Water quality analysis of River Thames

S/16/499

2/28/2021

Water Quality of River Thames

Importing the dataset

```
waterQualitydf<-read.csv("F:\\rStudio Projects\\ST305\\Assignment\\Assignment 1\\River_Thames_Water_
```

Head of the data

```
head(waterQualitydf)
```

```
                    Site Sampling.date..dd.mm.yyyy. Sampling.time..hh.mm.
1 River Thame at Wheatley                 3/03/2009                  9:25
2 River Thame at Wheatley                 9/03/2009                  9:40
3 River Thame at Wheatley                16/03/2009                 10:00
4 River Thame at Wheatley                24/03/2009                  9:45
5 River Thame at Wheatley                 1/04/2009                  9:46
6 River Thame at Wheatley                 6/04/2009                  9:48
  Water.temperature...C.   pH Alkalinity..µ.equ.l.1.
1                    7.2 8.01                   4915
2                    6.8 7.94                   5637
3                    9.3 8.05                   5393
4                    7.8 8.14                   5351
5                    8.9 8.20                   5129
6                   11.3 8.20                   5067
  Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
1                          7.7                   438                   0.2
2                          7.5                   341                 0.232
3                          5.3                   415                 0.176
4                          6.0                   381                 0.364
5                          4.4                   480                 0.384
6                          5.4                   568                 0.292
  Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                           5.8                   6.93
2                           5.3                   9.56
3                           4.4                   8.88
4                           2.8                  29.21
5                           2.3                  17.63
6                           2.3                  21.03
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                         0.2                         41.0
2                         0.2                         42.5
```

```
3                        0.2                        43.5
4                        0.2                        46.0
5                        0.2                        48.5
6                        0.2                        47.5
  Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                              34.0                                77.0
2                              30.5                                81.5
3                              30.5                                80.5
4                              36.5                                76.0
5                              34.5                                70.0
6                              35.5                                68.0
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                      26.7                         6.5
2                      29.7                         6.5
3                      29.4                         7.1
4                      34.5                         8.0
5                      36.9                         9.0
6                      34.2                         8.9
  Dissolved.calcium...........mg.l.1. Dissolved.magnesium..mg.l.1.
1                              140.0                            6.0
2                              139.1                            6.4
3                              142.9                            6.3
4                              141.3                            6.1
5                              145.8                            6.3
6                              142.7                            6.1
  Dissolved.boron....µg.l.1.
1                         81
2                         88
3                         89
4                         83
5                         79
6                         91
```

Changing the data type of last column("Dissolved boron (µg l-1)")

```
waterQualitydf$Ammonium..mg.l.1.NH4.<-as.numeric(waterQualitydf$Ammonium..mg.l.1.NH4.)
```

```
Warning: NAs introduced by coercion
```

```
waterQualitydf$Dissolved.silicon..mg.l.1.Si.<-as.numeric(waterQualitydf$Dissolved.silicon..mg.l.1.Si
```

```
Warning: NAs introduced by coercion
```

```
waterQualitydf$Dissolved.fluoride..mg.l.1.<-as.numeric(waterQualitydf$Dissolved.fluoride..mg.l.1.)
```

```
Warning: NAs introduced by coercion
```

```
waterQualitydf$Dissolved.boron....µg.l.1.<-as.numeric(waterQualitydf$Dissolved.boron....µg.l.1.)
```

```
Warning: NAs introduced by coercion
```

```
waterQualitydf$Sampling.date..dd.mm.yyyy.<-as.Date(waterQualitydf$Sampling.date..dd.mm.yyyy.,format=
```

Counting missing values and removing them

```
waterQualitydf %>%
  select(everything()) %>%  # replace to your needs
  summarise_all(~(sum(is.na(.))))
```

```
  Site Sampling.date..dd.mm.yyyy. Sampling.time..hh.mm. Water.temperature...C.
1    0                         21                     0                     58
  pH Alkalinity..µ.equ.l.1. Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P.
1 47                     47                           49                    36
  Ammonium..mg.l.1.NH4. Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                   115                          28                     52
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                          46                         25
  Dissolved.nitrate.....mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                                26                                 25
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                        25                          26
  Dissolved.calcium.....mg.l.1. Dissolved.magnesium..mg.l.1.
1                                25                         25
  Dissolved.boron....µg.l.1.
1                         26
```

Removing missing values from the data set

```
df<-na.omit(waterQualitydf)
head(df)
```

```
                   Site Sampling.date..dd.mm.yyyy. Sampling.time..hh.mm.
1 River Thame at Wheatley                2009-03-03                  9:25
2 River Thame at Wheatley                2009-03-09                  9:40
3 River Thame at Wheatley                2009-03-16                 10:00
4 River Thame at Wheatley                2009-03-24                  9:45
5 River Thame at Wheatley                2009-04-01                  9:46
6 River Thame at Wheatley                2009-04-06                  9:48
  Water.temperature...C.   pH Alkalinity..µ.equ.l.1.
1                    7.2 8.01                   4915
2                    6.8 7.94                   5637
3                    9.3 8.05                   5393
4                    7.8 8.14                   5351
5                    8.9 8.20                   5129
6                   11.3 8.20                   5067
  Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
1                          7.7                   438                 0.200
2                          7.5                   341                 0.232
3                          5.3                   415                 0.176
4                          6.0                   381                 0.364
5                          4.4                   480                 0.384
6                          5.4                   568                 0.292
  Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                           5.8                  6.93
2                           5.3                  9.56
```

```
3                          4.4                   8.88
4                          2.8                  29.21
5                          2.3                  17.63
6                          2.3                  21.03
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                         0.2                         41.0
2                         0.2                         42.5
3                         0.2                         43.5
4                         0.2                         46.0
5                         0.2                         48.5
6                         0.2                         47.5
  Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                               34.0                                77.0
2                               30.5                                81.5
3                               30.5                                80.5
4                               36.5                                76.0
5                               34.5                                70.0
6                               35.5                                68.0
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                      26.7                          6.5
2                      29.7                          6.5
3                      29.4                          7.1
4                      34.5                          8.0
5                      36.9                          9.0
6                      34.2                          8.9
  Dissolved.calcium...........mg.l.1. Dissolved.magnesium..mg.l.1.
1                               140.0                           6.0
2                               139.1                           6.4
3                               142.9                           6.3
4                               141.3                           6.1
5                               145.8                           6.3
6                               142.7                           6.1
  Dissolved.boron....µg.l.1.
1                         81
2                         88
3                         89
4                         83
5                         79
6                         91
```

Re-check

```
df %>%
  select(everything()) %>%  # replace to your needs
  summarise_all(~(sum(is.na(.))))
```

```
  Site Sampling.date..dd.mm.yyyy. Sampling.time..hh.mm. Water.temperature...C.
1    0                          0                     0                       0
  pH Alkalinity..µ.equ.l.1. Suspended.solids......mg.l.1. phosphorus..µg.l.1.P.
1  0                     0                             0                      0
  Ammonium..mg.l.1.NH4. Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                    0                             0                      0
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                           0                           0
  Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                                  0                                   0
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                         0                           0
```

```
  Dissolved.calcium..........mg.l.1. Dissolved.magnesium..mg.l.1.
1                                  0                             0
  Dissolved.boron....µg.l.1.
1                          0
```

