Assignment 7: Time Series Analysis

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on time series analysis.

Directions

1. Change "Student Name" on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., "Fay_A07_TimeSeries.Rmd") prior to submission.

The completed exercise is due on Tuesday, March 16 at 11:59 pm.

Set up

1. Set up your session:

- Check your working directory
- Load the tidyverse, lubridate, zoo, and trend packages
- Set your ggplot theme

2. Import the ten datasets from the Ozone_TimeSeries folder in the Raw data folder. These contain ozone concentrations at Garinger High School in North Carolina from 2010-2019 (the EPA air database only allows downloads for one year at a time). Import these either individually or in bulk and then combine them into a single dataframe named `GaringerOzone` of 3589 observation and 20 variables.

```
#1.

## Load library

library(tidyverse)
library(lubridate)
library (zoo)
library (trend)
library(Kendall)


## Check working directory

getwd()
```

```
## [1] "C:/Users/sasho/Desktop/Environ Data Analytics/Env872 Workspace/EDA-Fall2022_SM/Assignments"
```

```
setwd("C:/Users/sasho/Desktop/Environ Data Analytics/Env872 Workspace/EDA-Fall2022_SM")

##Set theme
mytheme <- theme_classic(base_size = 14) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top")
theme_set(mytheme)


## Load datasets

EPAair_O3_GaringerNC2010_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2010_raw.csv")
summary(EPAair_O3_GaringerNC2010_raw)
```

```
##      Date              Source             Site ID               POC
##  Length:360         Length:360         Min.   :371190041   Min.   :1
##  Class :character   Class :character   1st Qu.:371190041   1st Qu.:1
##  Mode  :character   Mode  :character   Median :371190041   Median :1
##                                        Mean   :371190041   Mean   :1
##                                        3rd Qu.:371190041   3rd Qu.:1
##                                        Max.   :371190041   Max.   :1
##  Daily Max 8-hour Ozone Concentration    UNITS           DAILY_AQI_VALUE
##  Min.   :0.01300                     Length:360         Min.   : 12.00
##  1st Qu.:0.03200                     Class :character   1st Qu.: 30.00
##  Median :0.04400                     Mode  :character   Median : 41.00
##  Mean   :0.04469                                        Mean   : 47.13
##  3rd Qu.:0.05600                                        3rd Qu.: 54.00
##  Max.   :0.09100                                        Max.   :164.00
##   Site Name         DAILY_OBS_COUNT PERCENT_COMPLETE AQS_PARAMETER_CODE
##  Length:360         Min.   :13.00   Min.   : 76.00   Min.   :44201
##  Class :character   1st Qu.:17.00   1st Qu.:100.00   1st Qu.:44201
##  Mode  :character   Median :17.00   Median :100.00   Median :44201
##                     Mean   :16.97   Mean   : 99.82   Mean   :44201
##                     3rd Qu.:17.00   3rd Qu.:100.00   3rd Qu.:44201
##                     Max.   :17.00   Max.   :100.00   Max.   :44201
##  AQS_PARAMETER_DESC   CBSA_CODE      CBSA_NAME           STATE_CODE
##  Length:360         Min.   :16740   Length:360         Min.   :37
##  Class :character   1st Qu.:16740   Class :character   1st Qu.:37
##  Mode  :character   Median :16740   Mode  :character   Median :37
##                     Mean   :16740                      Mean   :37
##                     3rd Qu.:16740                      3rd Qu.:37
##                     Max.   :16740                      Max.   :37
##     STATE            COUNTY_CODE     COUNTY           SITE_LATITUDE
##  Length:360         Min.   :119   Length:360         Min.   :35.24
##  Class :character   1st Qu.:119   Class :character   1st Qu.:35.24
##  Mode  :character   Median :119   Mode  :character   Median :35.24
##                     Mean   :119                      Mean   :35.24
##                     3rd Qu.:119                      3rd Qu.:35.24
##                     Max.   :119                      Max.   :35.24
##  SITE_LONGITUDE
##  Min.   :-80.79
##  1st Qu.:-80.79
```

```
##  Median :-80.79
##  Mean   :-80.79
##  3rd Qu.:-80.79
##  Max.   :-80.79
```

```
unique(EPAair_O3_GaringerNC2010_raw)
```

```
## # A tibble: 360 x 20
##    Date       Source Site ~1   POC Daily~2 UNITS DAILY~3 Site ~4 DAILY~5 PERCE~6
##    <chr>      <chr>    <dbl> <dbl>   <dbl> <chr>   <dbl> <chr>     <dbl>   <dbl>
##  1 01/01/2010 AQS     3.71e8     1   0.031 ppm        29 Garing~      17     100
##  2 01/02/2010 AQS     3.71e8     1   0.033 ppm        31 Garing~      17     100
##  3 01/03/2010 AQS     3.71e8     1   0.035 ppm        32 Garing~      17     100
##  4 01/04/2010 AQS     3.71e8     1   0.031 ppm        29 Garing~      17     100
##  5 01/05/2010 AQS     3.71e8     1   0.027 ppm        25 Garing~      17     100
##  6 01/07/2010 AQS     3.71e8     1   0.033 ppm        31 Garing~      17     100
##  7 01/08/2010 AQS     3.71e8     1   0.035 ppm        32 Garing~      17     100
##  8 01/09/2010 AQS     3.71e8     1   0.032 ppm        30 Garing~      17     100
##  9 01/10/2010 AQS     3.71e8     1   0.032 ppm        30 Garing~      17     100
## 10 01/11/2010 AQS     3.71e8     1   0.03  ppm        28 Garing~      17     100
## # ... with 350 more rows, 10 more variables: AQS_PARAMETER_CODE <dbl>,
## #   AQS_PARAMETER_DESC <chr>, CBSA_CODE <dbl>, CBSA_NAME <chr>,
## #   STATE_CODE <dbl>, STATE <chr>, COUNTY_CODE <dbl>, COUNTY <chr>,
## #   SITE_LATITUDE <dbl>, SITE_LONGITUDE <dbl>, and abbreviated variable names
## #   1: 'Site ID', 2: 'Daily Max 8-hour Ozone Concentration',
## #   3: DAILY_AQI_VALUE, 4: 'Site Name', 5: DAILY_OBS_COUNT, 6: PERCENT_COMPLETE
```

```
EPAair_O3_GaringerNC2011_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2011_raw.csv")

EPAair_O3_GaringerNC2012_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2012_raw.csv")

EPAair_O3_GaringerNC2013_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2013_raw.csv")

EPAair_O3_GaringerNC2014_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2014_raw.csv")

EPAair_O3_GaringerNC2015_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2015_raw.csv")

EPAair_O3_GaringerNC2016_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2016_raw.csv")

EPAair_O3_GaringerNC2017_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2017_raw.csv")

EPAair_O3_GaringerNC2018_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2018_raw.csv")

EPAair_O3_GaringerNC2019_raw <- read_csv("Data/Raw/Ozone_TimeSeries/EPAair_O3_GaringerNC2019_raw.csv")


# Combine data into one dataset

GaringerOzone_list <- list(EPAair_O3_GaringerNC2010_raw,EPAair_O3_GaringerNC2011_raw,
EPAair_O3_GaringerNC2012_raw,EPAair_O3_GaringerNC2013_raw,EPAair_O3_GaringerNC2014_raw,
EPAair_O3_GaringerNC2015_raw,EPAair_O3_GaringerNC2016_raw,EPAair_O3_GaringerNC2017_raw,
EPAair_O3_GaringerNC2018_raw, EPAair_O3_GaringerNC2019_raw)
```

```
GaringerOzone <- Reduce(function(x,y) merge (x, y, all = TRUE), GaringerOzone_list)
dim(GaringerOzone) # Check dimensions
```

```
## [1] 3589   20
```

