Assignment 8: Time Series Analysis

Caroline Watson

```
warning = FALSE
message = FALSE
```

OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics (ENV872L) on time series analysis.

Directions

1. Change "Student Name" on line 3 (above) with your name.
2. Use the lesson as a guide. It contains code that can be modified to complete the assignment.
3. Work through the steps, **creating code and output** that fulfill each instruction.
4. Be sure to **answer the questions** in this assignment document. Space for your answers is provided in this document and is indicated by the ">" character. If you need a second paragraph be sure to start the first line with ">". You should notice that the answer is highlighted in green by RStudio.
5. When you have completed the assignment, **Knit** the text and code into a single PDF file. You will need to have the correct software installed to do this (see Software Installation Guide) Press the `Knit` button in the RStudio scripting panel. This will save the PDF output in your Assignments folder.
6. After Knitting, please submit the completed exercise (PDF file) to the dropbox in Sakai. Please add your last name into the file name (e.g., "Salk_A08_TimeSeries.pdf") prior to submission.

The completed exercise is due on Tuesday, 19 March, 2019 before class begins.

Brainstorm a project topic

1. Spend 15 minutes brainstorming ideas for a project topic, and look for a dataset if you are choosing your own rather than using a class dataset. Remember your topic choices are due by the end of March, and you should post your choice ASAP to the forum on Sakai.

Question: Did you do this?

> ANSWER: Yes and I posted my research question and dataset to the forum on Sakai.

Set up your session

2. Set up your session. Upload the EPA air quality raw dataset for PM2.5 in 2018, and the processed NTL-LTER dataset for nutrients in Peter and Paul lakes. Build a ggplot theme and set it as your default theme. Make sure date variables are set to a date format.

```
getwd()
```

```
## [1] "/Users/carolinewatson/Documents/Spring 2019/Environmental Data Analytics/Env_Data_Analytics/Ass
```

```
suppressMessages(library(tidyverse))
library(viridis)
```

```
## Loading required package: viridisLite
```

```
library(gridExtra)
```

```
##
## Attaching package: 'gridExtra'
```

```
## The following object is masked from 'package:dplyr':
##
##     combine
```

```
library(RColorBrewer)
library(colormap)
library(dplyr)
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
```

```
## The following object is masked from 'package:base':
##
##     date
```

```
library(nlme)
```

```
##
## Attaching package: 'nlme'
```

```
## The following object is masked from 'package:dplyr':
##
##     collapse
```

```
library(lsmeans)
```

```
## Loading required package: emmeans
```

```
## The 'lsmeans' package is now basically a front end for 'emmeans'.
## Users are encouraged to switch the rest of the way.
## See help('transition') for more information, including how to
## convert old 'lsmeans' objects and scripts to work with 'emmeans'.
```

```
library(multcompView)
library(trend)

#uploading EPA Air Quality raw data for PM2.5 in 2018
epa_air2018 <- read.csv("../Data/Raw/EPAair_PM25_NC2018_raw.csv")

#uploading NTL-LTER processed data set for nutrients in Peter and Paul Lakes
nutrients_peterpaul <- read.csv("../Data/Processed/NTL-LTER_Lake_Nutrients_PeterPaul_Processed.csv")

#creating ggplot theme
caroline_theme <- theme_classic(base_size = 16) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "right")

theme_set(caroline_theme)

#checking date classes in datasets
class(epa_air2018$Date)
```

```
## [1] "factor"
```

```r
class(nutrients_peterpaul$sampledate)
```

```
## [1] "factor"
```

```r
#changing date column to date format
epa_air2018$Date <- as.Date(epa_air2018$Date, format = "%m/%d/%y")

nutrients_peterpaul$sampledate <- as.Date(nutrients_peterpaul$sampledate, format = "%Y-%m-%d")
```

Run a hierarchical (mixed-effects) model

Research question: Do PM2.5 concentrations have a significant trend in 2018?

3. Run a repeated measures ANOVA, with PM2.5 concentrations as the response, Date as a fixed effect, and Site.Name as a random effect. This will allow us to extrapolate PM2.5 concentrations across North Carolina.