Types of columns in the dataframe

```
glimpse(df)
```

```
Rows: 4,140
Columns: 20
$ Site                              <chr> "River Thame at Wheatley", "River ~
$ Sampling.date..dd.mm.yyyy.        <date> 2009-03-03, 2009-03-09, 2009-03-1~
$ Sampling.time..hh.mm.             <chr> "9:25", "9:40", "10:00", "9:45", "~
$ Water.temperature...C.            <dbl> 7.2, 6.8, 9.3, 7.8, 8.9, 11.3, 11.~
$ pH                                <dbl> 8.01, 7.94, 8.05, 8.14, 8.20, 8.20~
$ Alkalinity..µ.equ.l.1.            <int> 4915, 5637, 5393, 5351, 5129, 5067~
$ Suspended.solids......mg.l.1.     <dbl> 7.70, 7.50, 5.30, 6.00, 4.40, 5.40~
$ phosphorus..µg.l.1.P.             <int> 438, 341, 415, 381, 480, 568, 568,~
$ Ammonium..mg.l.1.NH4.             <dbl> 0.200, 0.232, 0.176, 0.364, 0.384,~
$ Dissolved.silicon..mg.l.1.Si.     <dbl> 5.8, 5.3, 4.4, 2.8, 2.3, 2.3, 4.6,~
$ Chlorophyll.a..µg.l.1.            <dbl> 6.93, 9.56, 8.88, 29.21, 17.63, 21~
$ Dissolved.fluoride..mg.l.1.       <dbl> 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2,~
$ Dissolved.chloride..mg.l.1.       <dbl> 41.0, 42.5, 43.5, 46.0, 48.5, 47.5~
$ Dissolved.nitrate......mg.l.1.NO3. <dbl> 34.0, 30.5, 30.5, 36.5, 34.5, 35.5~
$ Dissolved.sulphate.....mg.l.1.SO4. <dbl> 77.0, 81.5, 80.5, 76.0, 70.0, 68.0~
$ Dissolved.sodium..mg.l.1.         <dbl> 26.7, 29.7, 29.4, 34.5, 36.9, 34.2~
$ Dissolved.potassium..mg.l.1.      <dbl> 6.5, 6.5, 7.1, 8.0, 9.0, 8.9, 9.5,~
$ Dissolved.calcium..........mg.l.1. <dbl> 140.0, 139.1, 142.9, 141.3, 145.8,~
$ Dissolved.magnesium..mg.l.1.      <dbl> 6.0, 6.4, 6.3, 6.1, 6.3, 6.1, 6.3,~
$ Dissolved.boron....µg.l.1.        <dbl> 81, 88, 89, 83, 79, 91, 94, 96, 10~
```

Summary of the data set

```
summary(df[-c(1,2,3)])
```

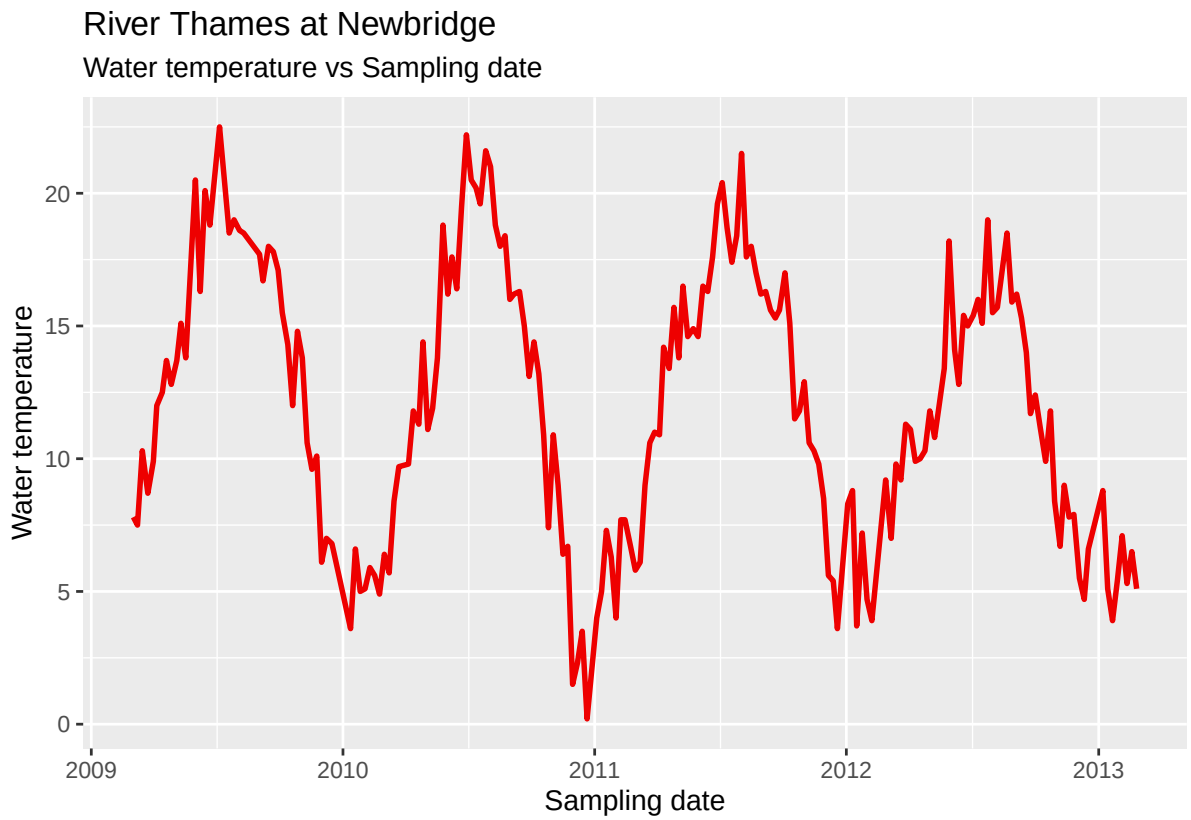
```
 Water.temperature...C.       pH        Alkalinity..µ.equ.l.1.
 Min.   :  0.00         Min.   :7.120   Min.   :1191
 1st Qu.:  7.90         1st Qu.:7.810   1st Qu.:3789
 Median : 11.90         Median :7.920   Median :4179
 Mean   : 11.83         Mean   :7.907   Mean   :4047
 3rd Qu.: 15.60         3rd Qu.:8.020   3rd Qu.:4465
 Max.   :118.00         Max.   :8.880   Max.   :5976
 Suspended.solids......mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
 Min.   :  0.00                Min.   :  11.0        Min.   :0.00000
 1st Qu.:  4.42                1st Qu.: 115.0        1st Qu.:0.03200
 Median :  7.30                Median : 199.0        Median :0.05000
 Mean   : 10.95                Mean   : 258.6        Mean   :0.07788
 3rd Qu.: 12.01                3rd Qu.: 317.0        3rd Qu.:0.08500
 Max.   :334.62                Max.   :2545.0        Max.   :2.16000
 Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
 Min.   : 0.020                Min.   :  0.210
 1st Qu.: 2.920                1st Qu.:  1.800
 Median : 4.660                Median :  3.050
 Mean   : 4.741                Mean   :  9.509
```

```
 3rd Qu.: 6.562                3rd Qu.:  6.372
 Max.   :10.000                Max.   :328.500
 Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
 Min.   :0.0000              Min.   :  9.63
 1st Qu.:0.1100              1st Qu.: 25.51
 Median :0.1400              Median : 37.48
 Mean   :0.1501              Mean   : 42.13
 3rd Qu.:0.1800              3rd Qu.: 51.43
 Max.   :0.5000              Max.   :248.06
 Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
 Min.   :  2.39                     Min.   : 10.70
 1st Qu.: 23.36                     1st Qu.: 35.79
 Median : 27.79                     Median : 47.51
 Mean   : 30.26                     Mean   : 51.85
 3rd Qu.: 32.02                     3rd Qu.: 64.39
 Max.   :151.33                     Max.   :184.98
 Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
 Min.   :  6.50            Min.   : 1.1
 1st Qu.: 14.40            1st Qu.: 3.1
 Median : 23.10            Median : 4.8
 Mean   : 27.64            Mean   : 5.6
 3rd Qu.: 34.60            3rd Qu.: 6.9
 Max.   :154.20            Max.   :22.5
 Dissolved.calcium..........mg.l.1. Dissolved.magnesium..mg.l.1.
 Min.   : 34.2                      Min.   : 1.200
 1st Qu.: 96.3                      1st Qu.: 4.200
 Median :104.5                      Median : 4.800
 Mean   :103.0                      Mean   : 4.973
 3rd Qu.:111.4                      3rd Qu.: 5.500
 Max.   :150.5                      Max.   :15.100
 Dissolved.boron....µg.l.1.
 Min.   :  5.00
 1st Qu.: 31.00
 Median : 52.00
 Mean   : 53.91
 3rd Qu.: 67.20
 Max.   :184.00
```