Wrangle

3. Set your date column as a date class.

4. Wrangle your dataset so that it only contains the columns Date, Daily.Max.8.hour.Ozone.Concentration, and DAILY_AQI_VALUE.

5. Notice there are a few days in each year that are missing ozone concentrations. We want to generate a daily dataset, so we will need to fill in any missing days with NA. Create a new data frame that contains a sequence of dates from 2010-01-01 to 2019-12-31 (hint: `as.data.frame(seq())`). Call this new data frame Days. Rename the column name in Days to "Date".

6. Use a `left_join` to combine the data frames. Specify the correct order of data frames within this function so that the final dimensions are 3652 rows and 3 columns. Call your combined data frame GaringerOzone.

```
# 3. Set date column as date class

GaringerOzone$Date <- mdy(GaringerOzone$Date)
class(GaringerOzone$Date) #Check class
```

```
## [1] "Date"
```

```
summary(GaringerOzone)
```

```
##       Date               Source              Site ID               POC
##  Min.   :2010-01-01   Length:3589        Min.   :371190041   Min.   :1
##  1st Qu.:2012-07-03   Class :character   1st Qu.:371190041   1st Qu.:1
##  Median :2015-01-04   Mode  :character   Median :371190041   Median :1
##  Mean   :2015-01-01                      Mean   :371190041   Mean   :1
##  3rd Qu.:2017-07-02                      3rd Qu.:371190041   3rd Qu.:1
##  Max.   :2019-12-31                      Max.   :371190041   Max.   :1
##  Daily Max 8-hour Ozone Concentration    UNITS           DAILY_AQI_VALUE
##  Min.   :0.00200                     Length:3589        Min.   :  2.00
##  1st Qu.:0.03200                     Class :character   1st Qu.: 30.00
##  Median :0.04100                     Mode  :character   Median : 38.00
##  Mean   :0.04163                                        Mean   : 41.57
##  3rd Qu.:0.05100                                        3rd Qu.: 47.00
##  Max.   :0.09300                                        Max.   :169.00
##   Site Name         DAILY_OBS_COUNT PERCENT_COMPLETE AQS_PARAMETER_CODE
##  Length:3589        Min.   : 6.00   Min.   : 35.0    Min.   :44201
##  Class :character   1st Qu.:17.00   1st Qu.:100.0    1st Qu.:44201
##  Mode  :character   Median :17.00   Median :100.0    Median :44201
##                     Mean   :16.97   Mean   : 99.8    Mean   :44201
##                     3rd Qu.:17.00   3rd Qu.:100.0    3rd Qu.:44201
##                     Max.   :19.00   Max.   :100.0    Max.   :44201
```

```
##  AQS_PARAMETER_DESC   CBSA_CODE      CBSA_NAME           STATE_CODE
##  Length:3589        Min.   :16740   Length:3589        Min.   :37
##  Class :character   1st Qu.:16740   Class :character   1st Qu.:37
##  Mode  :character   Median :16740   Mode  :character   Median :37
##                     Mean   :16740                      Mean   :37
##                     3rd Qu.:16740                      3rd Qu.:37
##                     Max.   :16740                      Max.   :37
##     STATE            COUNTY_CODE     COUNTY          SITE_LATITUDE
##  Length:3589        Min.   :119   Length:3589        Min.   :35.24
##  Class :character   1st Qu.:119   Class :character   1st Qu.:35.24
##  Mode  :character   Median :119   Mode  :character   Median :35.24
##                     Mean   :119                      Mean   :35.24
##                     3rd Qu.:119                      3rd Qu.:35.24
##                     Max.   :119                      Max.   :35.24
##  SITE_LONGITUDE
##  Min.   :-80.79
##  1st Qu.:-80.79
##  Median :-80.79
##  Mean   :-80.79
##  3rd Qu.:-80.79
##  Max.   :-80.79
```

```
# 4. Subset data

GaringerOzone_processed <- GaringerOzone %>%
  select(Date, `Daily Max 8-hour Ozone Concentration`, DAILY_AQI_VALUE)

View(GaringerOzone)

# 5. Explore data
Days <- as.data.frame(seq(ymd('2010-01-01'), ymd('2019-12-31'), by = 'days'))
#Daily Dataset
head(Days) # Check data
```

```
##   seq(ymd("2010-01-01"), ymd("2019-12-31"), by = "days")
## 1                                             2010-01-01
## 2                                             2010-01-02
## 3                                             2010-01-03
## 4                                             2010-01-04
## 5                                             2010-01-05
## 6                                             2010-01-06
```

```
## Get column name

colnames(Days)
```

```
## [1] "seq(ymd(\"2010-01-01\"), ymd(\"2019-12-31\"), by = \"days\")"
```

```
## Rename column days to date

Days <- Days %>%
  rename(Date = "seq(ymd(\"2010-01-01\"), ymd(\"2019-12-31\"), by = \"days\")")
```

```
head(Days) #Check column name change
```

```
##         Date
## 1 2010-01-01
## 2 2010-01-02
## 3 2010-01-03
## 4 2010-01-04
## 5 2010-01-05
## 6 2010-01-06
```

```
# 6.Join days and GaringerOzone

GaringerOzone <- left_join(Days, GaringerOzone_processed) #Rewrite GaringerOzone
```

```
## Joining, by = "Date"
```

```
dim(GaringerOzone) # Check dimensions
```

```
## [1] 3652    3
```

```
head(GaringerOzone) #Check data
```

```
##         Date Daily Max 8-hour Ozone Concentration DAILY_AQI_VALUE
## 1 2010-01-01                                0.031              29
## 2 2010-01-02                                0.033              31
## 3 2010-01-03                                0.035              32
## 4 2010-01-04                                0.031              29
## 5 2010-01-05                                0.027              25
## 6 2010-01-06                                   NA              NA
```

```
summary(GaringerOzone)
```

```
##       Date            Daily Max 8-hour Ozone Concentration DAILY_AQI_VALUE
##  Min.   :2010-01-01   Min.   :0.00200                      Min.   :  2.00
##  1st Qu.:2012-07-01   1st Qu.:0.03200                      1st Qu.: 30.00
##  Median :2014-12-31   Median :0.04100                      Median : 38.00
##  Mean   :2014-12-31   Mean   :0.04163                      Mean   : 41.57
##  3rd Qu.:2017-07-01   3rd Qu.:0.05100                      3rd Qu.: 47.00
##  Max.   :2019-12-31   Max.   :0.09300                      Max.   :169.00
##                       NA's   :63                           NA's   :63
```