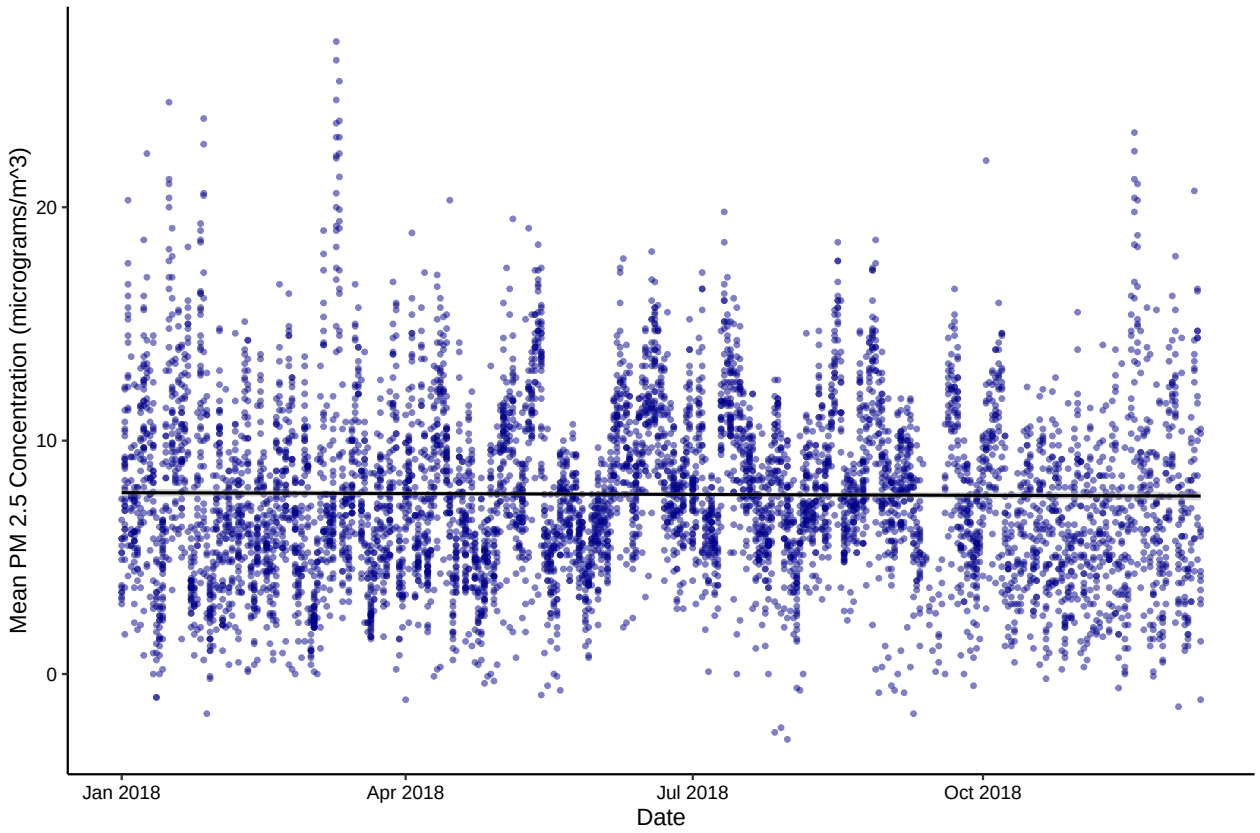
3a. Illustrate PM2.5 concentrations by date. Do not split aesthetics by site.

```r
#renaming PM concentration column
colnames(epa_air2018)[5] <- c("PM2.5")

#remove NAs from dataset
epa_airwrangled <- epa_air2018 %>%
  na.exclude()

#3a. repeated measures ANOVA
epaAirTest_mixed <- lme(data = epa_airwrangled,
                        PM2.5 ~ Date,
                       random = ~1|Site.Name)
summary(epaAirTest_mixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: epa_airwrangled
##        AIC      BIC    logLik
##   35104.9 35132.07 -17548.45
##
## Random effects:
##  Formula: ~1 | Site.Name
##         (Intercept) Residual
## StdDev:    1.728641 3.450187
##
## Fixed effects: PM2.5 ~ Date
##                 Value Std.Error   DF   t-value p-value
## (Intercept) 14.297350  7.965514 6566  1.794906  0.0727
## Date        -0.000391  0.000450 6566 -0.870232  0.3842
##  Correlation:
##      (Intr)
## Date -0.999
##
## Standardized Within-Group Residuals:
##        Min         Q1        Med         Q3        Max
## -3.4360977 -0.6896514 -0.1274684  0.6008556  5.2500490
##
## Number of Observations: 6586
```

```
## Number of Groups: 19
```

```
#illustrate repeated measures ANOVA
ggplot(epa_airwrangled, aes(x = Date, y = PM2.5)) +
  geom_point(color = "dark blue", alpha = 0.5) +
  labs(x = "Date", y = "Mean PM 2.5 Concentration (micrograms/m^3)") +
  geom_smooth(method = "lm", color = "black")
```