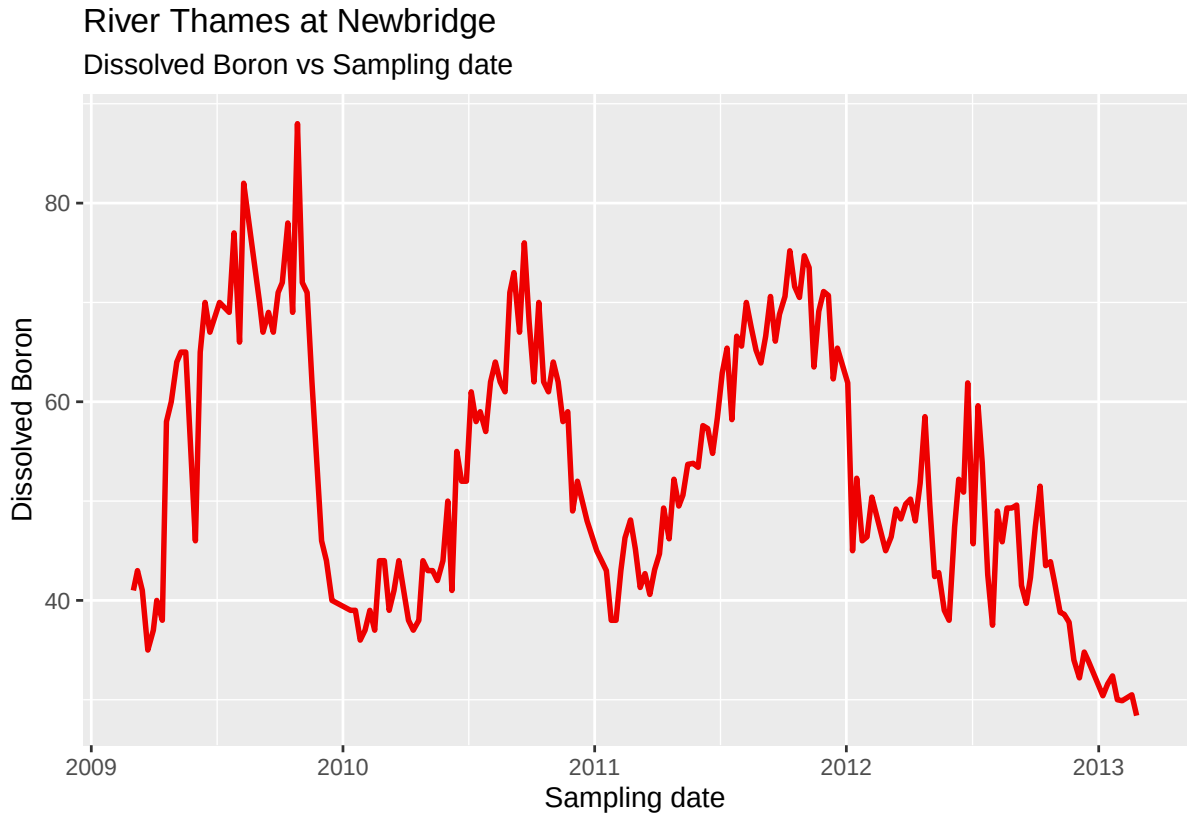
```
options(scipen=100)
options(digits=2)
a<-stat.desc(df[-c(1,2,3)])

write.csv(a,"F:\\rStudio Projects\\ST305\\Assignment\\Assignment 1\\summary1.csv",row.names = TRUE)
```

Plots and diagrams drawn versus time(Month)

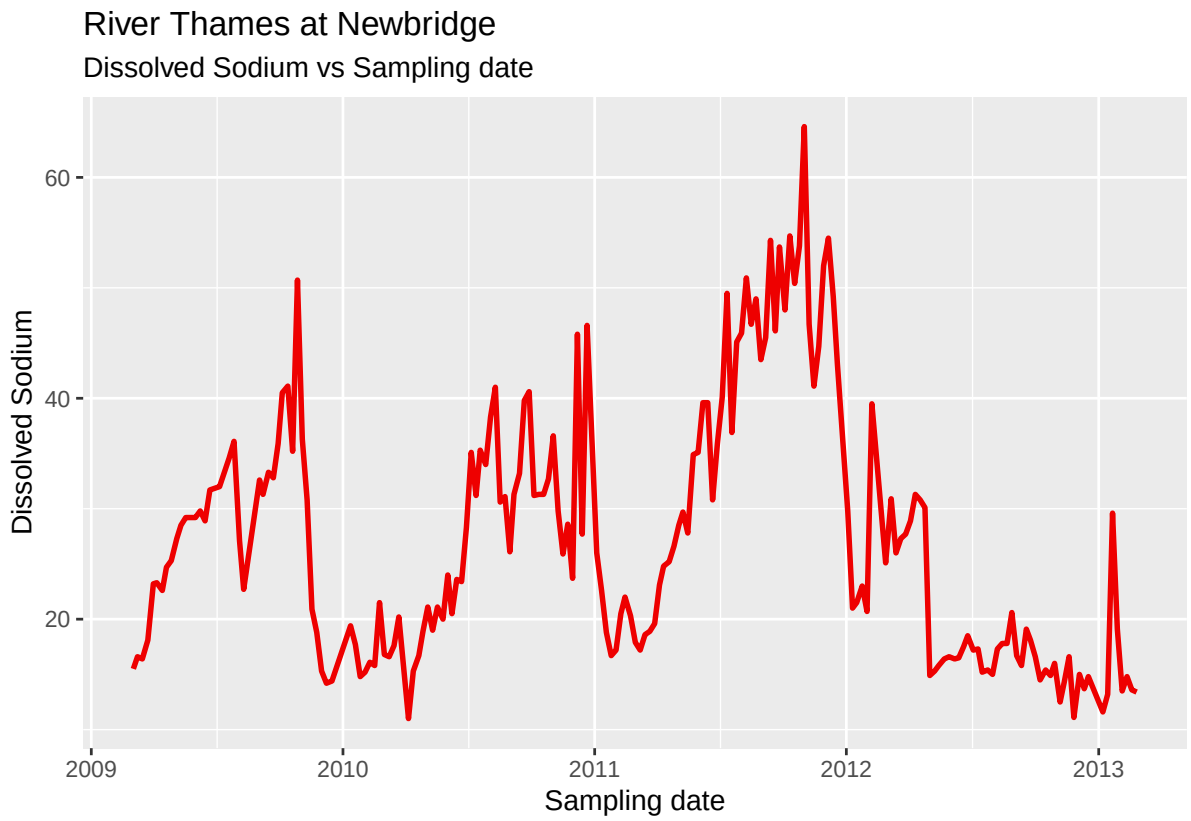
```
#unique(df$Site)

df1<-df %>%
  select(everything()) %>%
  filter(Site=="River Thames at Newbridge")
#head(df1)

ggplot(df1)+geom_line(aes(x=Sampling.date..dd.mm.yyyy.,y=Water.temperature...C.),color="red2",size=1
  labs(x="Sampling date",y="Water temperature",title = "River Thames at Newbridge",subtitle = "Water
```