Visualize

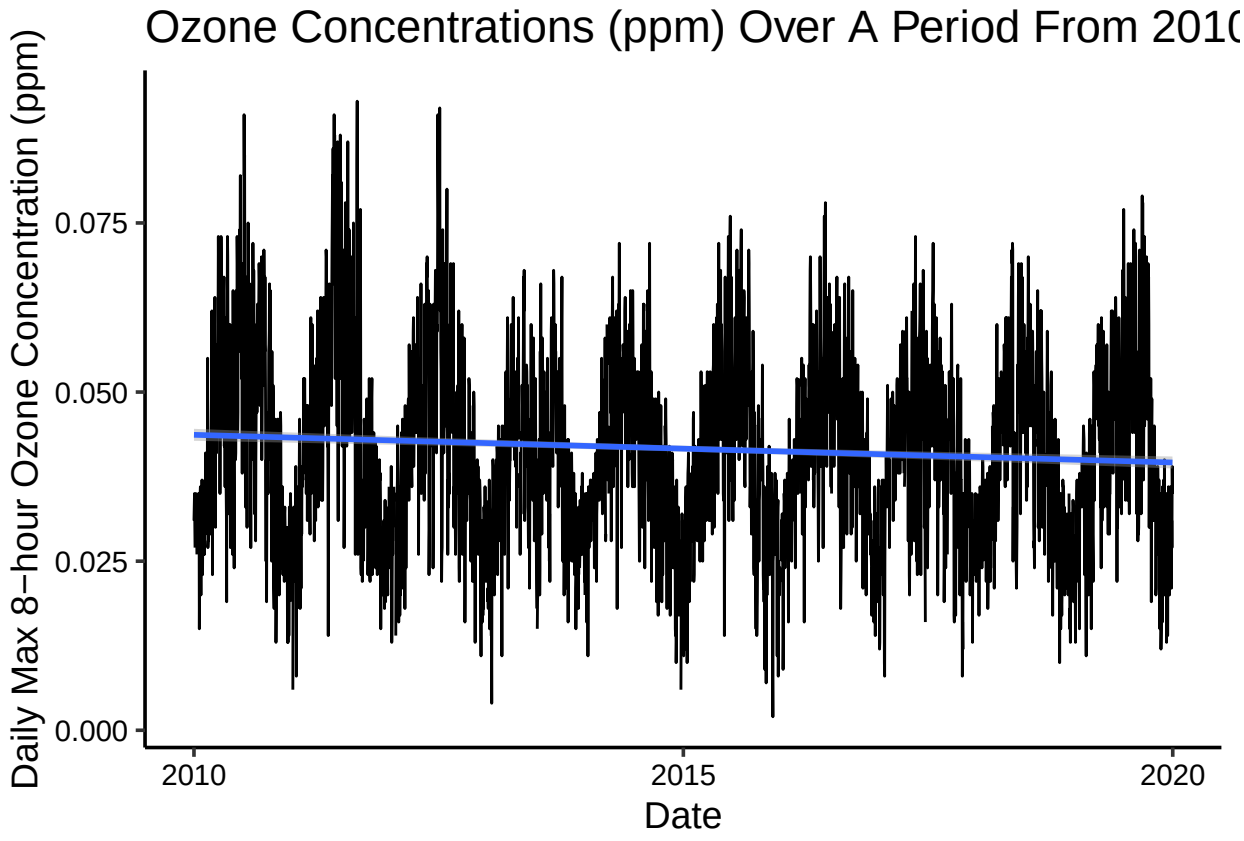
7. Create a line plot depicting ozone concentrations over time. In this case, we will plot actual concentrations in ppm, not AQI values. Format your axes accordingly. Add a smoothed line showing any linear trend of your data. Does your plot suggest a trend in ozone concentration over time?

```
#7. Plot line graph

class(GaringerOzone$`Daily Max 8-hour Ozone Concentration`)
```

```
## [1] "numeric"
```

```
ggplot(GaringerOzone, aes(x = Date, y = `Daily Max 8-hour Ozone Concentration`))+
  geom_line() +
  ylab("Daily Max 8-hour Ozone Concentration (ppm)")+
   geom_smooth (method = "lm") +
  ggtitle ("Ozone Concentrations (ppm) Over A Period From 2010 to 2019")
```

```
## `geom_smooth()` using formula 'y ~ x'

## Warning: Removed 63 rows containing non-finite values (stat_smooth).
```



