Energy Conservation and Economics by Assessing Water Quality of a Waste Treatment Plant

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Srikar Ponnapalli - Temperature
Sahitya P - pH
Vikranth Akarapu - Total Suspended Solids
Sairam Gunkala - Ammonia Nitrogen

Energy Conservation and Economics by Assessing Water Quality of a Waste Treatment Plant

- This research conducted by graduate students in the A-STATE College of Engineering under leadership of Dr. Segall studied five characteristics of water quality of a local waste treatment plant using techniques of statistical quality control as applied to actual 2014 data collected for an actual water treatment plant in United States.

- The resource characteristics of Carbonaceous Biochemical Oxygen Demand (CBOD), Total Suspended Solids (TSS), Ammonia Nitrogen (NH3-N), and pH are each evaluated and measured as indicators for obtaining effective energy conservation by maintaining water quality.

- This research illustrates the applications of engineering techniques for energy conservation and efficiency by means of maintaining acceptable water quality levels and subsequently energy economics. An overview of some of the results obtained using Minitab 17 are presented as well as conclusions and future directions of the research.

ABOUT WATER TREATMENT PLANT local to University:

① It (requested to anonymous) is one of a kind, in that, in Arkansas it is the only municipal improvement district set up which serves water, sewer and electricity to its citizens.

② The major advancements made by this utility can be contributed to conservative, but progressive leadership through its managers and the board of directors who have been willing to look to the future with the interests of Jonesboro in mind. This is evident by the existence of excess capacity in all three utilities and some of the lowest rates in the nation.

③ In conclusion, Water Treatment Plant's goal is to continue to meet the needs of a growing community and provide its services at the lowest cost consistent with sound business practices.

④ As of March 1, 2013, we have approximately 34,000 electric customers, 34,200 water customers (including 6,000 rural), 22,600 sewer customers and a city population of almost 69,000.

Introduction

- The presentation is a statistical study of the 2014 East Plant wastewater facility operated by a local waste treatment plant that requested to remain anonymous.

- The team members are Bharani Krishna, Srikar, Vikranth and Sairam. Each effluent variable that was measured and recorded for 2014 is analyzed. Sairam analyzed Ammonia Nitrogen (NH3-N), Sahitya analyzed pH, Vikranth Total Suspended Solids (TSS) and Bharani Krishna analyzed Carbonaceous Biochemical Oxygen Demand (CBOD) or Biochemical Oxygen Demand (BOD) and Temperature by Srikar.

- The effluent or outgoing water is the treated wastewater discharged from the facility. Effluent wastewater parameters are based on averages due to daily fluctuations due to seasonal changes, rain, etc…

- All data is analyzed with Minitab 17.0 software. The statistical analysis identifies out of control conditions, out of specification conditions and trends of each variable listed above.

- The 2014 wastewater specifications are from National Pollutant Discharge Elimination System (NPDES) Permit AR0037907 as on next slide.

NPDES AR0037907

PART I
PERMIT REQUIREMENTS

SECTION A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS: OUTFALL 001 - treated municipal wastewater.

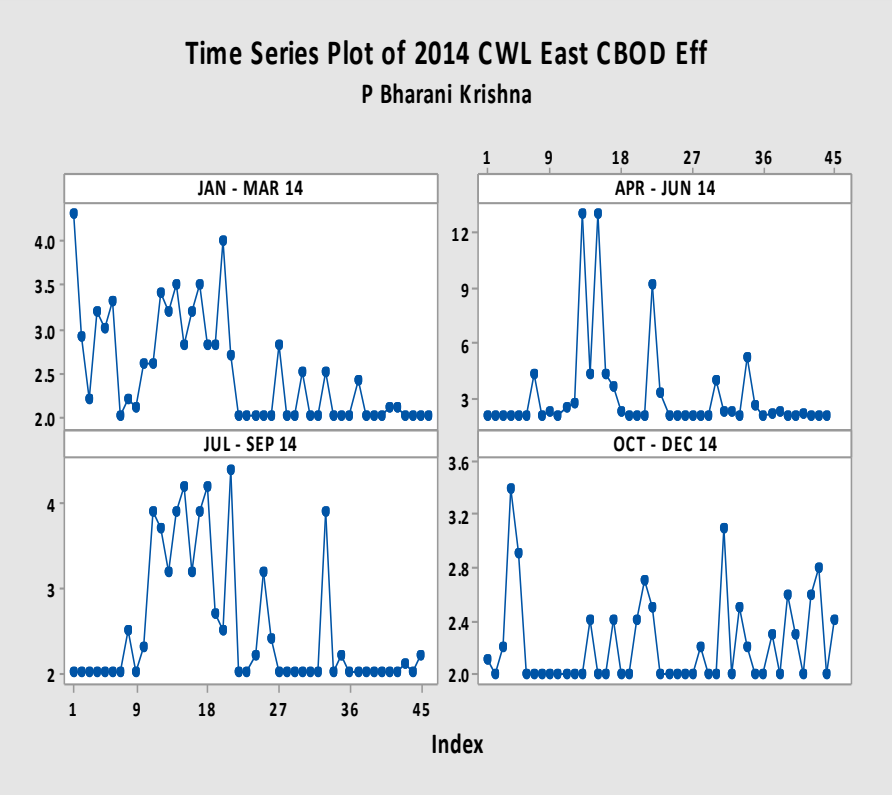
During the period beginning on the effective date and until the date of expiration, the permittee is authorized to discharge from Outfall 001. Such discharges shall be limited and monitored by the permittee as specified below from a treatment system consisting of bar screen, grit removal, primary sedimentation, first and second stage trickling filters, secondary sedimentation, chlorination, dechlorination, and re-aeration with a design flow of 3.0 MGD.

Effluent Characteristics	Discharge Limitations			Monitoring Requirements	
	Mass (lbs/day, unless otherwise specified)	Concentration (mg/l, unless otherwise specified)		Frequency	Sample Type
	Monthly Avg.	Monthly Avg.	7-Day Avg.		
Flow	N/A	Report, MGD	Report, MGD (Daily Max.)	once/day	totalizing meter
Carbonaceous Biochemical Oxygen Demand (CBOD5)	375.3	15	22.5	one/week	composite
Total Suspended Solids (TSS)	500.4	20	30	one/week	composite
Ammonia Nitrogen (NH3-N)	100.1	4	6	one/week	composite
Dissolved Oxygen (DO)	N/A	5.0, (Inst. Min.)		one/week	grab
Fecal Coliform Bacteria (FCB)		(colonies/100ml)			
	N/A	1000	2000	three/week	grab
Total Residual Chlorine (TRC)[1]	N/A	<0.1 mg/l (Inst. Max.)		one/week	grab
Total Phosphorus (TP)	N/A	Report	Report	one/month	composite
Nitrate + Nitrite Nitrogen (NO3 + NO2-N)	N/A	Report	Report	one/month	composite
Chlorides	N/A	Report	Report	one/quarter	composite
Total Dissolved Solids	N/A	Report	Report	one/quarter	composite
Aluminum, Total Recoverable	N/A	Report	Report	once/year	composite
pH	N/A	Minimum 6.0 s.u.	Maximum 9.0 s.u.	one/week	grab
Chronic Lethal WET Limit[2]	N/A	Not < 100%		once/quarter	composite

Carbonaceous Biochemical Oxygen Demand (CBOD)

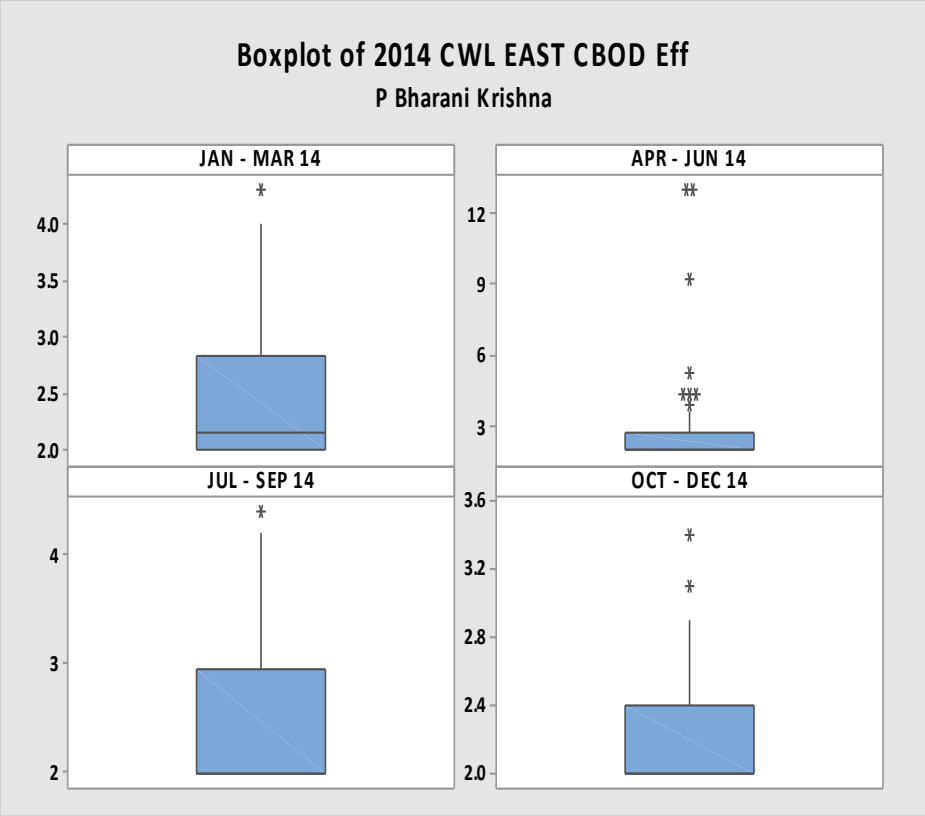
- Carbonaceous Biochemical Oxygen Demand is the rate at which organisms use the oxygen in water or wastewater to while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter services as food for the bacteria and energy results from its oxidation.
- CBOD acceptable range is 15 mg/l (ppm).

Time Series Plot of CBOD



- This plot contains data set for the entire year of 2014 which is splitted quarterly. The CBOD values are ranging between 2.0 and less than 6.0. The CBOD values are ranging between 3.0 and less than 15 which is acceptable for the CBOD effluent. This Time series plot shows a sequence of data points from the month of January till December for 2014 year. The CBOD value should be less than 15 mg/l (ppm).