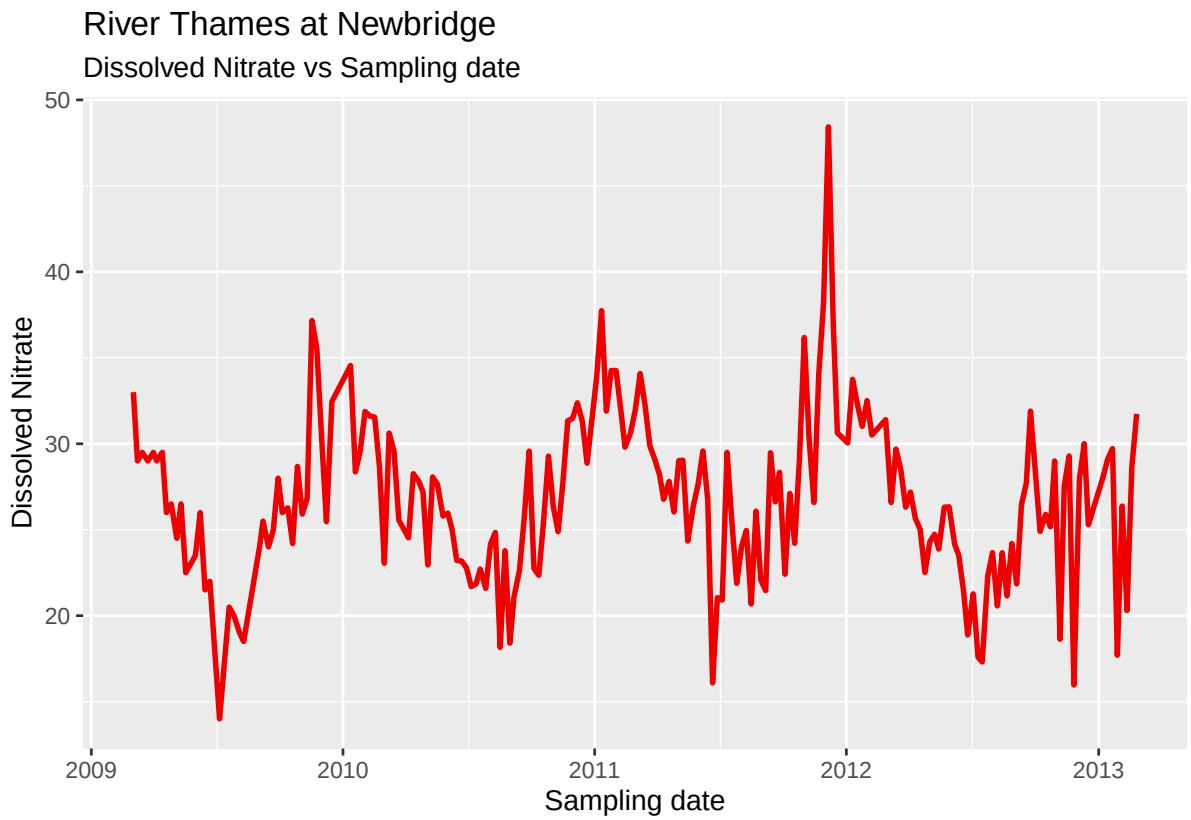

```
ggplot(df1)+geom_line(aes(x=Sampling.date..dd.mm.yyyy.,y=Dissolved.boron....µg.l.1.),color="red2",si
  labs(x="Sampling date",y="Dissolved Boron",title = "River Thames at Newbridge",subtitle = "Dissolv
```



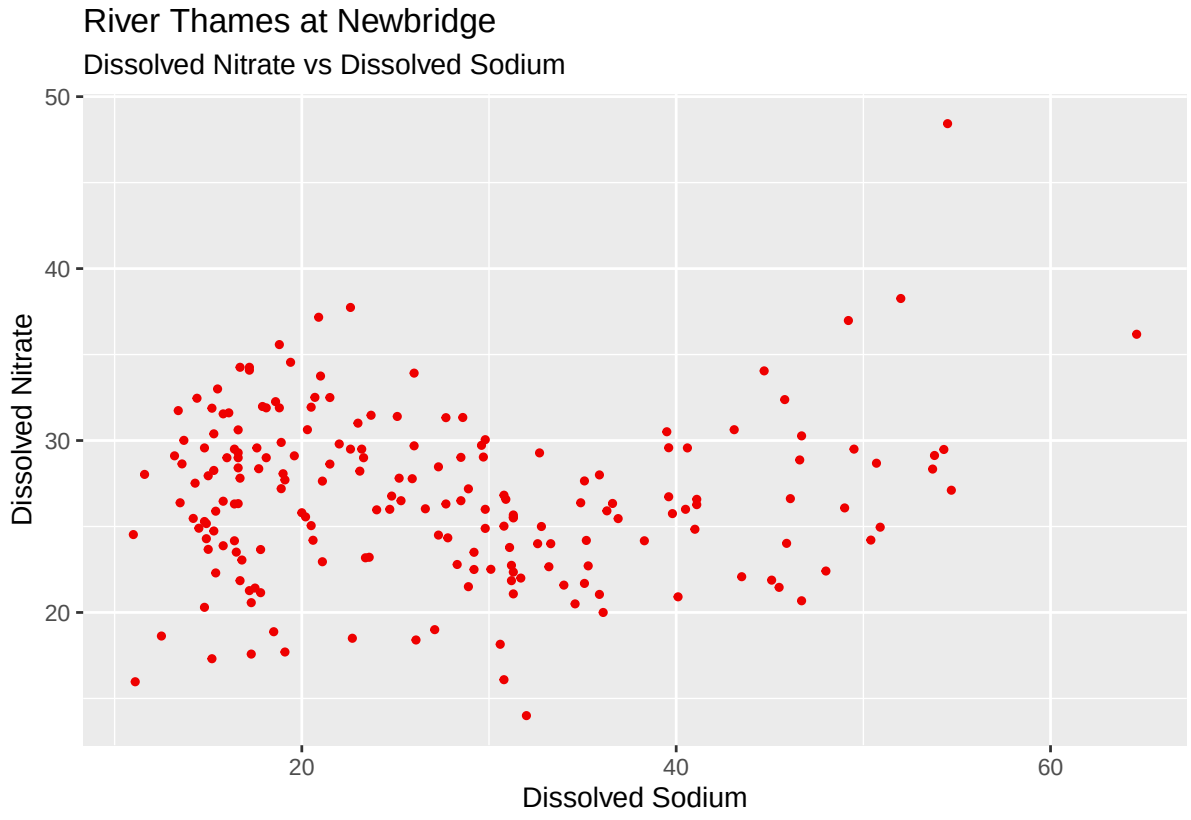
```
ggplot(df1)+geom_line(aes(x=Sampling.date..dd.mm.yyyy.,y=Dissolved.sodium..mg.l.1.),color="red2",siz
  labs(x="Sampling date",y="Dissolved Sodium",title = "River Thames at Newbridge",subtitle = "Dissol
```




```
ggplot(df1)+geom_line(aes(x=Sampling.date..dd.mm.yyyy.,y=Dissolved.nitrate.....mg.l.1.NO3.),color="
  labs(x="Sampling date",y="Dissolved Nitrate",title = "River Thames at Newbridge",subtitle = "Disso
```




```
ggplot(df1)+geom_point(aes(x=Dissolved.sodium..mg.l.1.,y=Dissolved.nitrate.....mg.l.1.NO3.),color="
  labs(x="Dissolved Sodium",y="Dissolved Nitrate",title = "River Thames at Newbridge",subtitle = "Di
```



Manova

MANOVA analysis was done at 5% significance level H0 : Mean water properties of each month is equal vs H1: Mean water properties of at least 2 months are not equal

Creating a new data frame to do MANOVA

```
df_manova<-df %>%
  select(everything()) %>%
  group_by(Site)

samplingYM<-format(df_manova$Sampling.date..dd.mm.yyyy.,"%Y-%m")

df_manova$samplingYM<-samplingYM

df_manova= subset(df_manova, select = -c(Sampling.time..hh.mm.,Sampling.date..dd.mm.yyyy.) )
head(df_manova)
```

```
# A tibble: 6 x 19
# Groups:   Site [1]
  Site         Water.temperature.~    pH Alkalinity..µ.equ~ Suspended.solids...~
  <chr>                      <dbl> <dbl>              <int>                <dbl>
1 River Thame~                 7.2  8.01               4915                  7.7
2 River Thame~                 6.8  7.94               5637                  7.5
3 River Thame~                 9.3  8.05               5393                  5.3
4 River Thame~                 7.8  8.14               5351                  6
5 River Thame~                 8.9  8.2                5129                  4.4
6 River Thame~                11.3  8.2                5067                  5.4
# ... with 14 more variables: phosphorus..µg.l.1.P. <int>,
#   Ammonium..mg.l.1.NH4. <dbl>, Dissolved.silicon..mg.l.1.Si. <dbl>,
#   Chlorophyll.a..µg.l.1. <dbl>, Dissolved.fluoride..mg.l.1. <dbl>,
#   Dissolved.chloride..mg.l.1. <dbl>,
#   Dissolved.nitrate.....mg.l.1.NO3. <dbl>,
#   Dissolved.sulphate.....mg.l.1.SO4. <dbl>, Dissolved.sodium..mg.l.1. <dbl>,
#   Dissolved.potassium..mg.l.1. <dbl>,
#   Dissolved.calcium.....mg.l.1. <dbl>,
#   Dissolved.magnesium..mg.l.1. <dbl>, Dissolved.boron....µg.l.1. <dbl>,
#   samplingYM <chr>
```