Answer: There is a slight decline in ozone concentration (ppm) seen over the period.

Time Series Analysis

Study question: Have ozone concentrations changed over the 2010s at this station?

8. Use a linear interpolation to fill in missing daily data for ozone concentration. Why didn't we use a piecewise constant or spline interpolation?

```
#8. Linear interpolation


GaringerOzone_interpolate <- GaringerOzone %>%
  mutate(Ozone_Concentration_cont = na.approx(`Daily Max 8-hour Ozone Concentration`))

summary(GaringerOzone_interpolate) # View data
```

```
##       Date            Daily Max 8-hour Ozone Concentration DAILY_AQI_VALUE
##  Min.   :2010-01-01   Min.   :0.00200                      Min.   :  2.00
##  1st Qu.:2012-07-01   1st Qu.:0.03200                      1st Qu.: 30.00
##  Median :2014-12-31   Median :0.04100                      Median : 38.00
##  Mean   :2014-12-31   Mean   :0.04163                      Mean   : 41.57
##  3rd Qu.:2017-07-01   3rd Qu.:0.05100                      3rd Qu.: 47.00
##  Max.   :2019-12-31   Max.   :0.09300                      Max.   :169.00
##                       NA's   :63                           NA's   :63
##  Ozone_Concentration_cont
##  Min.   :0.00200
##  1st Qu.:0.03200
##  Median :0.04100
##  Mean   :0.04151
##  3rd Qu.:0.05100
##  Max.   :0.09300
##
```

Answer: We did not use the piecewise function as we wanted to fill the gaps by predicting the value that may be miss from the trend based what we assummed may fall between two measurements rather than filling the data with data that is equal to the measurement neasrest to the date. This approach of "connecting the dots" rather than nearest nesighbor" is perhaps better suited because we see a slight decline in the trend of the data. The spline approach is not suited for this interpolation as the trend is more consistent with a striaght line rather than a quadratic function.

9. Create a new data frame called `GaringerOzone.monthly` that contains aggregated data: mean ozone concentrations for each month. In your pipe, you will need to first add columns for year and month to form the groupings. In a separate line of code, create a new Date column with each month-year combination being set as the first day of the month (this is for graphing purposes only)

```
#9.

GaringerOzone.monthly <- GaringerOzone_interpolate %>%
  mutate(Year = year(Date)) %>%
  mutate(Month = month(Date)) %>%
  mutate (Month_Year = my(paste0(Month,"-", Year))) %>%
  group_by(Month,Year, Month_Year) %>%
  summarise(MeanOzone = mean(Ozone_Concentration_cont))
```

```
## `summarise()` has grouped output by 'Month', 'Year'. You can override using the
## `.groups` argument.
```

```
head(GaringerOzone.monthly) # View data
```

```
## # A tibble: 6 x 4
## # Groups:   Month, Year [6]
##   Month  Year Month_Year MeanOzone
##   <dbl> <dbl> <date>         <dbl>
## 1     1  2010 2010-01-01    0.0305
## 2     1  2011 2011-01-01    0.0266
## 3     1  2012 2012-01-01    0.0288
## 4     1  2013 2013-01-01    0.0271
## 5     1  2014 2014-01-01    0.0310
## 6     1  2015 2015-01-01    0.0286
```

10. Generate two time series objects. Name the first `GaringerOzone.daily.ts` and base it on the dataframe of daily observations. Name the second `GaringerOzone.monthly.ts` and base it on the monthly average ozone values. Be sure that each specifies the correct start and end dates and the frequency of the time series.

```
#10.

#Daily time series

GaringerOzone.daily.ts <- ts(GaringerOzone_interpolate$Ozone_Concentration_cont,
                             start = c(2010,1), frequency = 365)
head (GaringerOzone.daily.ts)
```

