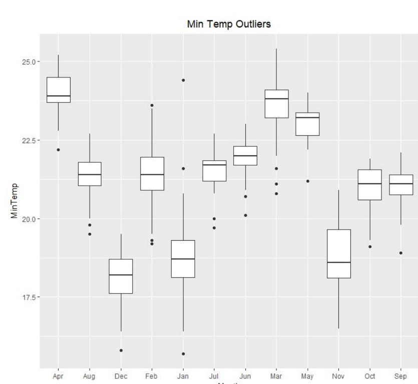


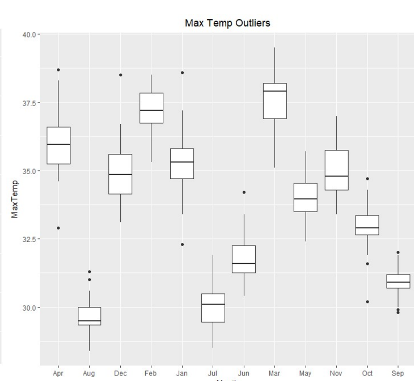
Analysis

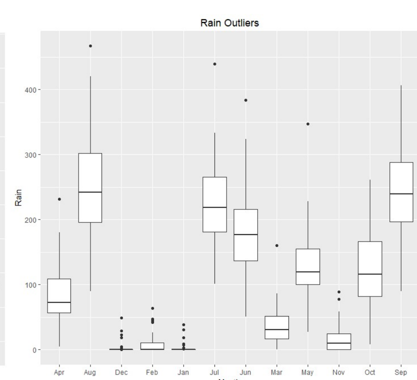
Looking at just the plots for minimum temperatures, maximum temperatures, and rainfall over time, there seems to be an outlier in the minimum temperature data, so we will remove this before doing any of the analysis. Additionally, the boxplots at the bottom of the page suggest there may be more outliers. To identify less obvious outliers, we need to also remove any observations that are more than four standard deviations away from the mean, grouped by month. This was completed before beginning any of the analyses.











<u>Rain vs Year</u>

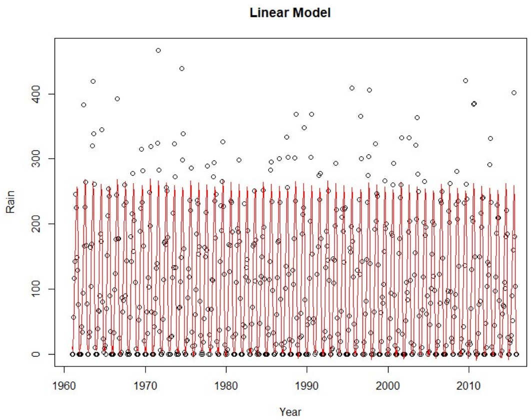
First, it makes sense to examine the change in rainfall over time. At first glance, as we can see from the plot above, it looks like there is not an obvious relationship between year and rainfall, but we will create linear models in order to check this.