Mean values when grouped by Site and Sample taken date

dependent variable extraction

```
d.v<-as.matrix(df_manova
               [2:18])
```

By SITE

```
df_groupedbySite<-aggregate(d.v~df_manova$Site,data = df_manova, function(x)round(mean(x),2))
colnames(df_groupedbySite)[1]<-"Site"
head(df_groupedbySite,n=10L)
```

```
                            Site Water.temperature...C.  pH
1   Jubilee River at Pocock's Bridge                   13 8.0
2    River Cherwell at Hampton Poyle                   12 7.9
3          River Cole at Lynt Bridge                   12 7.9
4             River Coln at Whelford                   12 8.0
```

```
5          River Enborne at Brimpton                    11 7.8
6  River Evenlode at Cassington Mill                    11 7.9
7        River Kennet at Woolhampton                    11 8.0
8  River Leach at Mill Lane,Lechlade                    11 7.9
9            River Lodden at Charvil                    12 7.8
10             River Ock at Abingdon                    12 8.0
   Alkalinity..µ.equ.l.1. Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P.
1                    4088                          8.4                   192
2                    4134                         13.3                   193
3                    4335                         15.2                   307
4                    4247                          5.4                    84
5                    2819                          9.5                   183
6                    4028                         15.7                   252
7                    4500                          9.3                    78
8                    4367                          3.0                    34
9                    3209                          7.3                   209
10                   4702                         11.1                   320
   Ammonium..mg.l.1.NH4. Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                   0.07                          5.2                   18.7
2                   0.04                          3.3                   14.1
3                   0.05                          6.4                    5.7
4                   0.04                          2.6                    3.0
5                   0.08                          6.9                    2.5
6                   0.04                          2.7                   12.4
7                   0.05                          6.8                    8.2
8                   0.06                          2.4                    1.9
9                   0.08                          5.4                    3.9
10                  0.06                          7.1                    3.9
   Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                         0.15                          44
2                         0.20                          54
3                         0.19                          46
4                         0.13                          17
5                         0.12                          34
6                         0.12                          26
7                         0.12                          24
8                         0.10                          16
9                         0.12                          60
10                        0.20                          39
   Dissolved.nitrate.....mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                                 26                                  47
2                                 25                                  65
3                                 18                                  53
4                                 26                                  34
5                                 17                                  26
6                                 25                                  46
7                                 24                                  20
8                                 31                                  35
9                                 34                                  48
10                                30                                  72
   Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                        27.4                          5.4
2                        35.6                          6.2
3                        27.4                          5.3
4                         8.8                          1.7
5                        17.8                          3.6
6                        16.2                          3.5
7                        12.4                          2.4
```

```
8                       8.3                          1.5
9                      38.6                          7.5
10                     25.0                          5.9
   Dissolved.calcium.....mg.l.1. Dissolved.magnesium..mg.l.1.
1                            102                          4.4
2                            104                          7.6
3                            110                          4.4
4                            101                          5.7
5                             68                          4.4
6                            102                          4.2
7                            107                          2.2
8                            109                          5.1
9                             83                          5.2
10                           126                          4.6
   Dissolved.boron....µg.l.1.
1                          54
2                          73
3                          55
4                          20
5                          26
6                          51
7                          22
8                          25
9                          56
10                         62
```

By Sample taken date

```
head(aggregate(d.v~df_manova$samplingYM,data = df_manova,function(x)round(mean(x),2)),n=10L)
```

```
   df_manova$samplingYM Water.temperature...C.  pH Alkalinity..µ.equ.l.1.
1               2009-03                   8.8 8.1                   4464
2               2009-04                  11.9 8.1                   4128
3               2009-05                  14.6 7.9                   3890
4               2009-06                  18.4 7.9                   3790
5               2009-07                  18.4 7.9                   3953
6               2009-08                  18.3 7.8                   4014
7               2009-09                  16.9 8.0                   4144
8               2009-10                  13.8 7.9                   4128
9               2009-11                  10.4 7.8                   3699
10              2009-12                   7.2 7.8                   3713
   Suspended.solids......mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
1                            6.8                   159                  0.05
2                            7.6                   222                  0.07
3                           11.7                   302                  0.06
4                           12.0                   357                  0.05
5                            9.5                   318                  0.04
6                            9.0                   324                  0.05
7                            9.0                   361                  0.04
8                            7.1                   370                  0.06
9                           21.7                   317                  0.09
10                          23.3                   215                  0.08
   Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                            3.9                   9.6
2                            2.8                  32.0
3                            3.4                  57.7
4                            4.3                  43.6
5                            4.8                  21.8
```

```
6                          5.2                   9.7
7                          4.9                  11.2
8                          5.0                   6.7
9                          5.0                   4.6
10                         4.8                   2.5
   Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                         0.13                          36
2                         0.15                          39
3                         0.13                          43
4                         0.15                          44
5                         0.18                          45
6                         0.18                          44
7                         0.13                          50
8                         0.10                          55
9                         0.15                          38
10                        0.20                          29
   Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                                  35                                   53
2                                  35                                   52
3                                  35                                   55
4                                  33                                   54
5                                  30                                   51
6                                  31                                   55
7                                  32                                   58
8                                  34                                   62
9                                  30                                   53
10                                 32                                   49
   Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                         23                          4.3
2                         27                          5.4
3                         31                          6.2
4                         30                          6.3
5                         31                          6.3
6                         30                          6.6
7                         36                          7.4
8                         41                          8.5
9                         25                          6.1
10                        17                          4.3
   Dissolved.calcium..........mg.l.1. Dissolved.magnesium..mg.l.1.
1                                 115                           5.4
2                                 116                           5.6
3                                 108                           5.6
4                                 104                           5.2
5                                  99                           4.9
6                                 102                           5.0
7                                 104                           5.1
8                                 108                           5.7
9                                  98                           5.3
10                                103                           5.2
   Dissolved.boron....µg.l.1.
1                          50
2                          58
3                          70
4                          67
5                          69
6                          75
7                          76
8                          79
```

```
9                           60
10                          49
```