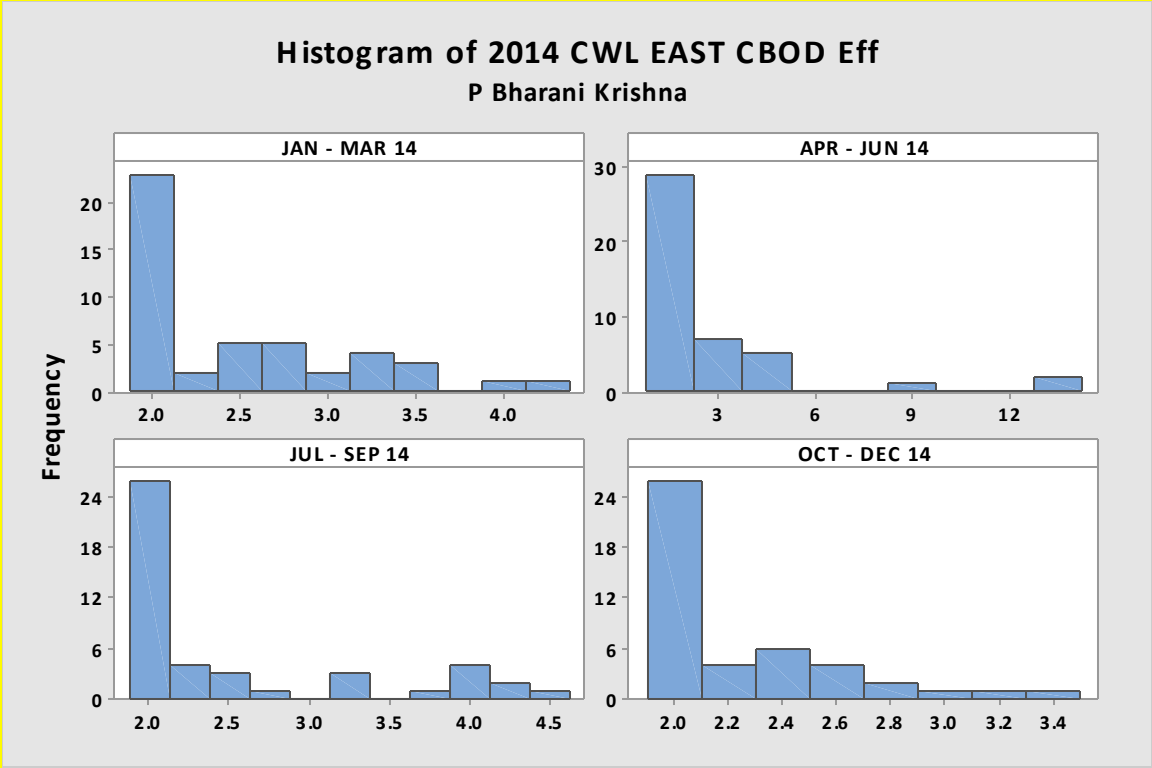
Boxplot of CBOD



- The point outside the end of the whisker for April to June, July to Sept and Oct to Dec is outlier or suspected outlier.

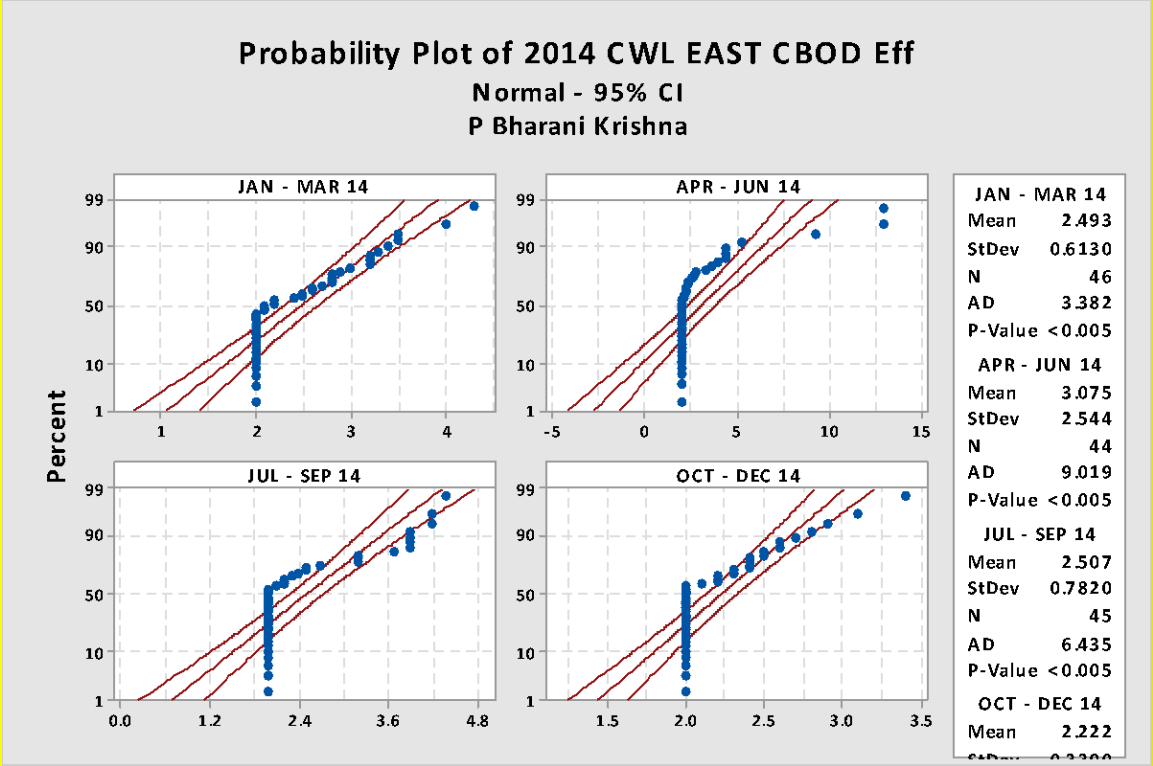
Histogram of CBOD

- Most of the data points fall into the range of 2.0 to 3.0 which means basically the quality process of 2014 was operated well



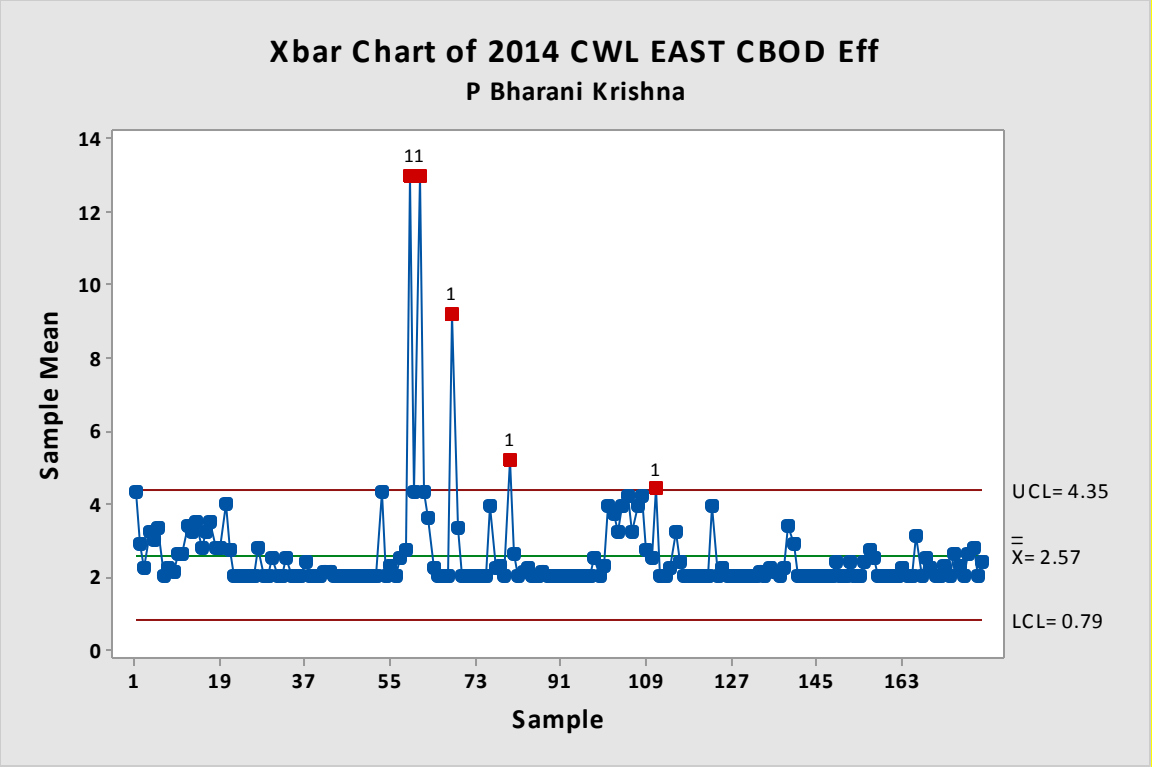
Probability Plot of CBOD

- The data for months of January, April, May, July, September, October, and November are slightly departing from the straight line. Generally, the points on this plot form a nearly linear pattern which indicates that the normal distribution is a good model for this data set of 2014.



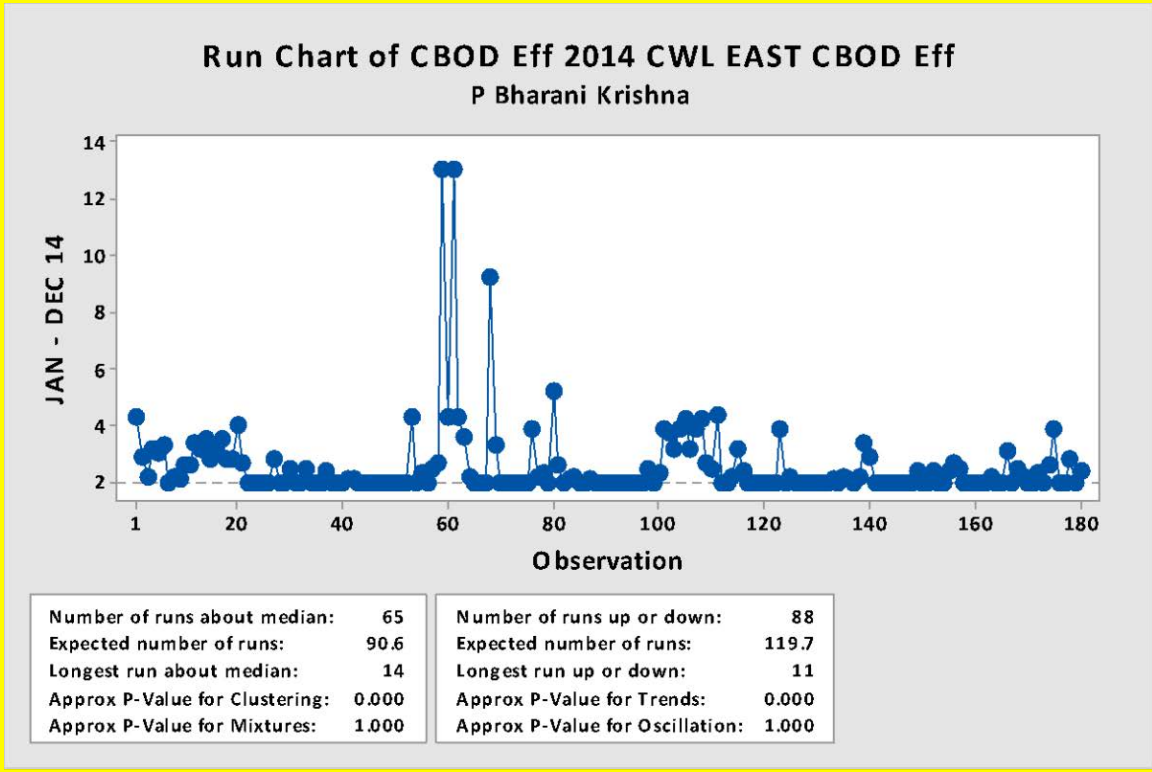
Xbar Chart of CBOD

- The CBOD values are ranging within the upper control limit of 4.35 and the lower control limit of 0.79