3b. Insert the following line of code into your R chunk. This will eliminate duplicate measurements on single dates for each site. PM2.5 = PM2.5[order(PM2.5[,'Date'],-PM2.5[,'Site.ID']),] PM2.5 = PM2.5[!duplicated(PM2.5$Date),]

3c. Determine the temporal autocorrelation in your model.

3d. Run a mixed effects model.

```
#3b. inserting chunk to get rid of duplicate measurements on a single date
epa_airwrangled2 = epa_airwrangled[order(epa_airwrangled[,'Date'],-epa_airwrangled[,'Site.ID']),]
epa_airwrangled2 = epa_airwrangled2[!duplicated(epa_airwrangled2$Date),]

#3c. temporal autocorrelation
epaAirTest_mixed2 <- lme(data = epa_airwrangled2,
                         PM2.5 ~ Date,
                        random = ~1|Site.Name)
summary(epaAirTest_mixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: epa_airwrangled
##        AIC      BIC    logLik
##   35104.9 35132.07 -17548.45
```

```
##
## Random effects:
##  Formula: ~1 | Site.Name
##         (Intercept) Residual
## StdDev:    1.728641 3.450187
##
## Fixed effects: PM2.5 ~ Date
##                 Value Std.Error   DF   t-value p-value
## (Intercept) 14.297350  7.965514 6566  1.794906  0.0727
## Date        -0.000391  0.000450 6566 -0.870232  0.3842
##  Correlation:
##      (Intr)
## Date -0.999
##
## Standardized Within-Group Residuals:
##        Min         Q1        Med         Q3        Max
## -3.4360977 -0.6896514 -0.1274684  0.6008556  5.2500490
##
## Number of Observations: 6586
## Number of Groups: 19
```

```
ACF(epaAirTest_mixed2)
```

```
##    lag          ACF
## 1    0  1.000000000
## 2    1  0.515649380
## 3    2  0.194630440
## 4    3  0.118437238
## 5    4  0.127546199
## 6    5  0.101062520
## 7    6  0.058085196
## 8    7 -0.052907307
## 9    8  0.017656228
## 10   9  0.012029022
## 11  10 -0.003788449
## 12  11 -0.020205308
## 13  12 -0.044426855
## 14  13 -0.055382050
## 15  14 -0.065561649
## 16  15 -0.123576691
## 17  16 -0.055173547
## 18  17  0.002979207
## 19  18  0.025150933
## 20  19 -0.015170235
## 21  20 -0.143012523
## 22  21 -0.155027059
## 23  22 -0.060167417
## 24  23  0.003982492
## 25  24  0.042233417
## 26  25  0.001384018
```

```
#3d. Mixed effects model
epa.air.mixed <- lme(data = epa_airwrangled2,
                     PM2.5 ~ Date,
                     random = ~1|Site.Name,
```

```
                    correlation = corAR1(form = ~ Date|Site.Name, value = 0.515),
                    method = "REML")

summary(epa.air.mixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: epa_airwrangled2
##        AIC      BIC    logLik
##   1760.033 1779.192 -875.0163
##
## Random effects:
##  Formula: ~1 | Site.Name
##         (Intercept) Residual
## StdDev:   0.9366661 3.586786
##
## Correlation Structure: ARMA(1,0)
##  Formula: ~Date | Site.Name
##  Parameter estimate(s):
##      Phi1
## 0.5324827
## Fixed effects: PM2.5 ~ Date
##                 Value Std.Error  DF   t-value p-value
## (Intercept) 86.46530  59.96524 337  1.441923  0.1503
## Date        -0.00449   0.00338 337 -1.325756  0.1858
##  Correlation:
##      (Intr)
## Date -1
##
## Standardized Within-Group Residuals:
##        Min         Q1        Med         Q3        Max
## -2.3339408 -0.6212666 -0.1099967  0.6243141  3.4234858
##
## Number of Observations: 343
## Number of Groups: 5
```