Manova Test

```
waterqualitymodel<-manova(d.v~df_manova$samplingYM*df_manova$Site)

summary(waterqualitymodel,test = "Pillai")
```

```
                                   Df Pillai approx F num Df den Df
df_manova$samplingYM                47   5.03     27.9    799  52989
df_manova$Site                      21   6.78     98.5    357  52989
df_manova$samplingYM:df_manova$Site  954   7.76      2.7  16218  52989
Residuals                           3117
                                             Pr(>F)
df_manova$samplingYM                <0.0000000000000002 ***
df_manova$Site                      <0.0000000000000002 ***
df_manova$samplingYM:df_manova$Site <0.0000000000000002 ***
Residuals
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(waterqualitymodel,test = "Wilk")
```

```
                                   Df     Wilks approx F num Df den Df
df_manova$samplingYM                47 0.0002881     41.3    799  49713
df_manova$Site                      21 0.0000002    251.9    357  41169
df_manova$samplingYM:df_manova$Site  954 0.0000076      3.3  16218  52827
Residuals                           3117
                                             Pr(>F)
df_manova$samplingYM                <0.0000000000000002 ***
df_manova$Site                      <0.0000000000000002 ***
df_manova$samplingYM:df_manova$Site <0.0000000000000002 ***
Residuals
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(waterqualitymodel,test = "Roy")
```

```
                                   Df  Roy approx F num Df den Df
df_manova$samplingYM                47  7.7      510     47   3117
df_manova$Site                      21 34.5     5116     21   3117
df_manova$samplingYM:df_manova$Site  954  4.7       15    954   3117
Residuals                           3117
                                             Pr(>F)
df_manova$samplingYM                <0.0000000000000002 ***
df_manova$Site                      <0.0000000000000002 ***
df_manova$samplingYM:df_manova$Site <0.0000000000000002 ***
Residuals
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(waterqualitymodel,test = "Hotelling-Lawley")
```

```
                                   Df Hotelling-Lawley approx F num Df
df_manova$samplingYM               47             17.8       69    799
df_manova$Site                     21             82.6      717    357
df_manova$samplingYM:df_manova$Site  954             21.1        4  16218
Residuals                        3117
                                  den Df              Pr(>F)
df_manova$samplingYM               52685 <0.0000000000000002 ***
df_manova$Site                     52685 <0.0000000000000002 ***
df_manova$samplingYM:df_manova$Site  52685 <0.0000000000000002 ***
Residuals
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Clustering

Estimating the optimal number of clusters

Creating a new data frame for clustering

```
df_forClustering<-aggregate(d.v~df_manova$Site,data = df_manova, function(x)round(mean(x),2))[,-1]
rownames(df_forClustering)<-aggregate(d.v~df_manova$Site,data = df_manova, function(x)round(mean(x),

head(df_forClustering)
```

```
                                Water.temperature...C.  pH
Jubilee River at Pocock's Bridge                     13 8.0
River Cherwell at Hampton Poyle                      12 7.9
River Cole at Lynt Bridge                            12 7.9
River Coln at Whelford                               12 8.0
River Enborne at Brimpton                            11 7.8
River Evenlode at Cassington Mill                    11 7.9
                                Alkalinity..µ.equ.l.1.
Jubilee River at Pocock's Bridge                   4088
River Cherwell at Hampton Poyle                    4134
River Cole at Lynt Bridge                          4335
River Coln at Whelford                             4247
River Enborne at Brimpton                          2819
River Evenlode at Cassington Mill                  4028
                                Suspended.solids.....mg.l.1.
Jubilee River at Pocock's Bridge                         8.4
River Cherwell at Hampton Poyle                         13.3
River Cole at Lynt Bridge                               15.2
River Coln at Whelford                                   5.4
River Enborne at Brimpton                                9.5
River Evenlode at Cassington Mill                       15.7
                                phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
Jubilee River at Pocock's Bridge                   192                  0.07
River Cherwell at Hampton Poyle                    193                  0.04
River Cole at Lynt Bridge                          307                  0.05
River Coln at Whelford                              84                  0.04
River Enborne at Brimpton                          183                  0.08
River Evenlode at Cassington Mill                  252                  0.04
                                Dissolved.silicon..mg.l.1.Si.
Jubilee River at Pocock's Bridge                         5.2
```

```
River Cherwell at Hampton Poyle                              3.3
River Cole at Lynt Bridge                                    6.4
River Coln at Whelford                                       2.6
River Enborne at Brimpton                                    6.9
River Evenlode at Cassington Mill                            2.7
                                 Chlorophyll.a..µg.l.1.
Jubilee River at Pocock's Bridge                    18.7
River Cherwell at Hampton Poyle                     14.1
River Cole at Lynt Bridge                            5.7
River Coln at Whelford                               3.0
River Enborne at Brimpton                            2.5
River Evenlode at Cassington Mill                   12.4
                                 Dissolved.fluoride..mg.l.1.
Jubilee River at Pocock's Bridge                          0.15
River Cherwell at Hampton Poyle                           0.20
River Cole at Lynt Bridge                                 0.19
River Coln at Whelford                                    0.13
River Enborne at Brimpton                                 0.12
River Evenlode at Cassington Mill                         0.12
                                 Dissolved.chloride..mg.l.1.
Jubilee River at Pocock's Bridge                            44
River Cherwell at Hampton Poyle                             54
River Cole at Lynt Bridge                                   46
River Coln at Whelford                                      17
River Enborne at Brimpton                                   34
River Evenlode at Cassington Mill                           26
                                 Dissolved.nitrate......mg.l.1.NO3.
Jubilee River at Pocock's Bridge                                  26
River Cherwell at Hampton Poyle                                   25
River Cole at Lynt Bridge                                         18
River Coln at Whelford                                            26
River Enborne at Brimpton                                         17
River Evenlode at Cassington Mill                                 25
                                 Dissolved.sulphate.....mg.l.1.SO4.
Jubilee River at Pocock's Bridge                                  47
River Cherwell at Hampton Poyle                                   65
River Cole at Lynt Bridge                                         53
River Coln at Whelford                                            34
River Enborne at Brimpton                                         26
River Evenlode at Cassington Mill                                 46
                                 Dissolved.sodium..mg.l.1.
Jubilee River at Pocock's Bridge                     27.4
River Cherwell at Hampton Poyle                      35.6
River Cole at Lynt Bridge                            27.4
River Coln at Whelford                                8.8
River Enborne at Brimpton                            17.8
River Evenlode at Cassington Mill                    16.2
                                 Dissolved.potassium..mg.l.1.
Jubilee River at Pocock's Bridge                          5.4
River Cherwell at Hampton Poyle                           6.2
River Cole at Lynt Bridge                                 5.3
River Coln at Whelford                                    1.7
River Enborne at Brimpton                                 3.6
River Evenlode at Cassington Mill                         3.5
                                 Dissolved.calcium...........mg.l.1.
Jubilee River at Pocock's Bridge                                  102
River Cherwell at Hampton Poyle                                   104
River Cole at Lynt Bridge                                         110
```

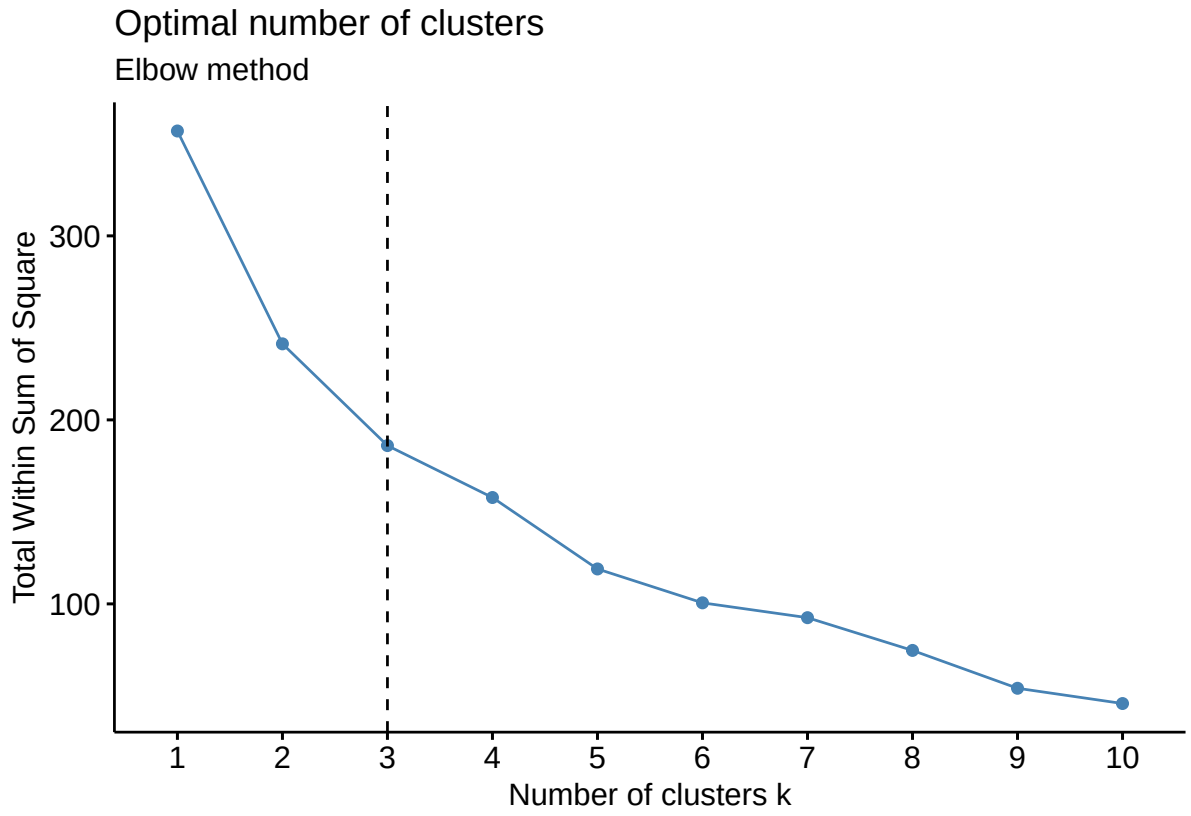
```
River Coln at Whelford                                          101
River Enborne at Brimpton                                        68
River Evenlode at Cassington Mill                               102
                                 Dissolved.magnesium..mg.l.1.
Jubilee River at Pocock's Bridge                              4.4
River Cherwell at Hampton Poyle                               7.6
River Cole at Lynt Bridge                                     4.4
River Coln at Whelford                                        5.7
River Enborne at Brimpton                                     4.4
River Evenlode at Cassington Mill                             4.2
                                 Dissolved.boron....µg.l.1.
Jubilee River at Pocock's Bridge                             54
River Cherwell at Hampton Poyle                              73
River Cole at Lynt Bridge                                    55
River Coln at Whelford                                       20
River Enborne at Brimpton                                    26
River Evenlode at Cassington Mill                            51
```

Scaling data frame (standardizing the data to make variables comparable)