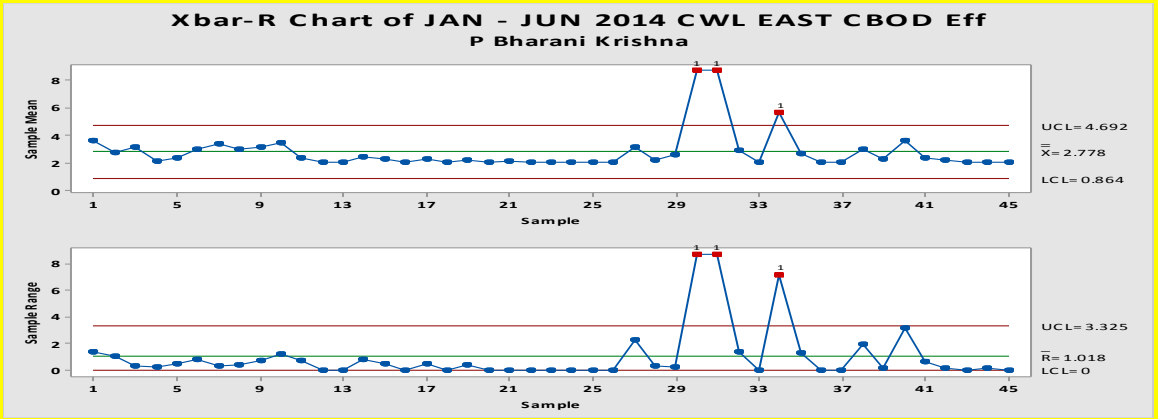
Run Chart of CBOD (Means)

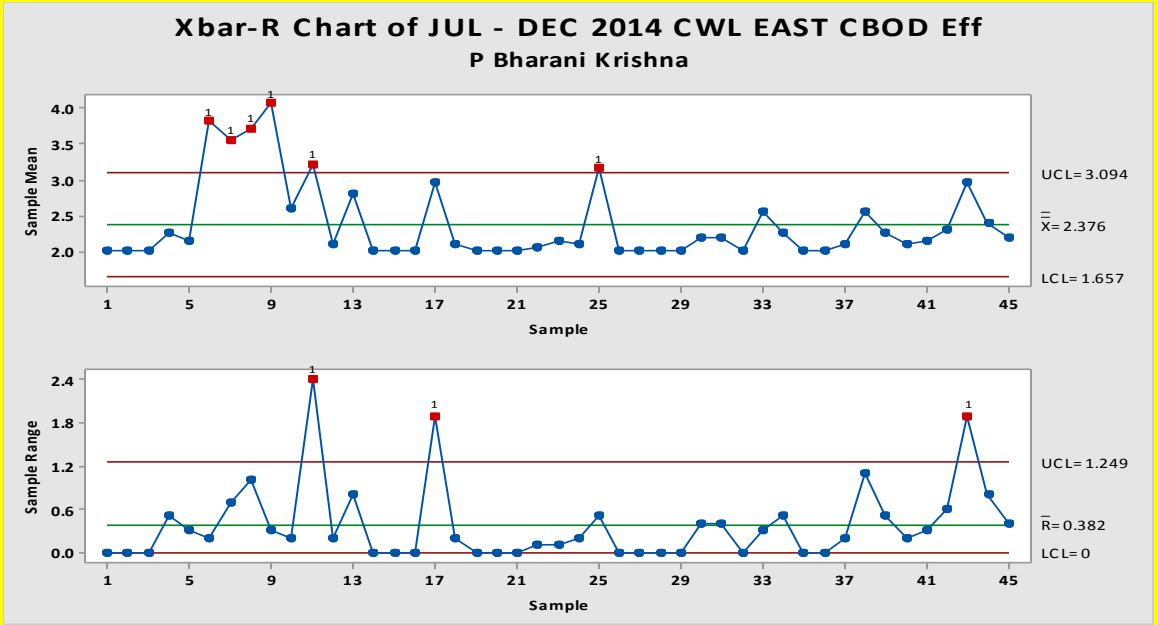
- The twelve mean values for six month are highlighted and connected together in order to compare the differences between them.



Run Chart of CBOD (Medians)

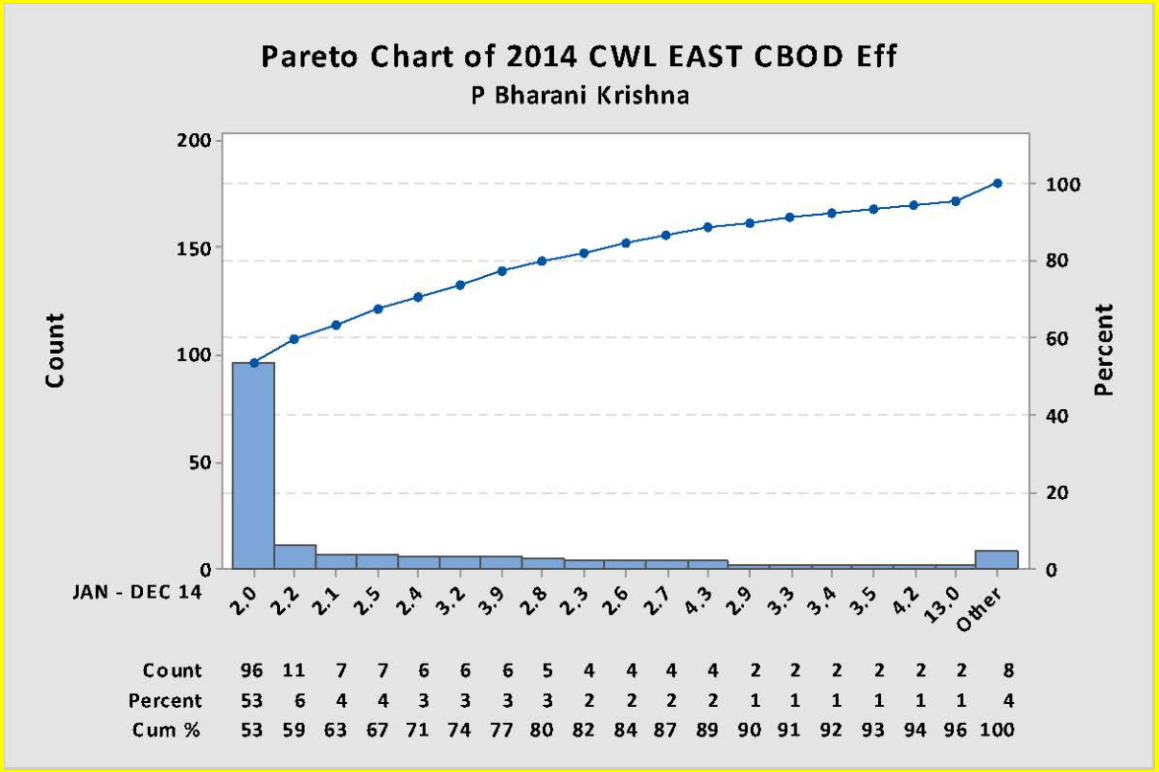
- While plotting the run chart of CBOD effluent with subgroup medians, we can see that there is a unstable wave from Jan to June well.





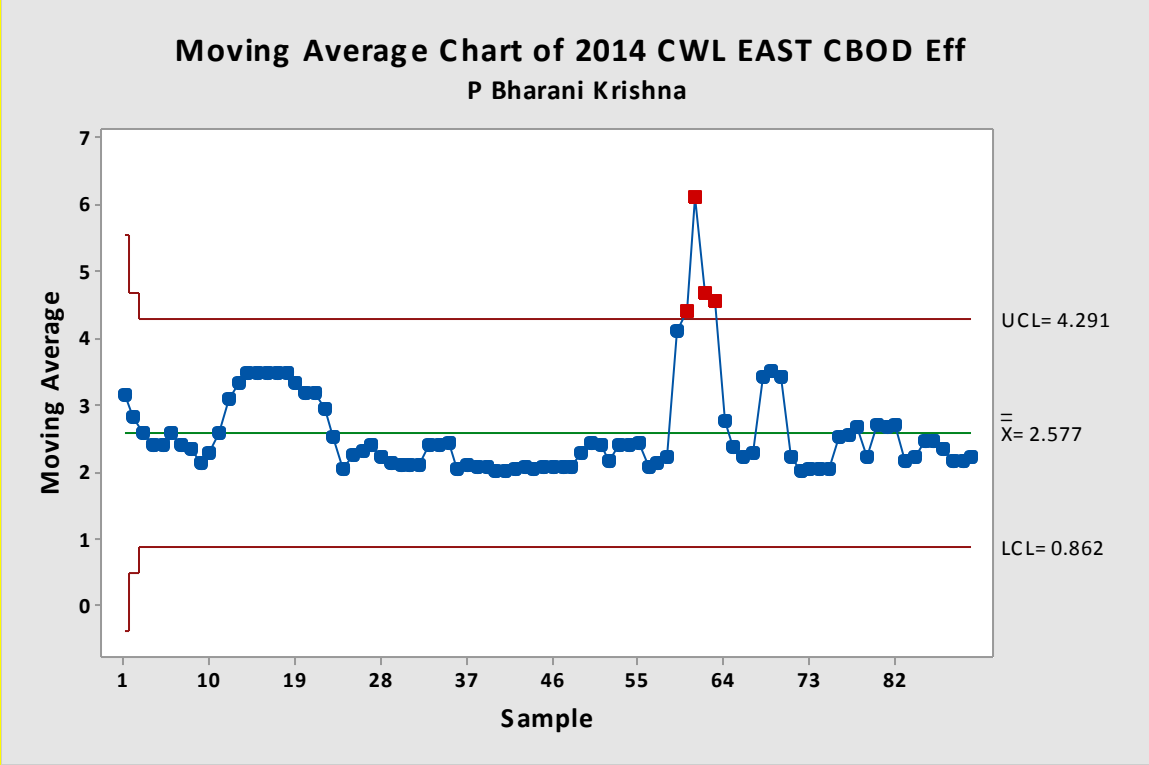
Pareto Chart of CBOD

- The values for the month of January, April, May, July, October, September, and November are mainly falling in the area of 2.0.



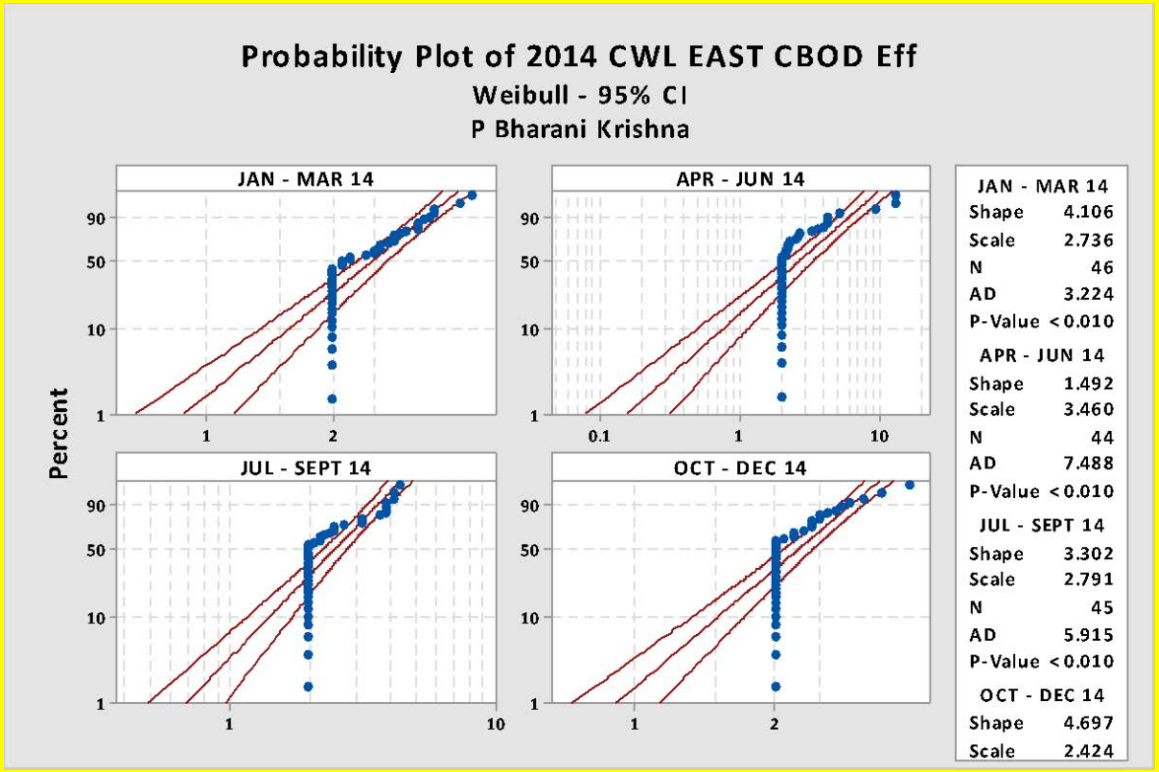
Moving Average Chart of CBOD

- We can see that this plot confirms the seasonal shifts of CBOD effluent. On the other hand, a few points collected near the middle of the year 2014 are outside the upper control limit.