Is there a significant increasing or decreasing trend in PM2.5 concentrations in 2018?

> ANSWER: The trend is decreaseing because the slope is negative. The p-value is greater than 0.05, so the trend is not significant for PM2.5 concentrations in 2018.

3e. Run a fixed effects model with Date as the only explanatory variable. Then test whether the mixed effects model is a better fit than the fixed effect model.

```
#3e. fixed effects model
epa_air_fixed <- gls(data = epa_airwrangled2,
                    PM2.5 ~ Date)

summary(epa_air_fixed)
```

```
## Generalized least squares fit by REML
##   Model: PM2.5 ~ Date
##   Data: epa_airwrangled2
##        AIC      BIC    logLik
##   1865.261 1876.757 -929.6307
##
## Coefficients:
```

```
##                Value Std.Error   t-value p-value
## (Intercept) 98.66793  34.60585  2.851192  0.0046
## Date        -0.00514   0.00195 -2.627388  0.0090
##
##  Correlation:
##      (Intr)
## Date -1
##
## Standardized residuals:
##        Min         Q1        Med         Q3        Max
## -2.3528126 -0.6429287 -0.1150800  0.6385145  3.4060776
##
## Residual standard error: 3.584632
## Degrees of freedom: 343 total; 341 residual
```

```
#comparing the mixed effects and fixed effects model
anova(epa_air_fixed, epa.air.mixed)
```

```
##                Model df      AIC      BIC    logLik   Test  L.Ratio p-value
## epa_air_fixed      1  3 1865.261 1876.757 -929.6307
## epa.air.mixed      2  5 1760.033 1779.192 -875.0163 1 vs 2 109.2288  <.0001
```

Which model is better?

> ANSWER: The mixed effect model is better because the AIC score is lower than the AIC score for the fixed effect model.

Run a Mann-Kendall test

Research question: Is there a trend in total N surface concentrations in Peter and Paul lakes?