```
df_scaled<-scale(df_forClustering)
```

Determining the optimal number of clusters for k-means clustering by ***Elbow method***

```
fviz_nbclust(df_scaled, kmeans, method = "wss") +
    geom_vline(xintercept = 3, linetype = 2)+
  labs(subtitle = "Elbow method")
```



Therefore we select k=3 as the number of clusters

Clustering using K-means

```
set.seed(123)

km.res <- kmeans(df_scaled, 3,nstart = 25)
```

Details

```
print(km.res)
```

```
K-means clustering with 3 clusters of sizes 8, 11, 3

Cluster means:
  Water.temperature...C.    pH Alkalinity..µ.equ.l.1.
1                -0.7659  0.29                 0.136
2                 0.5550  0.28                 0.084
3                 0.0073 -1.81                -0.670
  Suspended.solids......mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
1                        -0.328                -0.65                 -0.43
2                         0.235                -0.11                 -0.22
3                         0.012                 2.15                  1.95
  Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                        -0.046                 -0.60
2                        -0.056                  0.48
3                         0.329                 -0.17
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                       -0.94                       -0.91
2                        0.36                        0.22
3                        1.20                        1.60
  Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                             -0.33                               -0.97
2                             -0.20                                0.24
3                              1.62                                1.69
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                     -0.89                       -0.92
2                      0.18                        0.15
3                      1.74                        1.92
  Dissolved.calcium..........mg.l.1. Dissolved.magnesium..mg.l.1.
1                             -0.22                        -0.629
2                              0.12                         0.089
3                              0.17                         1.349
  Dissolved.boron....µg.l.1.
1                      -1.02
2                       0.28
3                       1.71

Clustering vector:
 Jubilee River at Pocock's Bridge   River Cherwell at Hampton Poyle
                                2                                 2
        River Cole at Lynt Bridge            River Coln at Whelford
                                2                                 1
        River Enborne at Brimpton River Evenlode at Cassington Mill
                                1                                 1
      River Kennet at Woolhampton River Leach at Mill Lane,Lechlade
                                1                                 1
          River Lodden at Charvil             River Ock at Abingdon
```

```
                              2                                   2
           River Pang at Tidmarsh                 River Ray at Islip
                              1                                   3
          River Thame at Wheatley   River Thames at Hannington Wick
                              3                                   2
        River Thames at Newbridge         River Thames at Runnymede
                              2                                   2
          River Thames at Sonning          River Thames at Swinford
                              2                                   2
      River Thames at Wallingford       River Windrush at Newbridge
                              2                                   1
          River Wye at Bourne End           The Cut at Paley Street
                              1                                   3

Within cluster sum of squares by cluster:
[1] 69 66 48
 (between_SS / total_SS =  48.7 %)

Available components:

[1] "cluster"      "centers"      "totss"        "withinss"     "tot.withinss"
[6] "betweenss"    "size"         "iter"         "ifault"
```

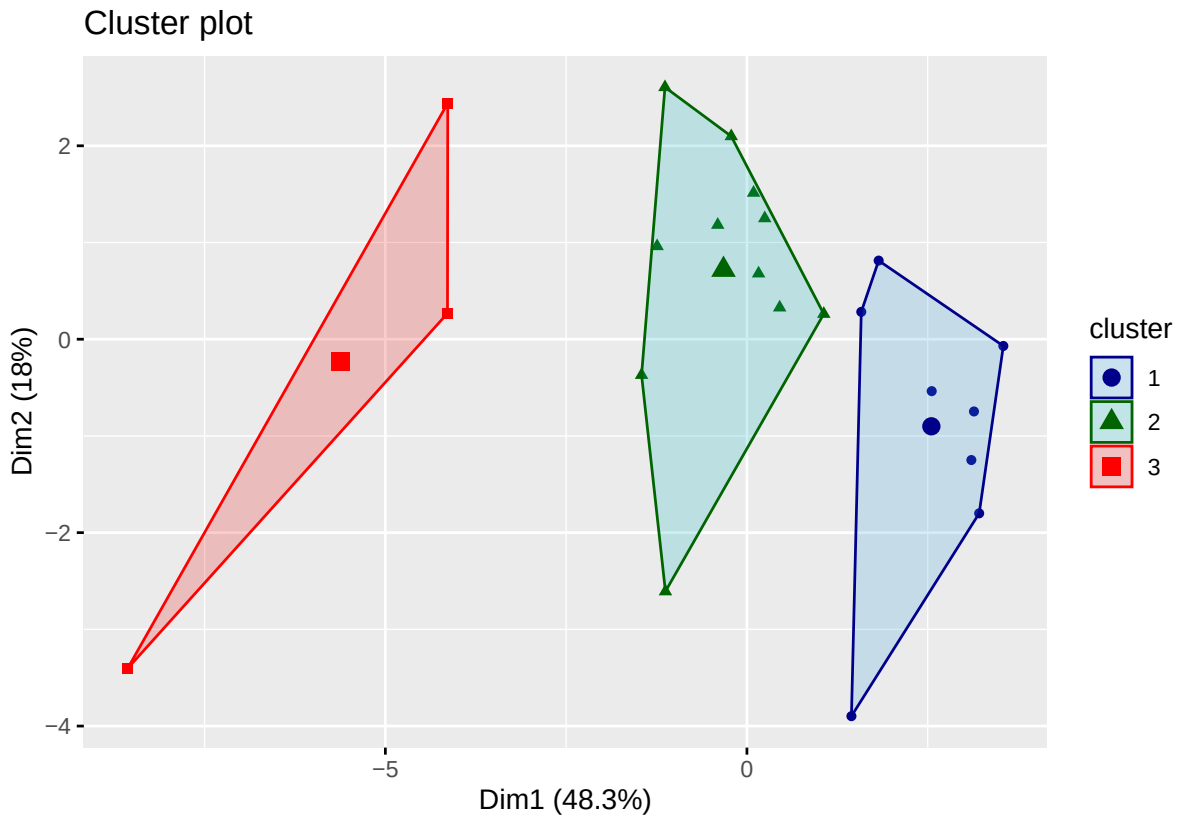
```
km.res$centers
```