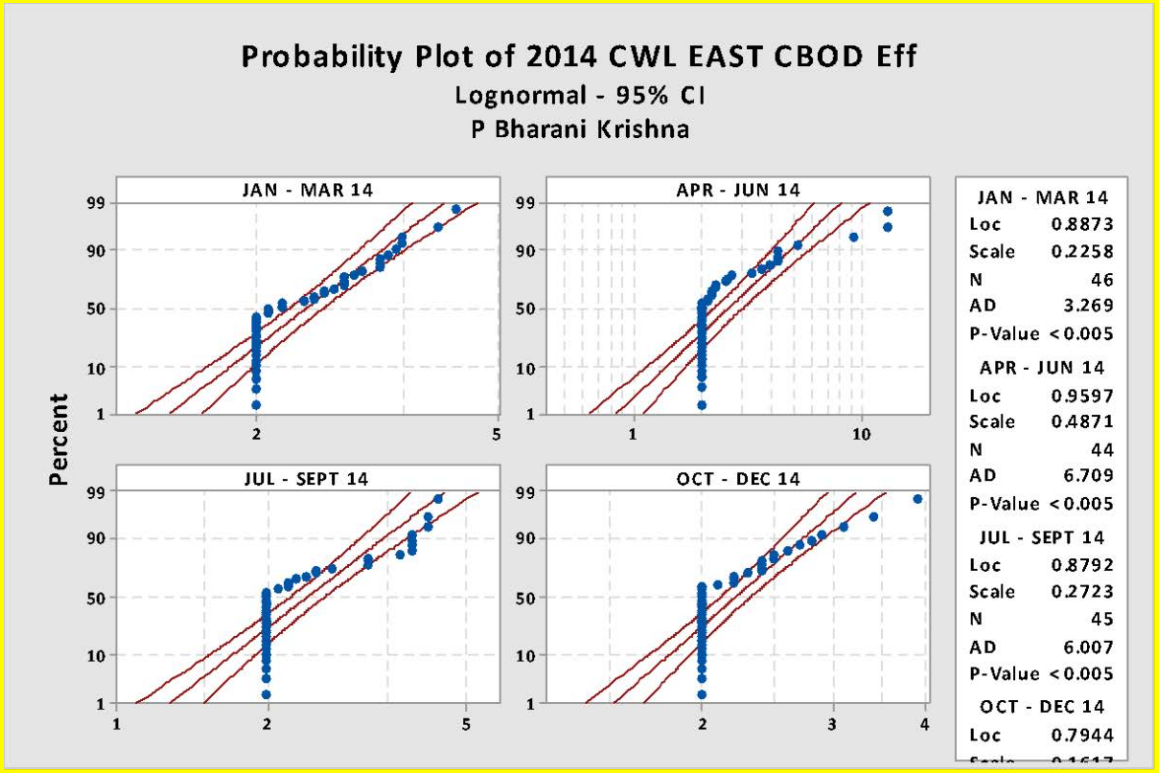
Weibull Plot of CBOD

- When temperature is between 14 and 24 and flow is below 9, the data is stable under 2.0 and a few suspected outliers.



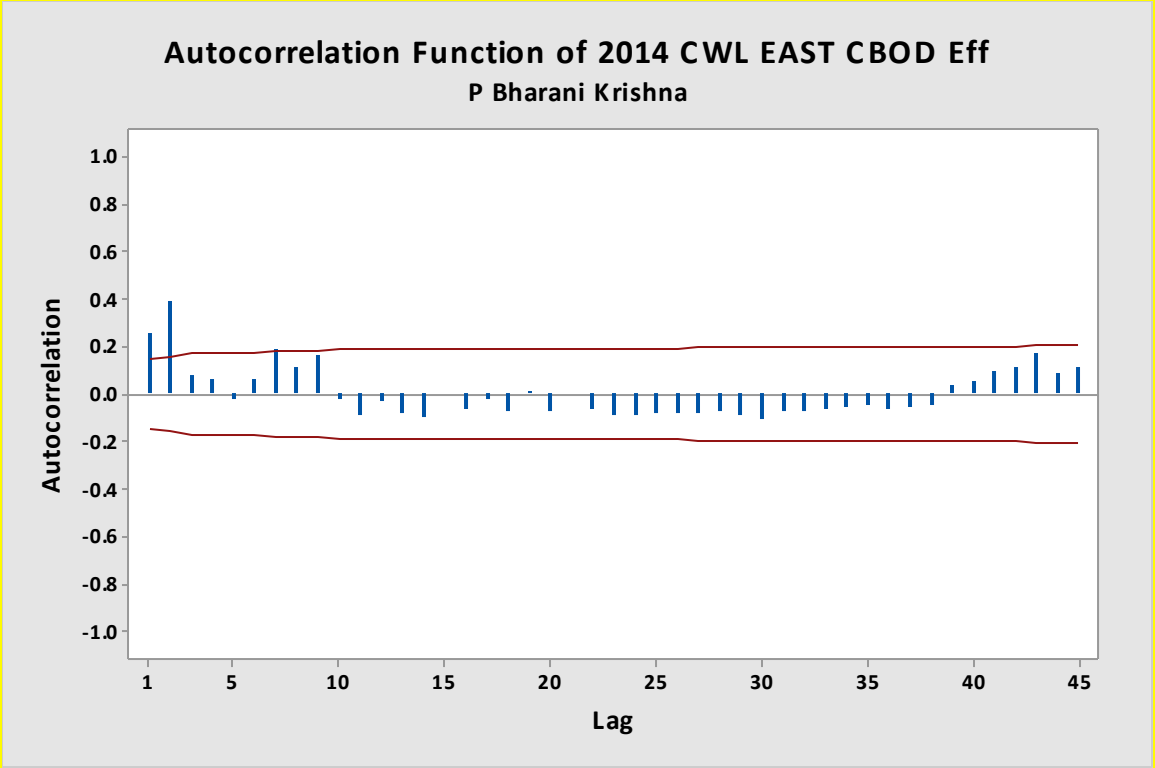
Lognormal Plot of CBOD

- When temperature is between 14 and 24 and flow is below 9, the data is stable under 2.



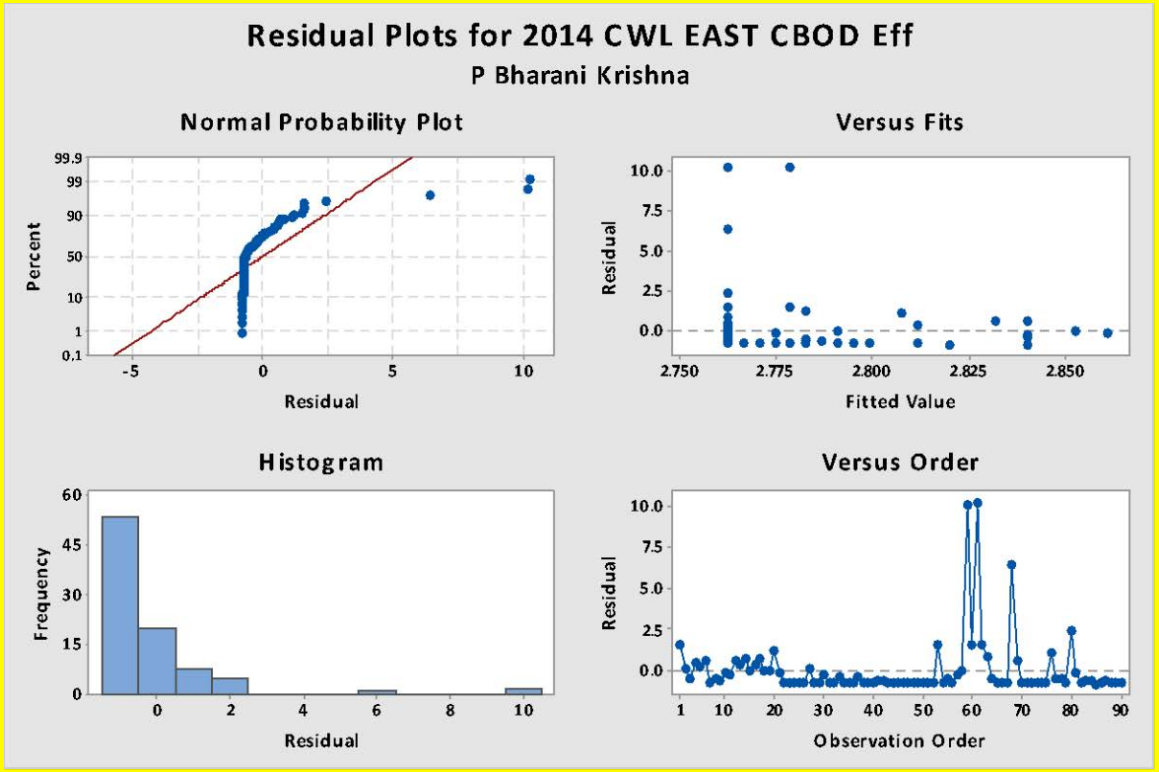
AutoCorrelation Function of CBOD

- Autocorrelation also known as serial correlation or cross-autocorrelation is the cross-correlation of a signal with itself at different points in time (that is what the cross stands for).



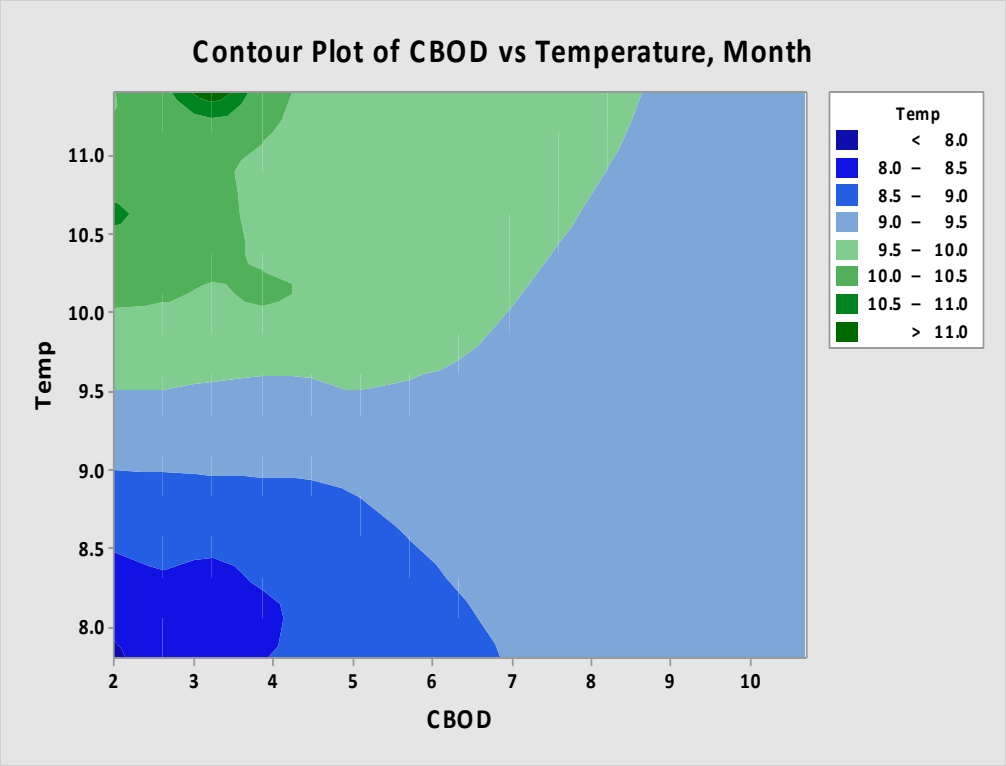
Residual Plots of CBOD

- When temperature is between 14 and 24 and flow is below 9, the data is stable under 2.5.