4. Duplicate the Mann-Kendall test we ran for total P in class, this time with total N for both lakes. Make sure to run a test for changepoints in the datasets (and run a second one if a second change point is likely).

```
# Wrangle our dataset
Nutrients.peterpaul.surface <-
  nutrients_peterpaul %>%
  select(-lakeid, -depth_id, -comments) %>%
  filter(depth == 0) %>%
  filter(!is.na(tn_ug))

#splitting lake data up into each lake
Nutrients.peter.surface <- filter(Nutrients.peterpaul.surface, lakename == "Peter Lake")

Nutrients.paul.surface <- filter(Nutrients.peterpaul.surface, lakename == "Paul Lake")

#Mann-Kendall test for total N in Peter and Paul lakes
mk.test(Nutrients.peter.surface$tn_ug)
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.peter.surface$tn_ug
## z = 7.2927, n = 98, p-value = 3.039e-13
## alternative hypothesis: true S is not equal to 0
```

```
## sample estimates:
##            S         varS          tau
## 2.377000e+03 1.061503e+05 5.001052e-01
```

```
mk.test(Nutrients.paul.surface$tn_ug)
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.paul.surface$tn_ug
## z = -0.35068, n = 99, p-value = 0.7258
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -1.170000e+02  1.094170e+05 -2.411874e-02
```

```
#running a Pettitt test to see if there is a change point
pettitt.test(Nutrients.peter.surface$tn_ug) #changepoint for Peter lake is noted at row 36
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  Nutrients.peter.surface$tn_ug
## U* = 1884, p-value = 3.744e-10
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              36
```

```
pettitt.test(Nutrients.paul.surface$tn_ug) #change point noted at 16 for Paul Lake
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  Nutrients.paul.surface$tn_ug
## U* = 704, p-value = 0.09624
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              16
```

```
#running another Mann-Kendall test before and after change point for Peter Lake
mk.test(Nutrients.peter.surface$tn_ug[1:35]) #p-value close to 1 and
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.peter.surface$tn_ug[1:35]
## z = -0.22722, n = 35, p-value = 0.8203
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
##  -17.00000000 4958.33333333   -0.02857143
```

```
#negative z score, so no trend detected
mk.test(Nutrients.peter.surface$tn_ug[36:98]) #p-value smaller than one
```

```
##
```

```
##  Mann-Kendall trend test
##
## data:  Nutrients.peter.surface$tn_ug[36:98]
## z = 3.1909, n = 63, p-value = 0.001418
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 5.390000e+02 2.842700e+04 2.759857e-01
```

```
#above with a positive z score, so trend is not significant

#running another Mann-Kendall test before and after change point for Paul Lake
mk.test(Nutrients.paul.surface$tn_ug[1:15]) #low p-value and negative z score, so
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.paul.surface$tn_ug[1:15]
## z = -2.6723, n = 15, p-value = 0.007533
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##           S        varS         tau
## -55.0000000 408.3333333  -0.5238095
```

```
mk.test(Nutrients.paul.surface$tn_ug[16:99]) #p-value greater than
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.paul.surface$tn_ug[16:99]
## z = 2.2058, n = 84, p-value = 0.0274
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 5.720000e+02 6.700867e+04 1.640849e-01
```

```
#0.05 and positive z score, so we accept the null that the data come
#from a population of independent realizations

#testing to see if there is a changepoint since last section has a small p-value
pettitt.test(Nutrients.peter.surface$tn_ug[36:98]) #changepoint at 21+36 = 57 because p-value from this
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  Nutrients.peter.surface$tn_ug[36:98]
## U* = 560, p-value = 0.001213
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              21
```

```
pettitt.test(Nutrients.paul.surface$tn_ug[16:99]) #changepoint at 36+16 = 52
```

```
##
##  Pettitt's test for single change-point detection
##
```

```
## data:  Nutrients.paul.surface$tn_ug[16:99]
## U* = 852, p-value = 0.001403
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              36
```

```
#Mann-Kendall test for second change point
mk.test(Nutrients.peter.surface$tn_ug[36:56]) #not a significant trend from 1993 - 1997
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.peter.surface$tn_ug[36:56]
## z = -1.0569, n = 21, p-value = 0.2906
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
##  -36.0000000 1096.6666667   -0.1714286
```

```
mk.test(Nutrients.peter.surface$tn_ug[57:98]) #also no significant trend
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.peter.surface$tn_ug[57:98]
## z = 0.15172, n = 42, p-value = 0.8794
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
##   15.0000000 8514.3333333    0.0174216
```

```
mk.test(Nutrients.paul.surface$tn_ug[16:51]) #no significant trend
```

```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.paul.surface$tn_ug[16:51]
## z = -1.8116, n = 36, p-value = 0.07005
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## -134.0000000 5390.0000000   -0.2126984
```

```
mk.test(Nutrients.paul.surface$tn_ug[52:99]) #no siginificant trend
```