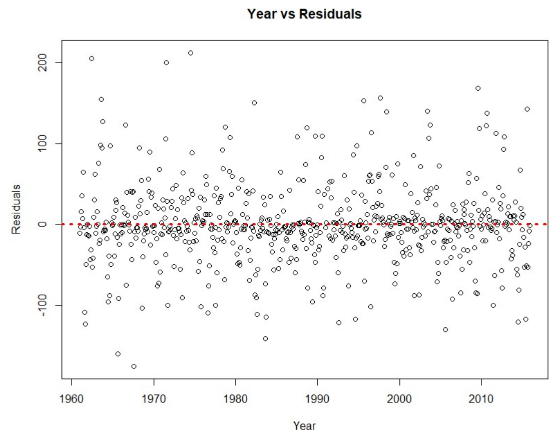
Looking at the output below, it seems like the year on its own is not significant, which means there is not a significant increase in rainfall over time. However, many of the sinusoidal terms are significant, which means rainfall patterns repeat significantly on certain multiples of months. The final output is shown below, using multiples of π that were significant up to 12π. Quadratic terms for year were attempted, but found to be insignificant. There are no obvious issues with the residuals.

```
Coefficients:
                                          Estimate Std. Error t value Pr(>|t|)    
(Intercept)                              4.108e+02  2.411e+02   1.704   0.0888 .  
raindata$year.rain.decimal              -1.522e-01  1.212e-01  -1.256   0.2096    
sin(2 * pi * raindata$year.rain.decimal)  -2.839e+01  2.721e+00 -10.434  < 2e-16 ***
cos(2 * pi * raindata$year.rain.decimal)  -1.257e+02  2.728e+00 -46.074  < 2e-16 ***
sin(4 * pi * raindata$year.rain.decimal)   3.561e+01  3.094e+00  11.510  < 2e-16 ***
cos(4 * pi * raindata$year.rain.decimal)   4.662e+00  2.725e+00   1.711   0.0876 .  
sin(6 * pi * raindata$year.rain.decimal)  -4.783e+00  2.718e+00  -1.760   0.0789 .  
cos(6 * pi * raindata$year.rain.decimal)   1.709e+01  2.731e+00   6.259 7.08e-10 ***
sin(8 * pi * raindata$year.rain.decimal)  -7.866e+00  2.723e+00  -2.889   0.0040 ** 
cos(8 * pi * raindata$year.rain.decimal)  -3.303e-02  2.725e+00  -0.012   0.9903    
sin(12 * pi * raindata$year.rain.decimal) -9.645e+11  4.524e+11  -2.132   0.0334 *  
cos(12 * pi * raindata$year.rain.decimal) -3.197e+00  2.336e+00  -1.368   0.1717    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 49.29 on 643 degrees of freedom
Multiple R-squared:  0.7912,	Adjusted R-squared:  0.7877 
F-statistic: 221.5 on 11 and 643 DF,  p-value: < 2.2e-16
```

```
                                                  2.5 %        97.5 %
(Intercept)                               -6.253894e+01  8.842153e+02
raindata$year.rain.decimal                -3.903127e-01  8.581585e-02
sin(2 * pi * raindata$year.rain.decimal)  -3.373683e+01 -2.304958e+01
cos(2 * pi * raindata$year.rain.decimal)  -1.310699e+02 -1.203544e+02
sin(4 * pi * raindata$year.rain.decimal)   2.953720e+01  4.168833e+01
cos(4 * pi * raindata$year.rain.decimal)  -6.896295e-01  1.001354e+01
sin(6 * pi * raindata$year.rain.decimal)  -1.011940e+01  5.542626e-01
cos(6 * pi * raindata$year.rain.decimal)   1.172865e+01  2.245240e+01
sin(8 * pi * raindata$year.rain.decimal)  -1.321336e+01 -2.519195e+00
cos(8 * pi * raindata$year.rain.decimal)  -5.384497e+00  5.318431e+00
sin(12 * pi * raindata$year.rain.decimal) -1.852791e+12 -7.625938e+10
cos(12 * pi * raindata$year.rain.decimal) -7.784051e+00  1.390876e+00
```