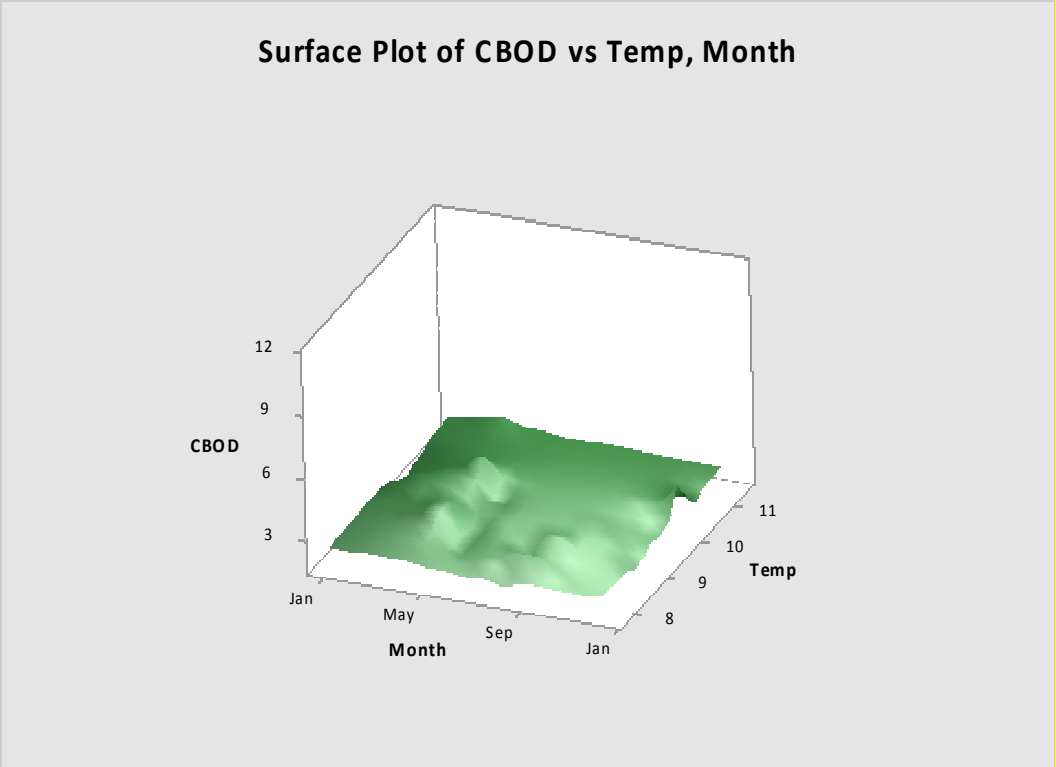
Contour Plot of CBOD versus Temperature of Previous Year 2013

- This may be a cheaper option to testing the levels of CBOD daily.
- This shows a correlation between temperature and CBOD values.



Surface Plot of CBOD versus Temperature of Previous Year 2013

- This surface plot shows the effluent CBOD is in control.



Total Suspended Solids (TSS)

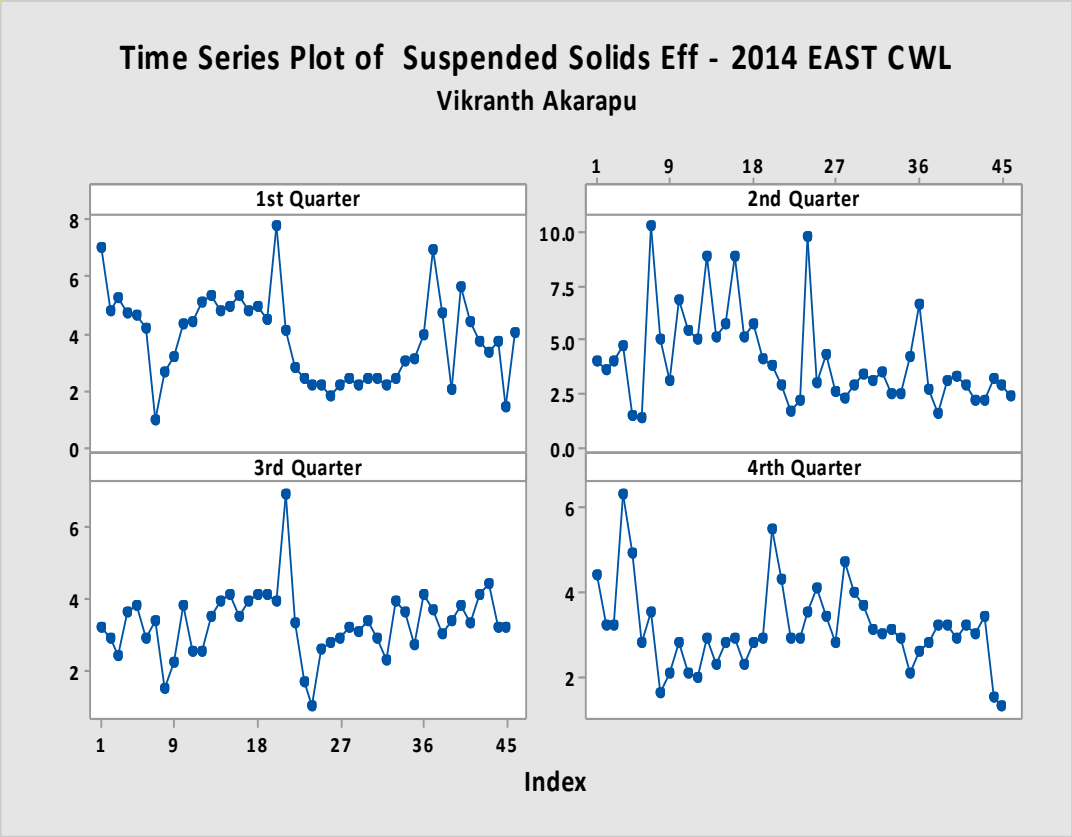
A water quality parameter used for example to assess the quality of wastewater after treatment in a wastewater treatment plant.

Total Suspended Solids (TSS)

- These are the Solids in the water that can be trapped by a filter.
- Can be organic or inorganic.
- Most of them are suspended and few of them can be dissolved.
- TSS includes silt, decaying plant and animal matter, and industrial wastes.
- High concentrations of suspended solids can cause many problems for stream health and aquatic life.

Time Series Plot

In the time series chart above, there is one sudden rise in the second quarter (Sample 7) which was around 10 (max. point attained in the entire year) and there is no regular trend followed in that period of time. The first quarter has its highest point at sample 20 and while the third quarter and final quarter have their highest points at sample 21 and sample 4 respectively. From this chart we can also observe that the second quarter generally gave high TSS readings, while the last quarter generally gave low TSS readings.

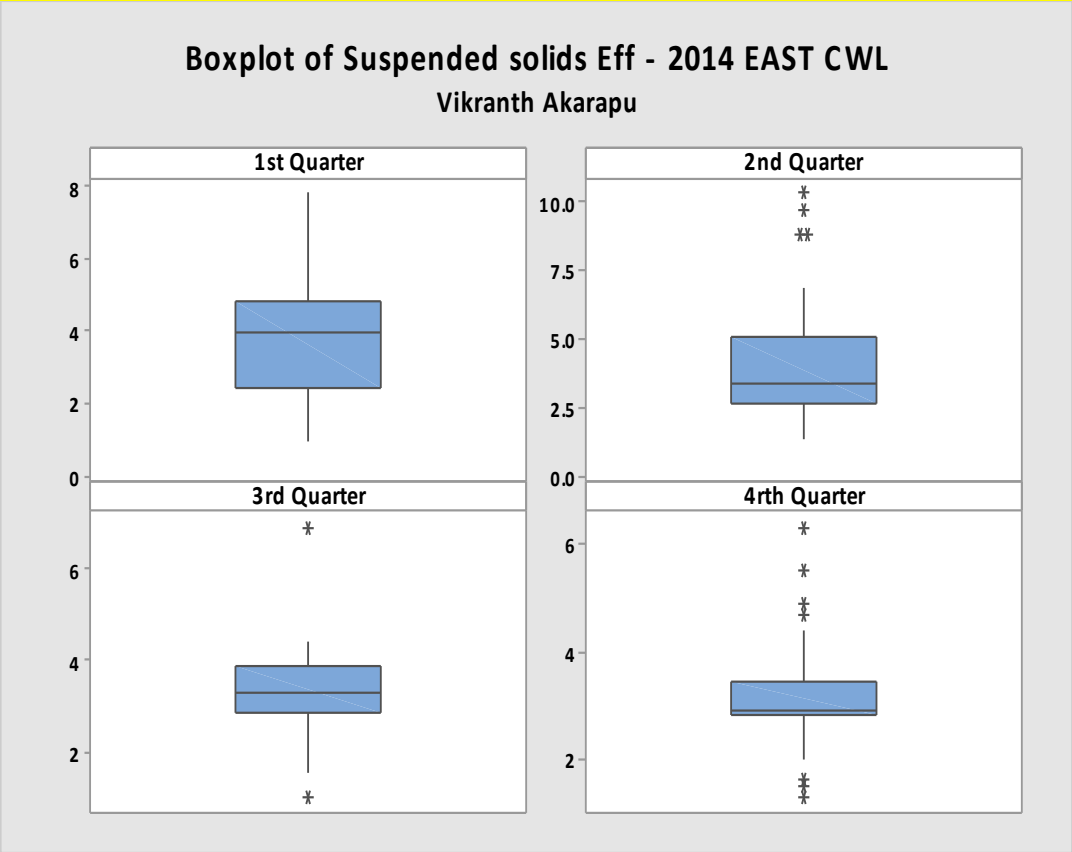


Box Plot

The samples are grouped and analyzed per quarter. Each quarter had a different mean.