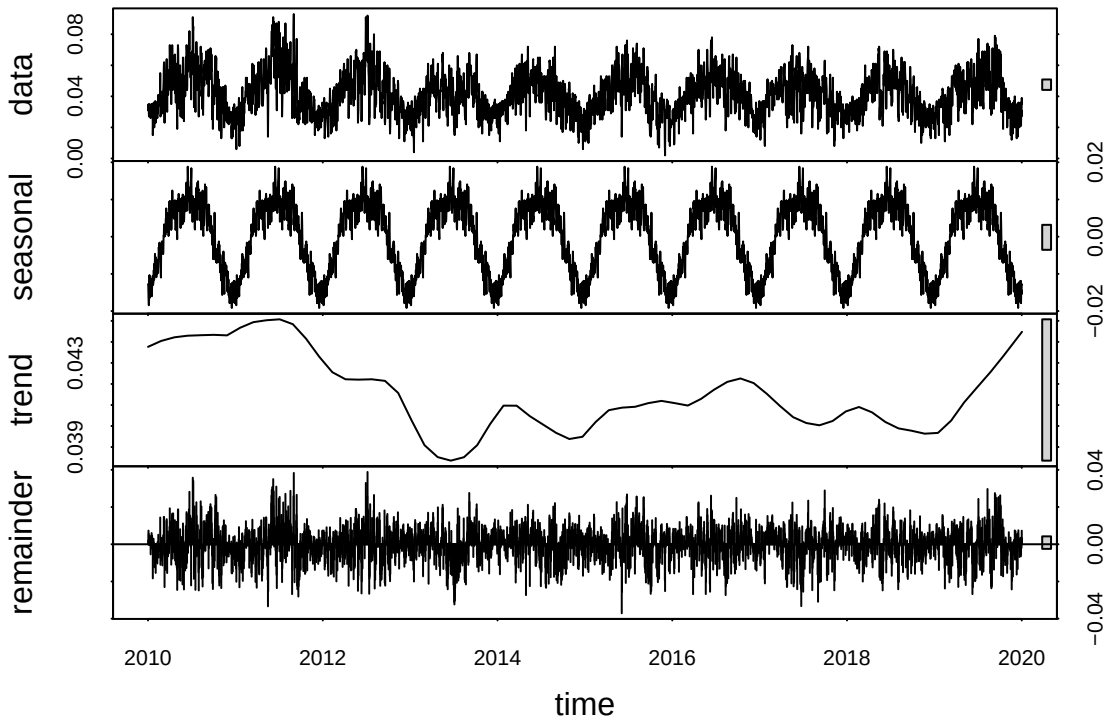
```
## [1] 0.031 0.033 0.035 0.031 0.027 0.030
```

```
#Monthly time series

Garinger.monthly.ts <- ts(GaringerOzone.monthly$MeanOzone, start = c(2010,1),
                          frequency = 12)
head (Garinger.monthly.ts)
```

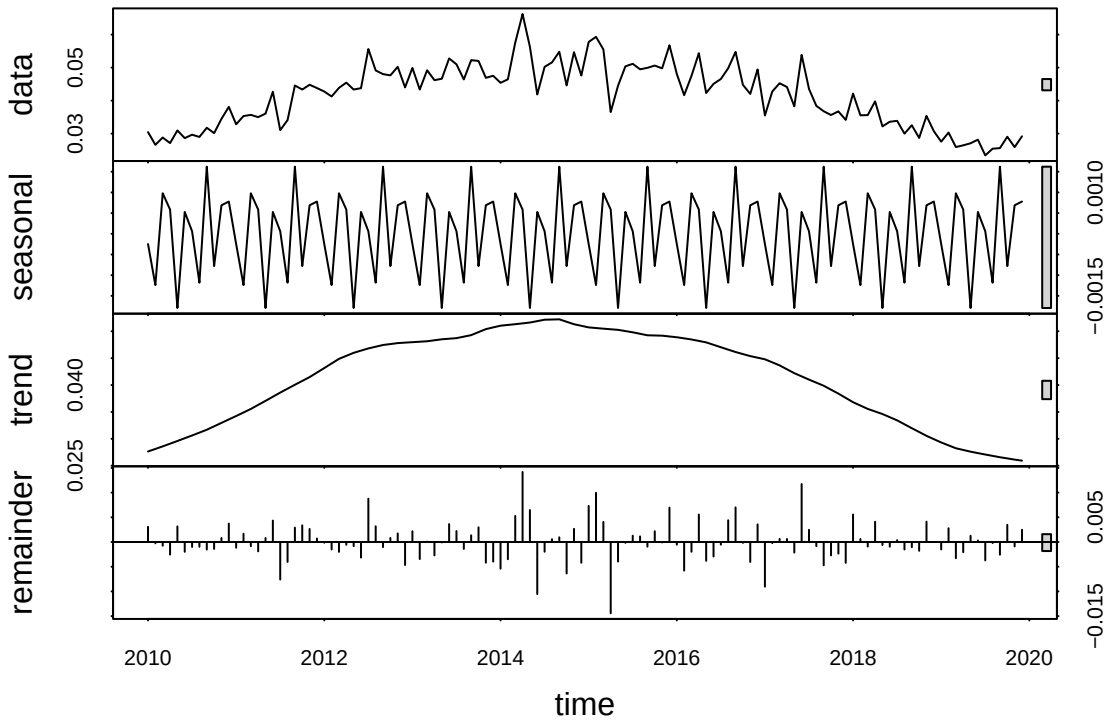
```
## [1] 0.03046774 0.02661290 0.02882258 0.02712903 0.03096774 0.02864516
```

11. Decompose the daily and the monthly time series objects and plot the components using the `plot()` function.

```
#11.

#Decompose the daily time series

GaringerOzone.daily_decomposed <- stl(GaringerOzone.daily.ts,
                                      s.window = "periodic")
plot(GaringerOzone.daily_decomposed)
```




```
#Decompose the monthly time series

Garinger.monthly.decomposed <- stl(Garinger.monthly.ts, s.window = "periodic")
plot(Garinger.monthly.decomposed)
```



12. Run a monotonic trend analysis for the monthly Ozone series. In this case the seasonal Mann-Kendall is most appropriate; why is this?

```
#12. Run the seasonal Mann-Kendall


GaringerOzone.monthly_trend <- Kendall::SeasonalMannKendall(Garinger.monthly.ts)
GaringerOzone.monthly_trend
```

```
## tau = -0.1, 2-sided pvalue =0.16323
```

```
summary(GaringerOzone.monthly_trend)
```