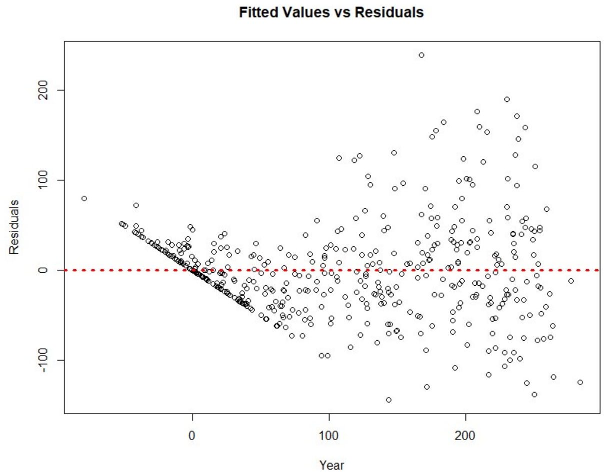
<u>Rain vs Temperature</u>

Next, we can try to use the minimum and maximum temperatures to see if there is a relationship between temperature and rainfall, rather than year and rainfall. Both the minimum and maximum temperatures are significant in predicting rainfall. The residual plot is shown below, and it does look like it has some issues with non-constant variance, but is not overly concerning.

```
Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     809.8779    38.1460   21.23   <2e-16 ***
alldata$MinTemp  17.8852     1.2408   14.41   <2e-16 ***
alldata$MaxTemp -32.0608     0.8966  -35.76   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 52.48 on 459 degrees of freedom
Multiple R-squared:  0.7527,	Adjusted R-squared:  0.7517
F-statistic: 698.6 on 2 and 459 DF,  p-value: < 2.2e-16
```

```
                   2.5 %    97.5 %
(Intercept)     734.91545 884.84040
alldata$MinTemp  15.44686  20.32350
alldata$MaxTemp -33.82281 -30.29885
```



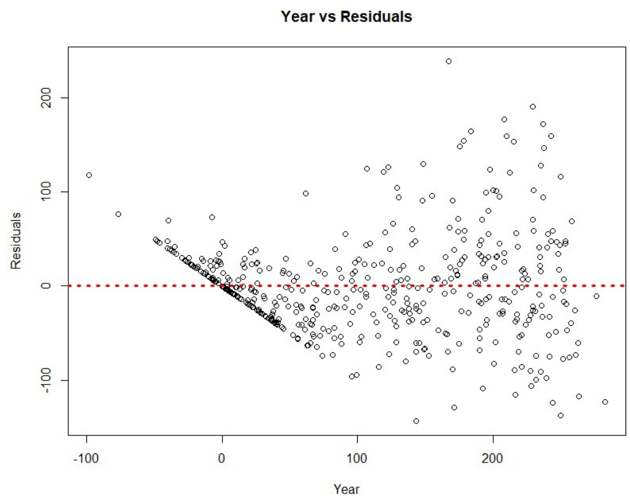
Rain vs Year and Temperature

The next model includes both year and temperature to predict rainfall, again including significant sinusoidal terms for the year. Year has interestingly become significant, and the sinusoidal terms, minimum temperatures, and maximum temperatures are all also significant in modeling rainfall. The residual plot looks very similar to the last one, which makes sense, but that means it still has all the same issues.

```
Coefficients:
                                     Estimate Std. Error t value Pr(>|t|)    
(Intercept)                        -6.641e+02  3.973e+02  -1.671 0.095345 .  
newdata$year.decimal                7.598e-01  2.076e-01   3.660 0.000282 ***
sin(2 * pi * newdata$year.decimal) -1.402e+01  3.598e+00  -3.896 0.000113 ***
cos(2 * pi * newdata$year.decimal)  1.391e+01  3.245e+00   4.285 2.23e-05 ***
sin(4 * pi * newdata$year.decimal) -5.379e-01  4.043e+00  -0.133 0.894219    
cos(4 * pi * newdata$year.decimal)  3.110e+01  5.578e+00   5.576 4.25e-08 ***
sin(6 * pi * newdata$year.decimal) -9.472e+00  4.473e+00  -2.118 0.034734 *  
cos(6 * pi * newdata$year.decimal)  4.493e+00  3.785e+00   1.187 0.235868    
sin(10 * pi * newdata$year.decimal)  2.120e+01  4.825e+00   4.393 1.40e-05 ***
cos(10 * pi * newdata$year.decimal) -1.438e+01  4.173e+00  -3.447 0.000620 ***
sin(12 * pi * newdata$year.decimal) -4.153e+11  5.255e+11  -0.790 0.429735    
cos(12 * pi * newdata$year.decimal) -1.248e+01  2.795e+00  -4.464 1.02e-05 ***
newdata$MinTemp                     6.404e+00  2.280e+00   2.809 0.005190 ** 
newdata$MaxTemp                    -2.611e+01  1.735e+00 -15.051  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 47.58 on 451 degrees of freedom
Multiple R-squared:  0.8029,	Adjusted R-squared:  0.7972 
F-statistic: 141.3 on 13 and 451 DF,  p-value: < 2.2e-16
```

```
                                            2.5 %       97.5 %
(Intercept)                          -1.444888e+03  1.167654e+02
newdata$year.decimal                  3.518178e-01  1.167870e+00
sin(2 * pi * newdata$year.decimal)   -2.108784e+01 -6.946221e+00
cos(2 * pi * newdata$year.decimal)    7.529228e+00  2.028574e+01
sin(4 * pi * newdata$year.decimal)   -8.483913e+00  7.408055e+00
cos(4 * pi * newdata$year.decimal)    2.014127e+01  4.206707e+01
sin(6 * pi * newdata$year.decimal)   -1.826171e+01 -6.825690e-01
cos(6 * pi * newdata$year.decimal)   -2.946072e+00  1.193228e+01
sin(10 * pi * newdata$year.decimal)   1.171318e+01  3.067908e+01
cos(10 * pi * newdata$year.decimal)  -2.258213e+01 -6.182001e+00
sin(12 * pi * newdata$year.decimal)  -1.448047e+12  6.173929e+11
cos(12 * pi * newdata$year.decimal)  -1.796959e+01 -6.984616e+00
newdata$MinTemp                       1.922999e+00  1.088390e+01
newdata$MaxTemp                      -2.952286e+01 -2.270364e+01
```