Again, it is shown that the last quarter had the lowest mean TSS (roughly around 3) and the

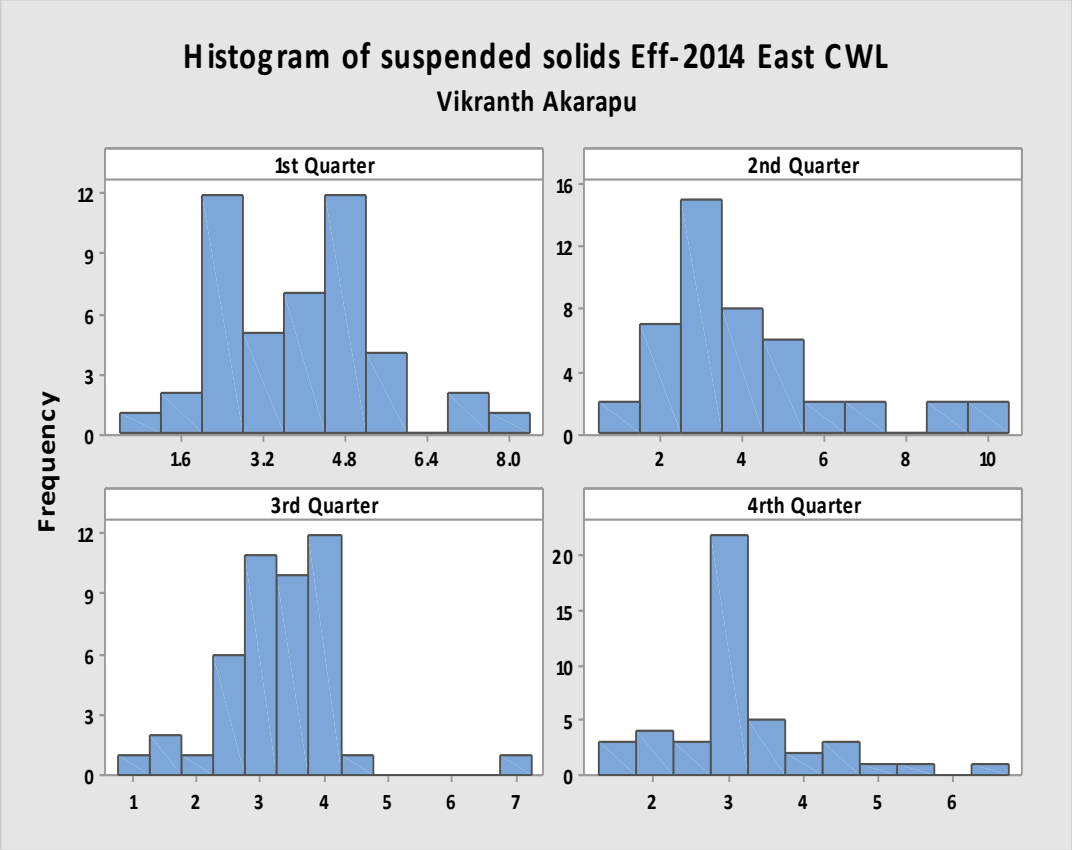
first quarter had the highest mean TSS(roughly around 4). And there lies a outlier in the second quarter at around a frequency of 7.5 as shown above.



Histogram

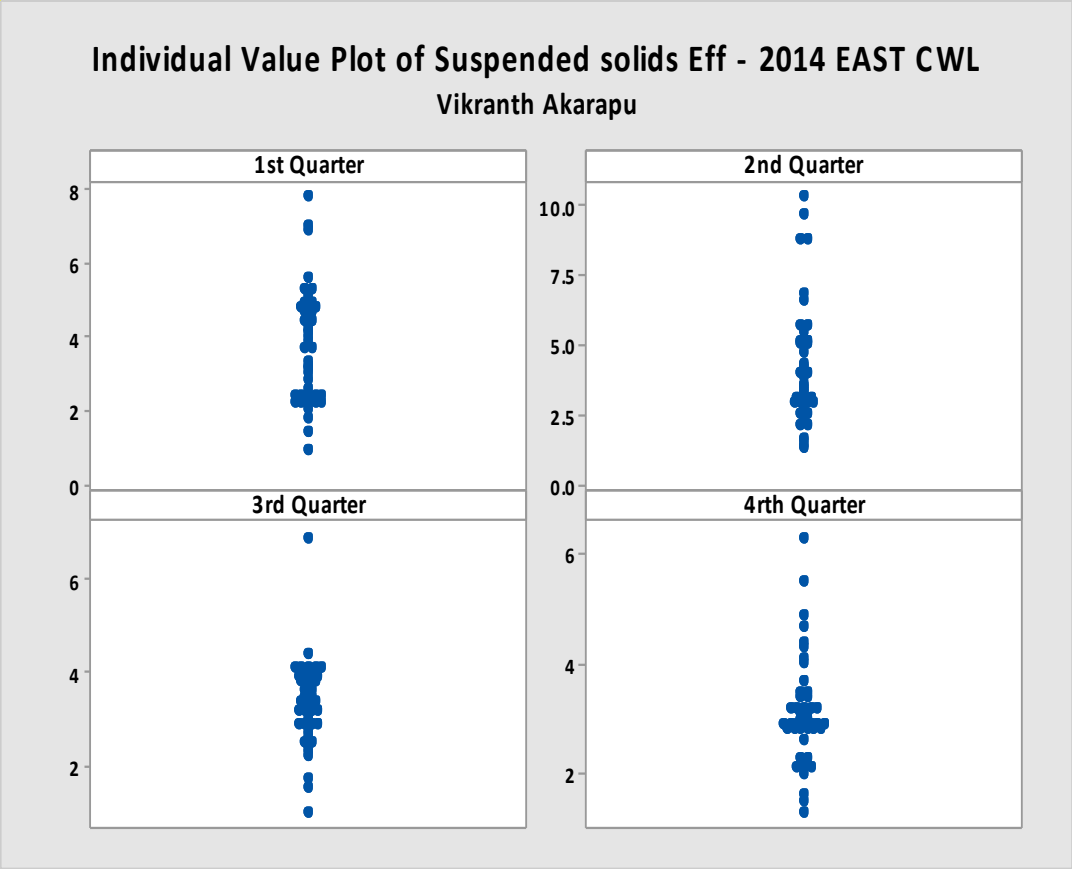
This diagram shows that the last quarter recorded the highest frequency among all the quarters which was around 20. While the third quarter showed almost zero frequency at the end of the period.

- The first quarter represents a bi-model and while the second and final quarters represents a single spike model. The third quarter shows us a spike with maximum frequency close to another spike. And also the TSS data is centered around a peak of 4.8 mg/l, 6mg/l, 4mg/l, and 4mg/l in the first, second, third and final quarters respectively. Which is well below the 20 mg/l monthly average TSS limit. This could indicate that TSS is not as susceptible to seasonal fluctuations.



Individual Value Plot

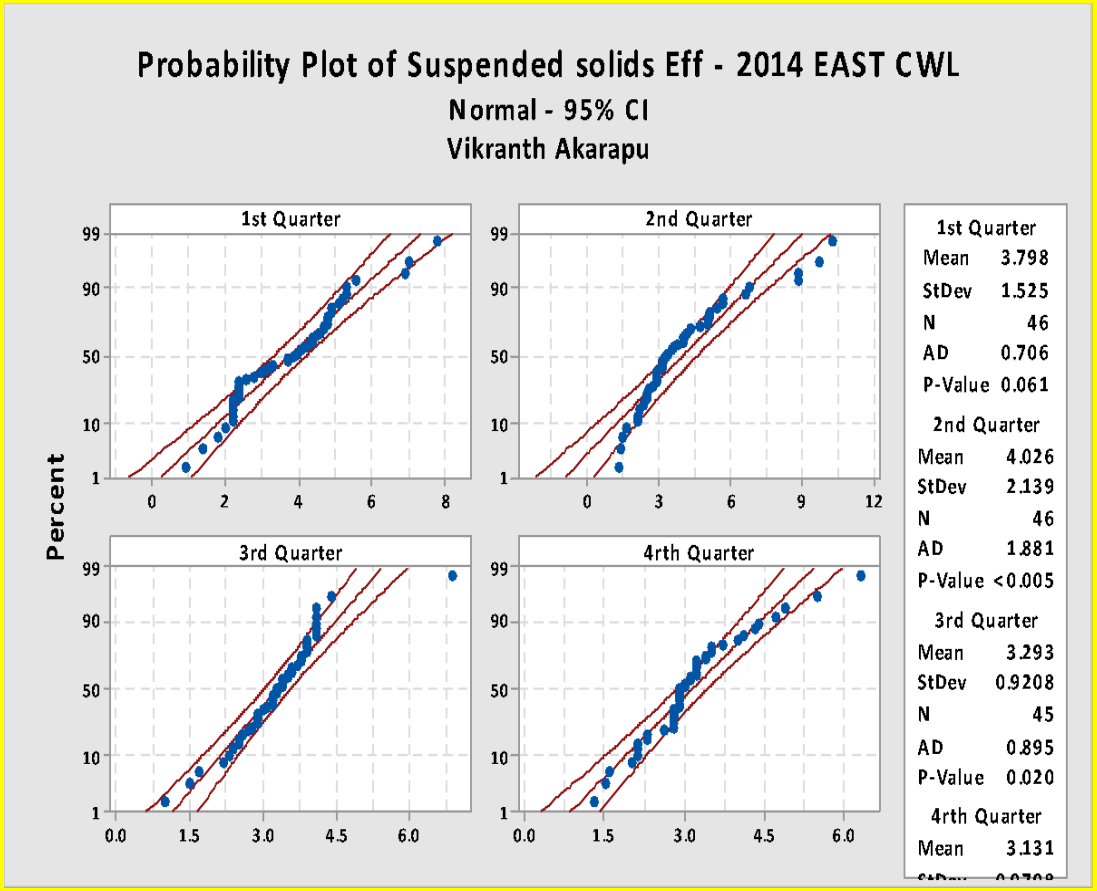
In this figure, as the points are offset, no identical points appeared atop each other and did not looked like a single point. There were many deviations from the center point. The second quarter showed the max. frequency of around 10. In the third quarter the average frequency was maintained at around 4. While only one reading was maintained at around 7 in that period of time.



Probability Plot

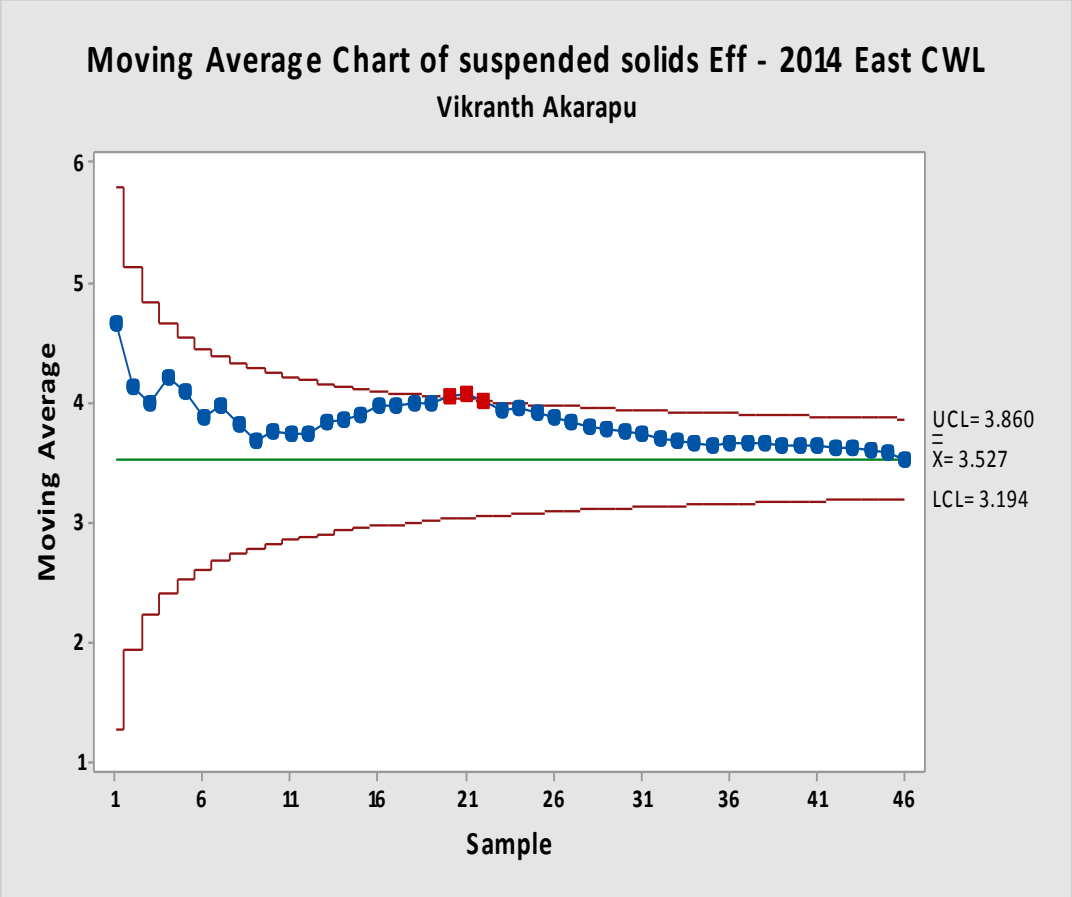
The graphical technique, probability plot was used for assessing whether or not a data set follows a given distribution such as the normal distribution. An approximate straight line was seen plotted against a theoretical distribution. Departures from this straight line indicated departures from the normality levels.