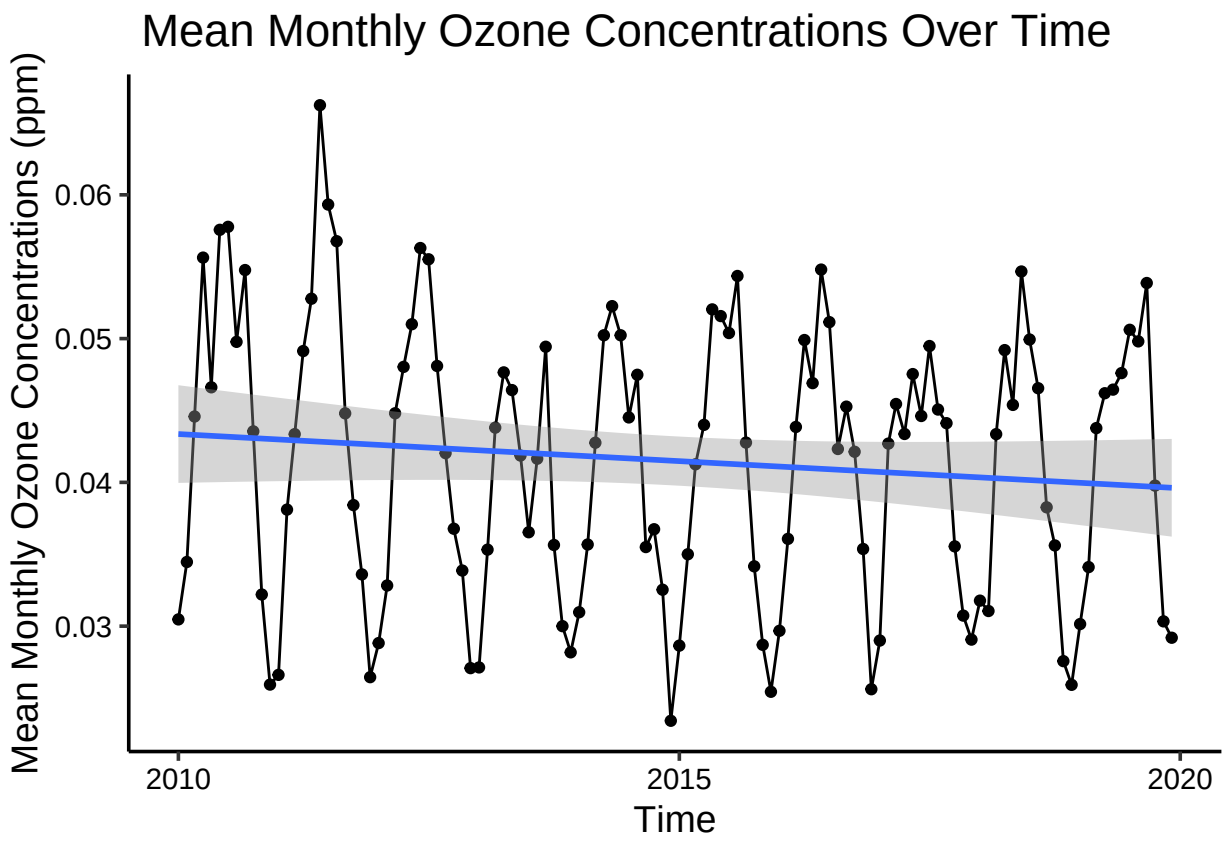
```
## Score =  -54 , Var(Score) = 1500
## denominator =  540
## tau = -0.1, 2-sided pvalue =0.16323
```

Answer: In this case, the seasonal Mann-Kendall is the most appropriate as there is a seasonal component to the time series.

13. Create a plot depicting mean monthly ozone concentrations over time, with both a geom_point and a geom_line layer. Edit your axis labels accordingly.

```r
# 13. Plot

ggplot(GaringerOzone.monthly, aes(x = Month_Year, y = MeanOzone)) +
  geom_line() +
  geom_point() +
  xlab("Time") +
  ylab ("Mean Monthly Ozone Concentrations (ppm)") +
  ggtitle (" Mean Monthly Ozone Concentrations Over Time") +
  geom_smooth(method = lm)
```

```
## `geom_smooth()` using formula 'y ~ x'
```



14. To accompany your graph, summarize your results in context of the research question. Include output from the statistical test in parentheses at the end of your sentence. Feel free to use multiple sentences in your interpretation.

    Answer: In the original plot, there was a slight decline seen in ozone concentrations over time. The results of the Mann-Kendall test indicates that the decline seen is insignificant, p =0.16323 and tau = -0.1, for the monthly trend.

15. Subtract the seasonal component from the `GaringerOzone.monthly.ts`. Hint: Look at how we extracted the series components for the EnoDischarge on the lesson Rmd file.

16. Run the Mann Kendall test on the non-seasonal Ozone monthly series. Compare the results with the ones obtained with the Seasonal Mann Kendall on the complete series.