Conclusion and Further Questions

According to the above analyses, we are not able to conclude that there has been a significant increase or a significant decrease in rainfall over time in the Togolese city of Kara, but rainfall follows a consistent pattern of increases and decrease over time which is consistent with the change in season. When only using time to model rainfall, the year is insignificant, but when temperature is added into the model, year suddenly becomes significant. This makes interpreting the model more difficult, and it is unclear whether or not there is actually an increase in rainfall over time. Specific to this data, an outlier is present in the minimum temperature data. This value requires some kind of explanation from the Togolese meteorologists. Is it possibly a mistaken value, is it a genuine spike in the minimum temperatures, is it a result of incorrect measuring? These questions throw off the data point and without explanation forces researchers to remove it. Although rainfall and time may not be related, rainfall and maximum as well as minimum temperatures are correlated. These findings suggest that as temperature increases, rainfall will also change, meaning the changes in one will see changes in the other. This leads to many concerns and implications for scientists, politicians, and many more. Policy implications abound, this relationship confirms many concerns of proponents of combatting global warming as increased temperatures and increased rainfall floods coastal regions. Togo being a coastal and low-lying nation is at the forefront of this issue as it will be one of the first affected nations.

It would be of great interest to analyze other information regarding global warming in addition to the above variables. This could include, but is not limited to sea level and length of coastal land. These variables would allow researchers to analyze if water levels have been increasing over time and determine if global warming is threatening the nation of Togo. This would require very accurate and precise data that is free from faults and issues. The data used in this study is of questionable authenticity due to the little information received about how it was collected. This is information that would be needed for future data sources and for the data at hand. It is important to understand where and how data has been collected so that it is clear to the researchers, the public, and the policy makers that the information has not been fabricated or made inaccurate. Without properly representative data conclusions cannot be made and analyses lack credibility.

Sources and Citations

- republicoftogo.com. "Togo." *République Togolaise*, www.republicoftogo.com/.
- "Togo Country Profile." *BBC News*, BBC, 4 Oct. 2017, www.bbc.com/news/world-africa-14106781.
- "The World Factbook: TOGO." *Central Intelligence Agency*, Central Intelligence Agency, 22 Feb. 2018, www.cia.gov/library/publications/the-world-factbook/geos/to.html.
  Map image: Togo EPS Map." *Netmaps Leading Mapping Company*, www.netmaps.net/netmaps/togo-eps-map/.
  Agriculture image: "Togo Sees Significant Return on Investment in Agriculture." *AllAfrica*, allafrica.com/stories/201108031311.html.