● This figure shows the probability plots quarter by quarter for the year 2014. There are some outliers in the second, third and fourth quarters. The second quarter has got its outliers at samples 43, 44, 45 and 46. And the third quarter has got its outliers at sample 46. While the final one has got its outliers at samples 45 and 46. These outliers tells us that the normality levels were not appropriate at those points.



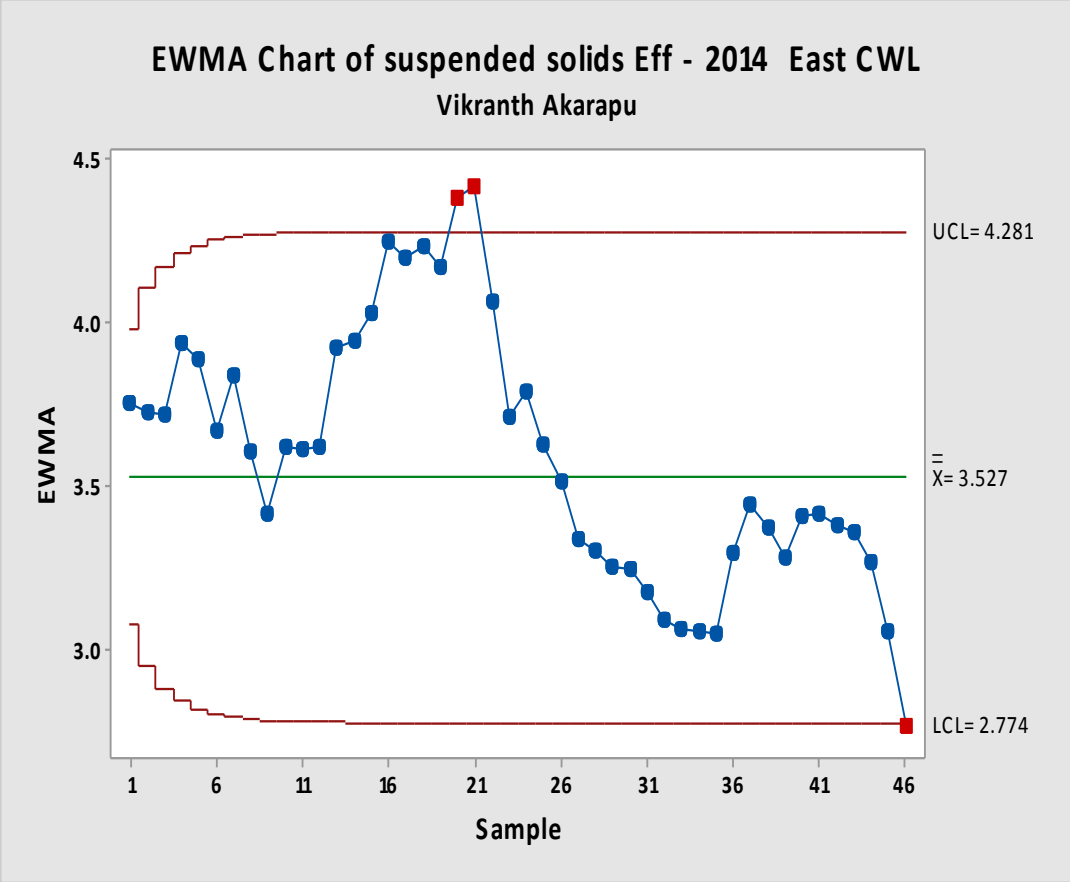
Moving Average Chart

Moving average control charts are generally used for detecting small shifts in the process mean. They will detect shifts of 0.5 sigma to 2 sigma much faster than Shewhart charts with the same sample size. Therefore, in examining the moving average analysis, the data points below the LCL are considered of exceptional quality and not an indication of an out of control process. Similarly, while three data points at samples 20, 21, 22 are above the upper control limit, these results are well below the permitted limits. As most of the readings are above the mean value it does not mean the process is out of control.



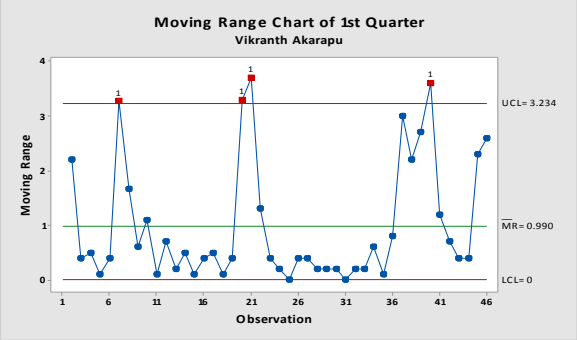
EWMA Chart

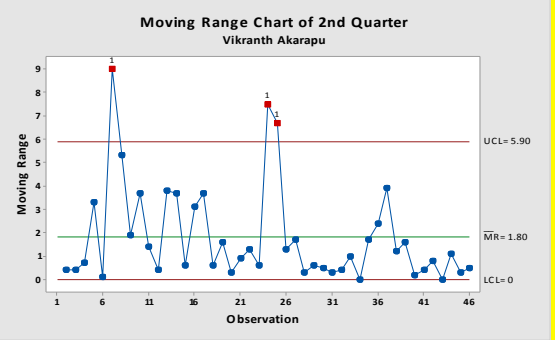
A lower out-of-control trend is displayed in the EWMA chart, as well as two overshooting samples during the mid-period. These over shooters are the outliers at samples 20, 21. In the EWMA chart, several trends are noticed that were not caught by the previous statistical tools, starting with the declining trend in the first quarter, which slowly ramps back up and peaks around March. Then there is a sudden decline during the summer and fall months, during which the TSS was always below the center line. This clearly shows that there is a decline in the stability at the end of the year.

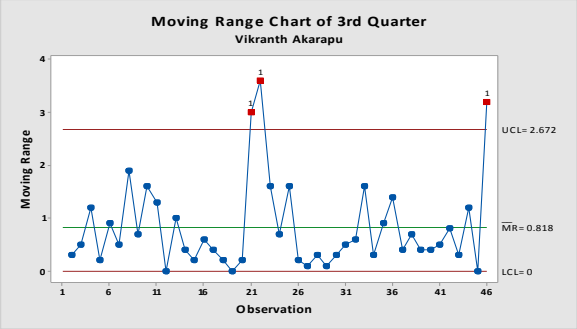


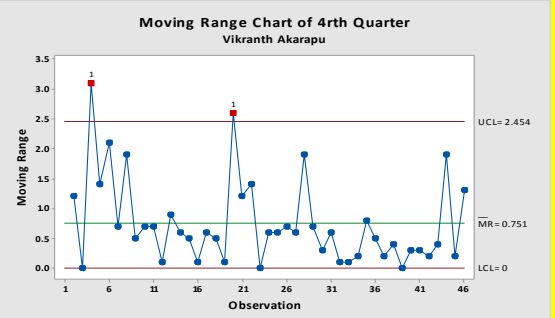
Moving Range Chart

The points that were statistically out of control belonged to all the quarters of the year. The data seems to be random since no particular trend can be identified. Each quarter's moving range plots are examined to see if any of the samples were out of control during each period, and also to see the difference in the means for each period. There are mid-quarter outliers for every quarter. The first quarter has its outliers at samples 6, 19, 20, 40. The second quarter with the outliers at samples 6, 23, 24. The third quarter with the outliers at samples 20, 21 and 46. And the final quarter with the outliers at samples 3 and 19.