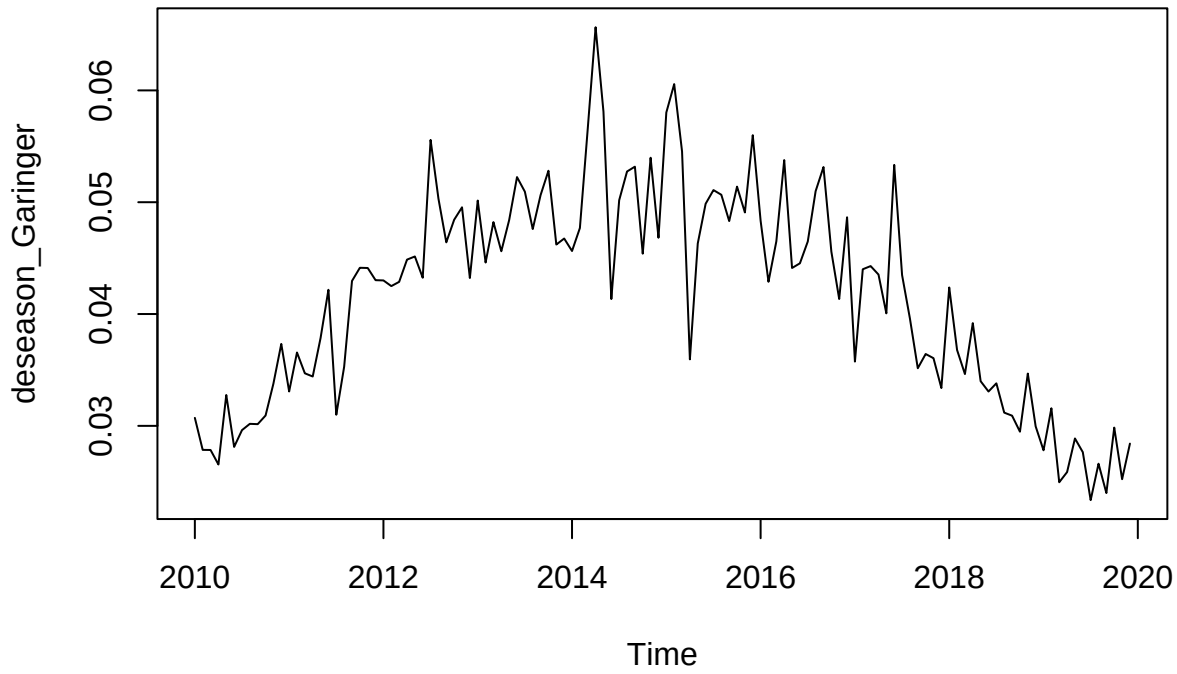
```
#15

Garinger.monthly.decomposed$time.series #View time series
```

```
##               seasonal      trend     remainder
## Jan 2010 -2.479523e-04 0.02764103  3.074662e-03
## Feb 2010 -1.239249e-03 0.02811666 -2.645067e-04
## Mar 2010  9.785830e-04 0.02859229 -7.482879e-04
## Apr 2010  5.855271e-04 0.02909129 -2.547788e-03
## May 2010 -1.793422e-03 0.02959030  3.170862e-03
## Jun 2010  5.278334e-04 0.03010575 -1.988427e-03
## Jul 2010  6.023144e-05 0.03062121 -1.004020e-03
## Aug 2010 -1.181396e-03 0.03115191 -9.705174e-04
## Sep 2010  1.622089e-03 0.03168262 -1.530514e-03
## Oct 2010 -7.808949e-04 0.03232091 -1.394852e-03
## Nov 2010  6.896486e-04 0.03295920  8.154396e-04
## Dec 2010  7.790005e-04 0.03359752  3.730624e-03
## Jan 2011 -2.479523e-04 0.03423584 -1.160300e-03
## Feb 2011 -1.239249e-03 0.03489433  1.666347e-03
## Mar 2011  9.785830e-04 0.03555282 -8.528338e-04
## Apr 2011  5.855271e-04 0.03630494 -1.890466e-03
## May 2011 -1.793422e-03 0.03705706  8.053314e-04
## Jun 2011  5.278334e-04 0.03782513  4.343468e-03
## Jul 2011  6.023144e-05 0.03859320 -7.599859e-03
## Aug 2011 -1.181396e-03 0.03932144 -4.032904e-03
## Sep 2011  1.622089e-03 0.04004968  2.908871e-03
## Oct 2011 -7.808949e-04 0.04076246  3.373277e-03
## Nov 2011  6.896486e-04 0.04147523  2.641575e-03
## Dec 2011  7.790005e-04 0.04231643  7.110250e-04
## Jan 2012 -2.479523e-04 0.04315762 -1.516072e-04
## Feb 2012 -1.239249e-03 0.04401268 -1.515370e-03
## Mar 2012  9.785830e-04 0.04486774 -1.991488e-03
## Apr 2012  5.855271e-04 0.04542865 -5.625594e-04
## May 2012 -1.793422e-03 0.04598955 -8.412863e-04
## Jun 2012  5.278334e-04 0.04639654 -3.150177e-03
## Jul 2012  6.023144e-05 0.04680353  8.769575e-03
## Aug 2012 -1.181396e-03 0.04712360  3.191132e-03
## Sep 2012  1.622089e-03 0.04744367 -1.032423e-03
## Oct 2012 -7.808949e-04 0.04762112  8.097771e-04
## Nov 2012  6.896486e-04 0.04779857  1.745116e-03
## Dec 2012  7.790005e-04 0.04788477 -4.663769e-03
## Jan 2013 -2.479523e-04 0.04797097  2.176984e-03
## Feb 2013 -1.239249e-03 0.04805548 -3.449564e-03
## Mar 2013  9.785830e-04 0.04813999  8.142592e-05
## Apr 2013  5.855271e-04 0.04832306 -2.708589e-03
## May 2013 -1.793422e-03 0.04850613 -9.980757e-05
## Jun 2013  5.278334e-04 0.04861269  3.633668e-03
## Jul 2013  6.023144e-05 0.04871925  2.220517e-03
## Aug 2013 -1.181396e-03 0.04899888 -1.398128e-03
## Sep 2013  1.622089e-03 0.04927851  1.357470e-03
## Oct 2013 -7.808949e-04 0.04983836  2.974792e-03
## Nov 2013  6.896486e-04 0.05039822 -4.184639e-03
## Dec 2013  7.790005e-04 0.05071778 -3.964522e-03
```

```
## Jan 2014 -2.479523e-04 0.05103734 -5.402294e-03
## Feb 2014 -1.239249e-03 0.05117568 -3.484822e-03
## Mar 2014  9.785830e-04 0.05131403  5.274058e-03
## Apr 2014  5.855271e-04 0.05146641  1.418140e-02
## May 2014 -1.793422e-03 0.05161879  6.474628e-03
## Jun 2014  5.278334e-04 0.05188143 -1.054259e-02
## Jul 2014  6.023144e-05 0.05214406 -1.970960e-03
## Aug 2014 -1.181396e-03 0.05218337  5.646935e-04
## Sep 2014  1.622089e-03 0.05222268  9.552343e-04
## Oct 2014 -7.808949e-04 0.05176634 -6.368777e-03
## Nov 2014  6.896486e-04 0.05131000  2.667017e-03
## Dec 2014  7.790005e-04 0.05101351 -4.192507e-03
## Jan 2015 -2.479523e-04 0.05071701  7.305135e-03
## Feb 2015 -1.239249e-03 0.05059878  9.963053e-03
## Mar 2015  9.785830e-04 0.05048054  4.057003e-03
## Apr 2015  5.855271e-04 0.05037211 -1.442538e-02
## May 2015 -1.793422e-03 0.05026367 -3.954123e-03
## Jun 2015  5.278334e-04 0.05003441 -1.751436e-04
## Jul 2015  6.023144e-05 0.04980514  1.279789e-03
## Aug 2015 -1.181396e-03 0.04952835  1.136913e-03
## Sep 2015  1.622089e-03 0.04925157 -9.381718e-04
## Oct 2015 -7.808949e-04 0.04921667  2.177132e-03
## Nov 2015  6.896486e-04 0.04918177 -9.722137e-05
## Dec 2015  7.790005e-04 0.04903220  6.962991e-03
## Jan 2016 -2.479523e-04 0.04888264 -5.379108e-04
## Feb 2016 -1.239249e-03 0.04867793 -5.793524e-03
## Mar 2016  9.785830e-04 0.04847323 -1.967944e-03
## Apr 2016  5.855271e-04 0.04820236  5.566947e-03
## May 2016 -1.793422e-03 0.04793150 -3.815495e-03
## Jun 2016  5.278334e-04 0.04747973 -2.943049e-03
## Jul 2016  6.023144e-05 0.04702797 -5.398108e-04
## Aug 2016 -1.181396e-03 0.04658378  4.404064e-03
## Sep 2016  1.622089e-03 0.04613960  7.004977e-03
## Oct 2016 -7.808949e-04 0.04575942 -1.785207e-04
## Nov 2016  6.896486e-04 0.04537923 -4.035546e-03
## Dec 2016  7.790005e-04 0.04508389  3.570444e-03
## Jan 2017 -2.479523e-04 0.04478855 -9.040594e-03
## Feb 2017 -1.239249e-03 0.04422105 -2.151369e-04
## Mar 2017  9.785830e-04 0.04365356  6.345248e-04
## Apr 2017  5.855271e-04 0.04292783  6.033138e-04
## May 2017 -1.793422e-03 0.04220209 -2.142004e-03
## Jun 2017  5.278334e-04 0.04160637  1.173246e-02
## Jul 2017  6.023144e-05 0.04101064  2.477511e-03
## Aug 2017 -1.181396e-03 0.04043867 -8.379198e-04
## Sep 2017  1.622089e-03 0.03986670 -4.714592e-03
## Oct 2017 -7.808949e-04 0.03913450 -2.708446e-03
## Nov 2017  6.896486e-04 0.03840231 -2.350021e-03
## Dec 2017  7.790005e-04 0.03760462 -4.222331e-03
## Jan 2018 -2.479523e-04 0.03680693  5.570050e-03
## Feb 2018 -1.239249e-03 0.03618298  6.046529e-04
## Mar 2018  9.785830e-04 0.03555903 -9.247119e-04
## Apr 2018  5.855271e-04 0.03508225  4.106412e-03
## May 2018 -1.793422e-03 0.03460548 -6.120551e-04
## Jun 2018  5.278334e-04 0.03401881 -9.466447e-04
```

```
## Jul 2018  6.023144e-05 0.03343215  3.742894e-04
## Aug 2018 -1.181396e-03 0.03270129 -1.519898e-03
## Sep 2018  1.622089e-03 0.03197044 -1.059197e-03
## Oct 2018 -7.808949e-04 0.03126175 -1.780852e-03
## Nov 2018  6.896486e-04 0.03055305  4.123964e-03
## Dec 2018  7.790005e-04 0.02993621  1.812584e-05
## Jan 2019 -2.479523e-04 0.02931936 -1.504741e-03
## Feb 2019 -1.239249e-03 0.02878129  2.791295e-03
## Mar 2019  9.785830e-04 0.02824321 -3.286313e-03
## Apr 2019  5.855271e-04 0.02792644 -2.060355e-03
## May 2019 -1.793422e-03 0.02760967  1.264399e-03
## Jun 2019  5.278334e-04 0.02734288  3.067044e-04
## Jul 2019  6.023144e-05 0.02707610 -3.716972e-03
## Aug 2019 -1.181396e-03 0.02682465 -2.077725e-04
## Sep 2019  1.622089e-03 0.02657321 -2.582395e-03
## Oct 2019 -7.808949e-04 0.02635189  3.493524e-03
## Nov 2019  6.896486e-04 0.02613056 -9.008583e-04
## Dec 2019  7.790005e-04 0.02593946  2.475090e-03
```

```r
deseason_Garinger <- Garinger.monthly.ts - Garinger.monthly.decomposed$time.series[,1]
plot(deseason_Garinger) # Check Seasonality
```




```r
#16

GaringerOzone.monthly_trend.deseason <- MannKendall(deseason_Garinger)
summary(GaringerOzone.monthly_trend.deseason)
```

```
## Score =  -718 , Var(Score) = 194366.7
## denominator =  7140
## tau = -0.101, 2-sided pvalue =0.10388
```

Answer: My results remain synonymous with the output obtained with the seasonal Mann-Kendall. These results also indicate that the slight decline seen in Ozone concentrations over the period of 2010 - 2019 was not significant, p = 0.10388 and tau = 0.1.