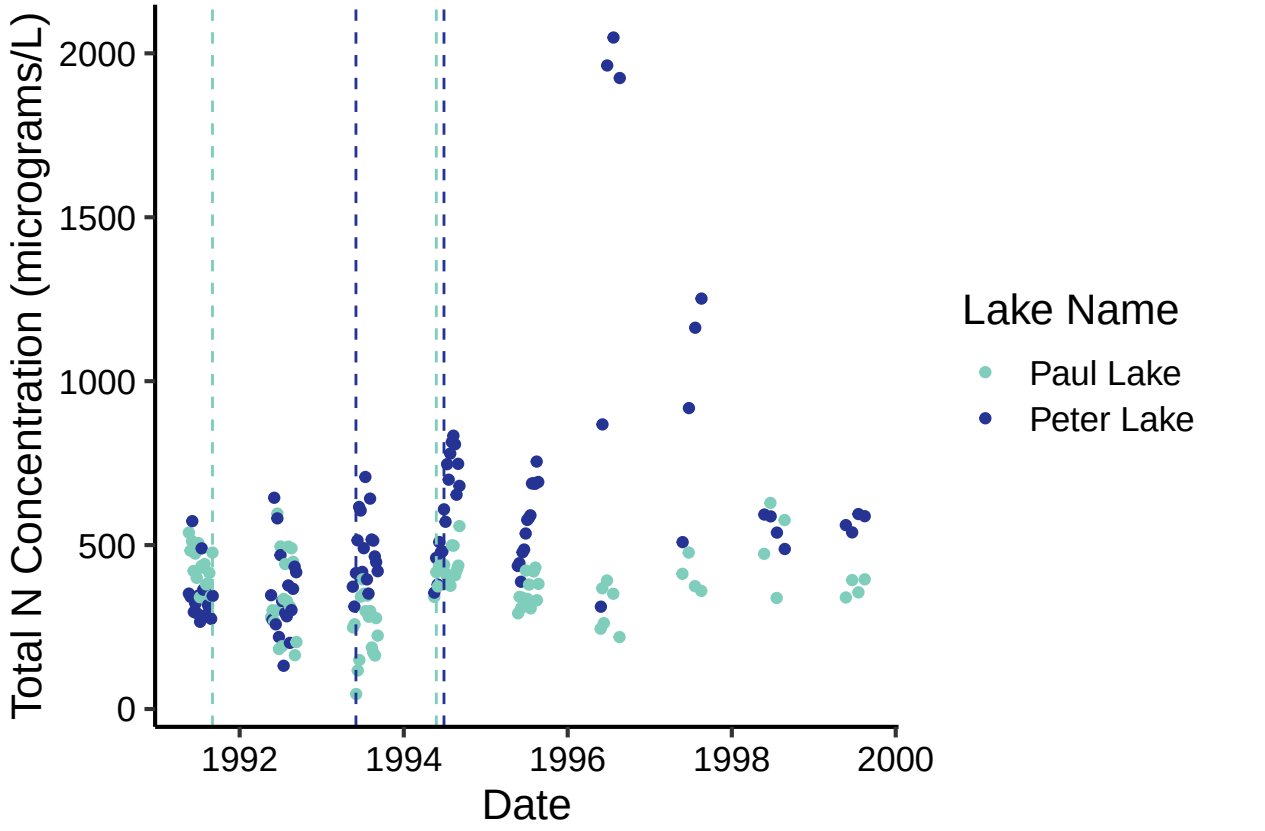
```
##
##  Mann-Kendall trend test
##
## data:  Nutrients.paul.surface$tn_ug[52:99]
## z = -1.2888, n = 48, p-value = 0.1975
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
##  -146.0000000 12658.6666667    -0.1294326
```

What are the results of this test?

ANSWER: The results of this test shows that there is a change point at row 16 and row 52 for Paul lake and row 36 and 52 for Peter lake. This indicates that there is an increasing and then decreasing and then increasing trend in the total N concentration in Peter and Paul lakes over time.

5. Generate a graph that illustrates the TN concentrations over time, coloring by lake and adding vertical line(s) representing changepoint(s).

```
#graph of TN concentration over time
ggplot(Nutrients.peterpaul.surface, aes(x = sampledate, y = tn_ug, color = lakename)) +
  geom_point() +
  labs(x = "Date", y = "Total N Concentration (micrograms/L)", color = "Lake Name") +
  scale_color_manual(values = c("#7fcdbb", "#253494")) +
  geom_vline(xintercept = as.Date("1993-06-02"), color="#253494", lty = 2) +  #Peter
  #Lake changepoint at 36
  geom_vline(xintercept = as.Date("1991-09-02"), color="#7fcdbb", lty = 2) + #Paul Lake at 16
 geom_vline(xintercept = as.Date("1994-05-26"), color="#7fcdbb", lty = 2) + #Paul Lake at 52
 geom_vline(xintercept = as.Date("1994-06-29"), color="#253494", lty = 2)  #Peter
```




```
#Lake changepoint at 57
```