```
  Water.temperature...C.    pH Alkalinity..µ.equ.l.1.
1               -0.7659  0.29                  0.136
2                0.5550  0.28                  0.084
3                0.0073 -1.81                 -0.670
  Suspended.solids......mg.l.1. phosphorus..µg.l.1.P. Ammonium..mg.l.1.NH4.
1                        -0.328                -0.65                 -0.43
2                         0.235                -0.11                 -0.22
3                         0.012                 2.15                  1.95
  Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1                        -0.046                 -0.60
2                        -0.056                  0.48
3                         0.329                 -0.17
  Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1                       -0.94                       -0.91
2                        0.36                        0.22
3                        1.20                        1.60
  Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1                             -0.33                               -0.97
2                             -0.20                                0.24
3                              1.62                                1.69
  Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1                     -0.89                       -0.92
2                      0.18                        0.15
3                      1.74                        1.92
  Dissolved.calcium...........mg.l.1. Dissolved.magnesium..mg.l.1.
1                             -0.22                        -0.629
2                              0.12                         0.089
3                              0.17                         1.349
  Dissolved.boron....µg.l.1.
1                      -1.02
2                       0.28
3                       1.71
```

Visualizing

```
fviz_cluster(km.res, data = df_scaled,
             palette = c("#2E9FDF", "#00AFBB", "#ed0000"),
             geom = "point",
             ellipse.type = "convex"
             )+scale_colour_manual(values = c("darkblue", "darkgreen", "red"))
```

```
Scale for 'colour' is already present. Adding another scale for 'colour',
which will replace the existing scale.
```




```
pc<-princomp(df_scaled)
plot3d(pc$scores[,1:3],col = km.res$cluster,size = 20)
```

cluster summarising

Attaching clusters to each observation accordingly

```
df_forClustering<-cbind(df_forClustering,cluster=km.res$cluster)
```

```
setDT(df_forClustering,keep.rownames = "Site")
head(df_forClustering)
```

```
                              Site Water.temperature...C.  pH
1:  Jubilee River at Pocock's Bridge                    13 8.0
2:   River Cherwell at Hampton Poyle                   12 7.9
3:         River Cole at Lynt Bridge                   12 7.9
4:            River Coln at Whelford                   12 8.0
```

```
5:         River Enborne at Brimpton                      11 7.8
6: River Evenlode at Cassington Mill                      11 7.9
   Alkalinity..µ.equ.l.1. Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P.
1:                   4088                          8.4                   192
2:                   4134                         13.3                   193
3:                   4335                         15.2                   307
4:                   4247                          5.4                    84
5:                   2819                          9.5                   183
6:                   4028                         15.7                   252
   Ammonium..mg.l.1.NH4. Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1:                  0.07                          5.2                  18.7
2:                  0.04                          3.3                  14.1
3:                  0.05                          6.4                   5.7
4:                  0.04                          2.6                   3.0
5:                  0.08                          6.9                   2.5
6:                  0.04                          2.7                  12.4
   Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1:                        0.15                          44
2:                        0.20                          54
3:                        0.19                          46
4:                        0.13                          17
5:                        0.12                          34
6:                        0.12                          26
   Dissolved.nitrate.....mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1:                                26                                  47
2:                                25                                  65
3:                                18                                  53
4:                                26                                  34
5:                                17                                  26
6:                                25                                  46
   Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1:                      27.4                         5.4
2:                      35.6                         6.2
3:                      27.4                         5.3
4:                       8.8                         1.7
5:                      17.8                         3.6
6:                      16.2                         3.5
   Dissolved.calcium.....mg.l.1. Dissolved.magnesium..mg.l.1.
1:                           102                          4.4
2:                           104                          7.6
3:                           110                          4.4
4:                           101                          5.7
5:                            68                          4.4
6:                           102                          4.2
   Dissolved.boron....µg.l.1. cluster
1:                        54       2
2:                        73       2
3:                        55       2
4:                        20       1
5:                        26       1
6:                        51       1
```

```
df_forClustering %>%
  select(everything()) %>%
  filter(cluster==1)
```

```
                           Site Water.temperature...C.  pH
1:           River Coln at Whelford                    12 8.0
```

```
2:         River Enborne at Brimpton                    11 7.8
3: River Evenlode at Cassington Mill                    11 7.9
4:       River Kennet at Woolhampton                    11 8.0
5: River Leach at Mill Lane,Lechlade                    11 7.9
6:            River Pang at Tidmarsh                    11 7.9
7:       River Windrush at Newbridge                    11 8.1
8:           River Wye at Bourne End                    12 8.1
   Alkalinity..µ.equ.l.1. Suspended.solids.....mg.l.1. phosphorus..µg.l.1.P.
1:                   4247                          5.4                    84
2:                   2819                          9.5                   183
3:                   4028                         15.7                   252
4:                   4500                          9.3                    78
5:                   4367                          3.0                    34
6:                   4495                          8.3                    68
7:                   3880                         14.0                   132
8:                   4593                         13.3                   290
   Ammonium..mg.l.1.NH4. Dissolved.silicon..mg.l.1.Si. Chlorophyll.a..µg.l.1.
1:                  0.04                          2.6                    3.0
2:                  0.08                          6.9                    2.5
3:                  0.04                          2.7                   12.4
4:                  0.05                          6.8                    8.2
5:                  0.06                          2.4                    1.9
6:                  0.04                          7.0                    2.7
7:                  0.04                          2.5                    4.0
8:                  0.11                          6.7                    3.7
   Dissolved.fluoride..mg.l.1. Dissolved.chloride..mg.l.1.
1:                        0.13                          17
2:                        0.12                          34
3:                        0.12                          26
4:                        0.12                          24
5:                        0.10                          16
6:                        0.14                          25
7:                        0.11                          23
8:                        0.11                          42
   Dissolved.nitrate......mg.l.1.NO3. Dissolved.sulphate.....mg.l.1.SO4.
1:                                 26                                  34
2:                                 17                                  26
3:                                 25                                  46
4:                                 24                                  20
5:                                 31                                  35
6:                                 28                                  19
7:                                 28                                  42
8:                                 27                                  20
   Dissolved.sodium..mg.l.1. Dissolved.potassium..mg.l.1.
1:                       8.8                          1.7
2:                      17.8                          3.6
3:                      16.2                          3.5
4:                      12.4                          2.4
5:                       8.3                          1.5
6:                      12.1                          2.9
7:                      13.3                          2.7
8:                      26.3                          4.2
   Dissolved.calcium.....mg.l.1. Dissolved.magnesium..mg.l.1.
1:                           101                           5.7
2:                            68                           4.4
3:                           102                           4.2
4:                           107                           2.2
5:                           109                           5.1
```

```
6:                                107                          3.2
7:                                 98                          4.5
8:                                107                          1.9
   Dissolved.boron....µg.l.1. cluster
1:                         20       1
2:                         26       1
3:                         51       1
4:                         22       1
5:                         25       1
6:                         21       1
7:                         33       1
8:                         35       1
```

```
dfcl<-df_forClustering %>%
  select(-Site) %>%
  group_by(cluster) %>%
  summarise_all("mean")

write.csv(dfcl,"F:\\3-1\\ST305\\Assignment\\meanclusters.csv", row.names = FALSE)
```

```
df_forClustering %>%
  select(Site,cluster) %>%
  group_by(cluster)
```

```
# A tibble: 22 x 2
# Groups:   cluster [3]
   Site                              cluster
   <chr>                               <int>
 1 Jubilee River at Pocock's Bridge        2
 2 River Cherwell at Hampton Poyle         2
 3 River Cole at Lynt Bridge               2
 4 River Coln at Whelford                  1
 5 River Enborne at Brimpton               1
 6 River Evenlode at Cassington Mill       1
 7 River Kennet at Woolhampton             1
 8 River Leach at Mill Lane,Lechlade       1
 9 River Lodden at Charvil                 2
10 River Ock at Abingdon                   2
# ... with 12 more rows
```