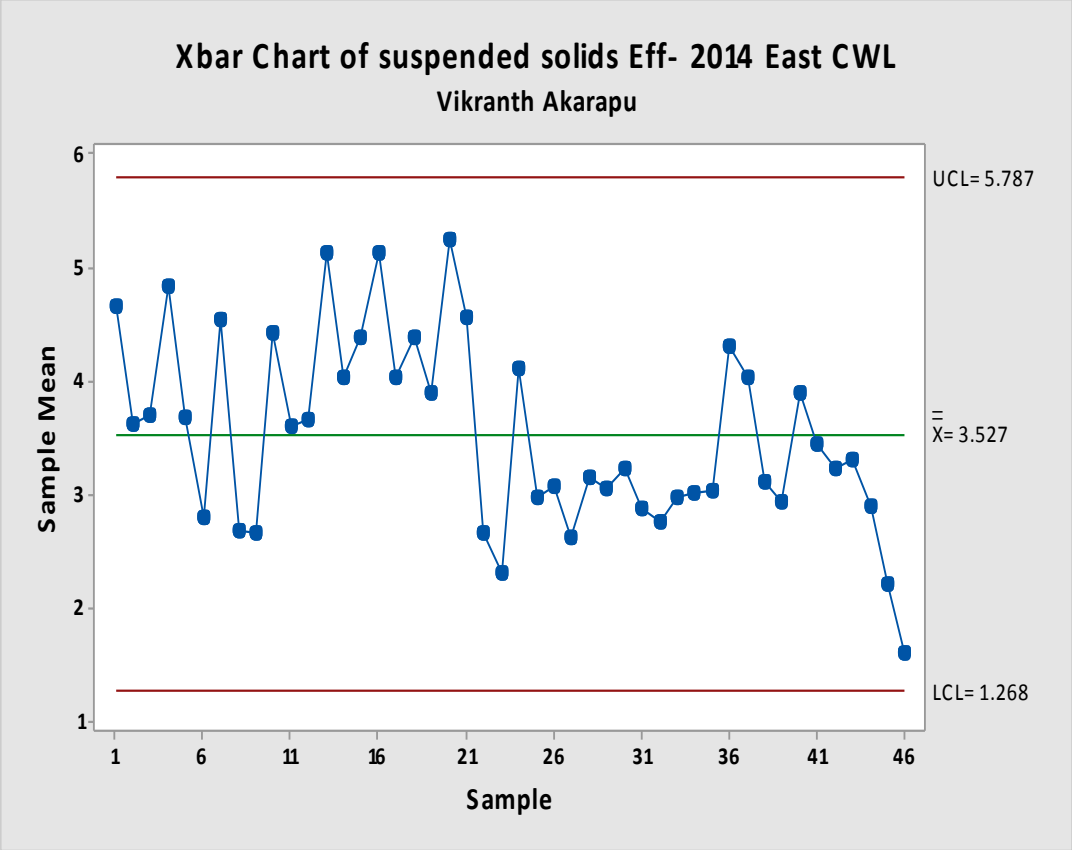






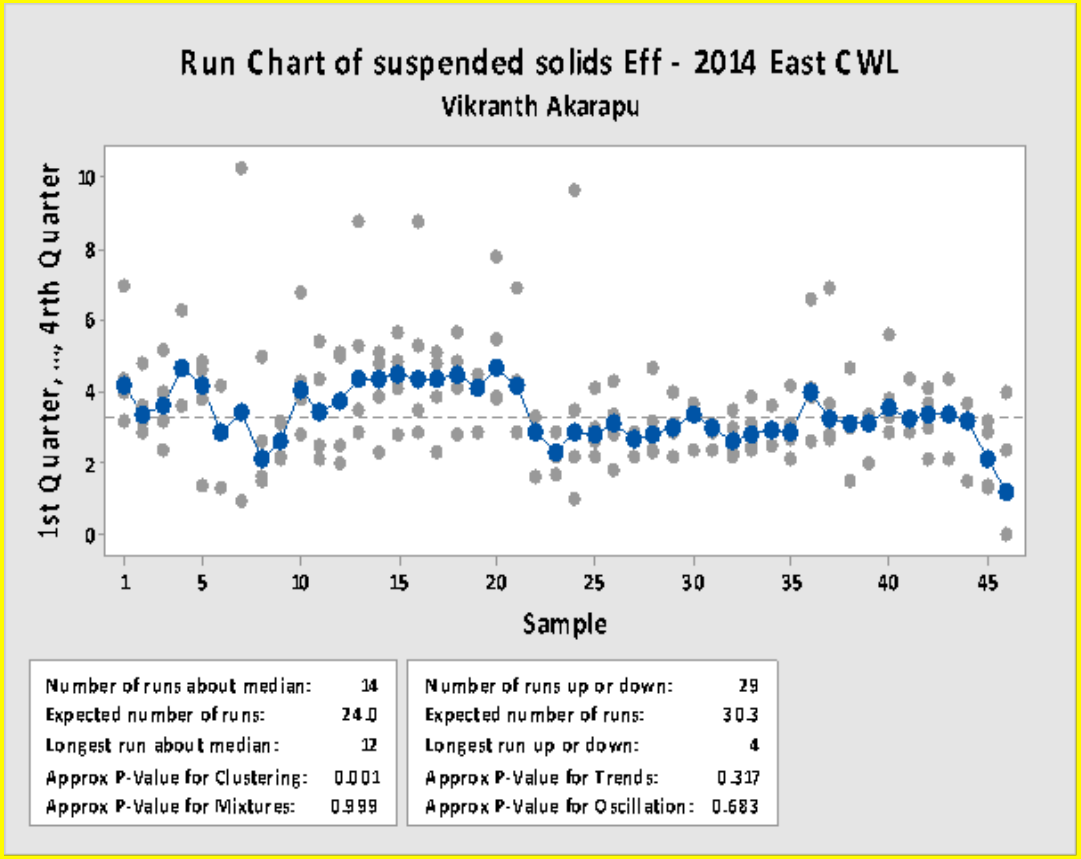
X- Bar Chart

In this figure, almost all the data points for the year 2014 seem to be within the control limits. The high TSS value is found in the second quarter. Whereas the low TSS value is found in the last period of last quarter. And also, there is no regular trend maintained throughout the year. Though low TSS values are seen in the last quarter but there are very few samples (36, 37, 40) which are above the mean line.



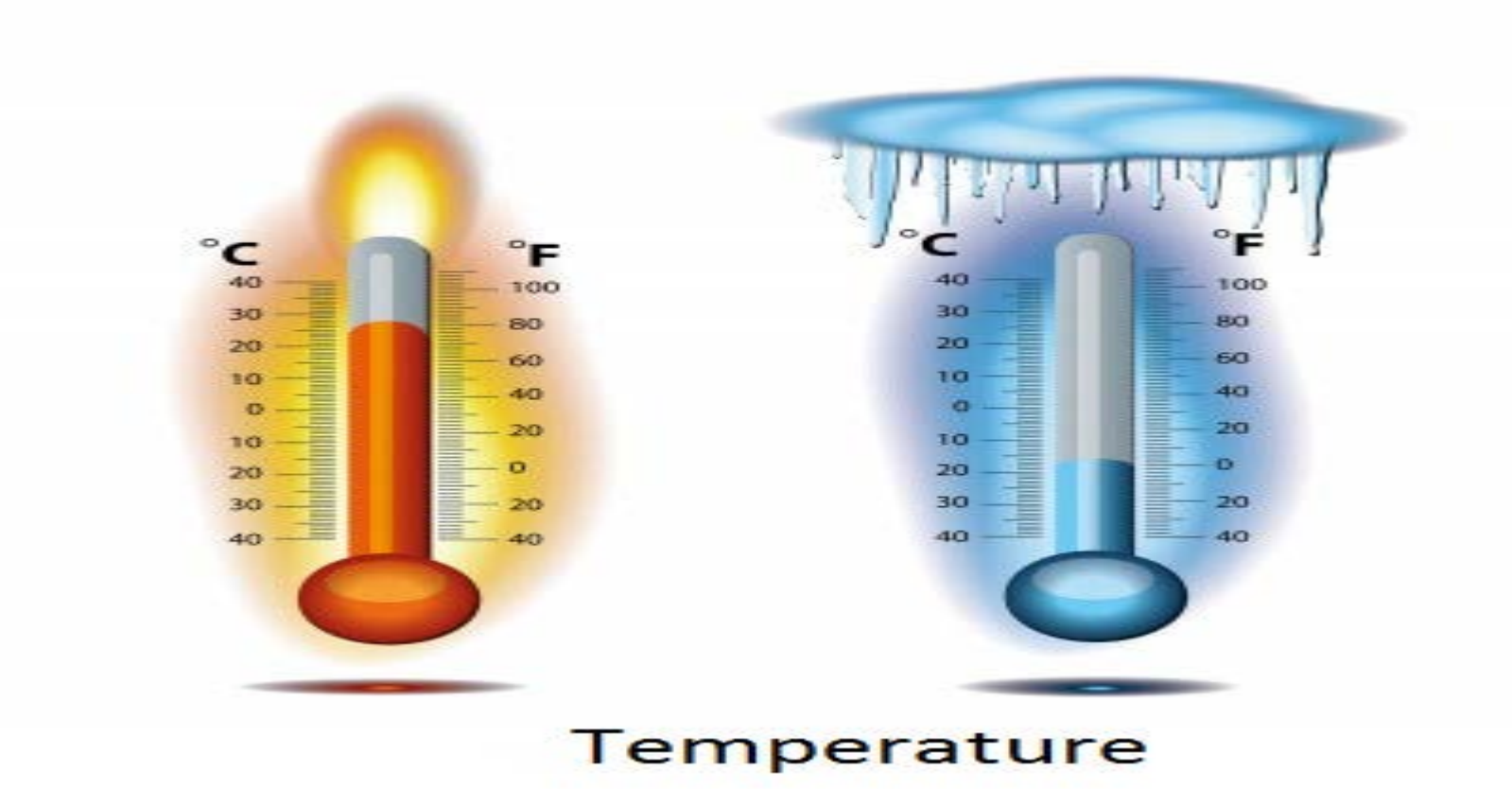
Run Chart

Run charts displays process performance of the TSS over time. Upward and downward trends, cycles, and large aberrations may be spotted and investigated. In a run chart, events, shown on the y axis, are graphed against a time period on the x axis. In the above figure, an average line (dark dotted line), representing the average of all the y values were recorded, which can easily be added to a run chart to clarify movement of the data away from the average. An average line runs parallel to the x axis. The light colored dots are all the sample values taken quarterly for the entire year. And some outliers can be easily seen in the second and final quarters.

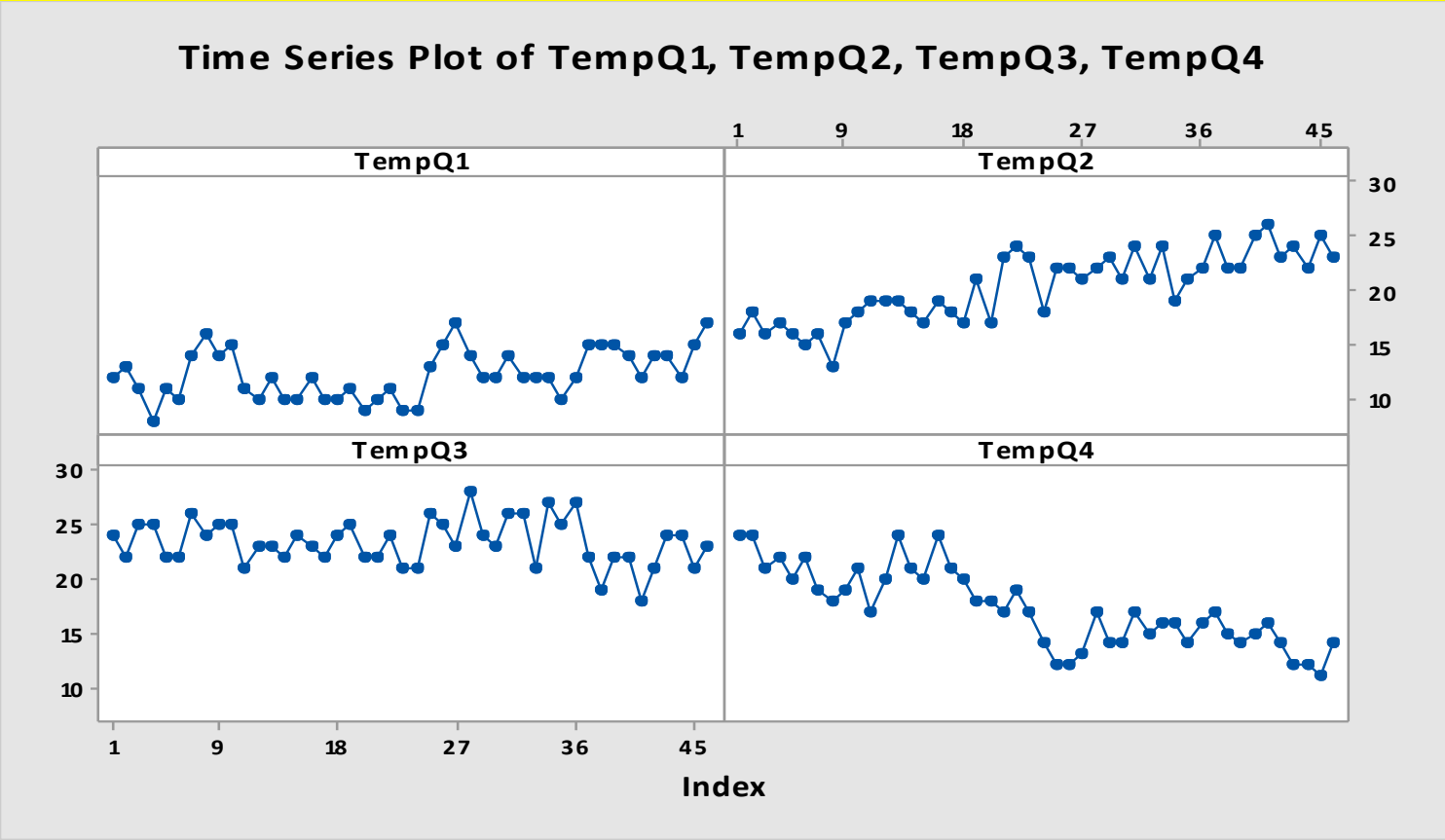


Temperature

Temperature

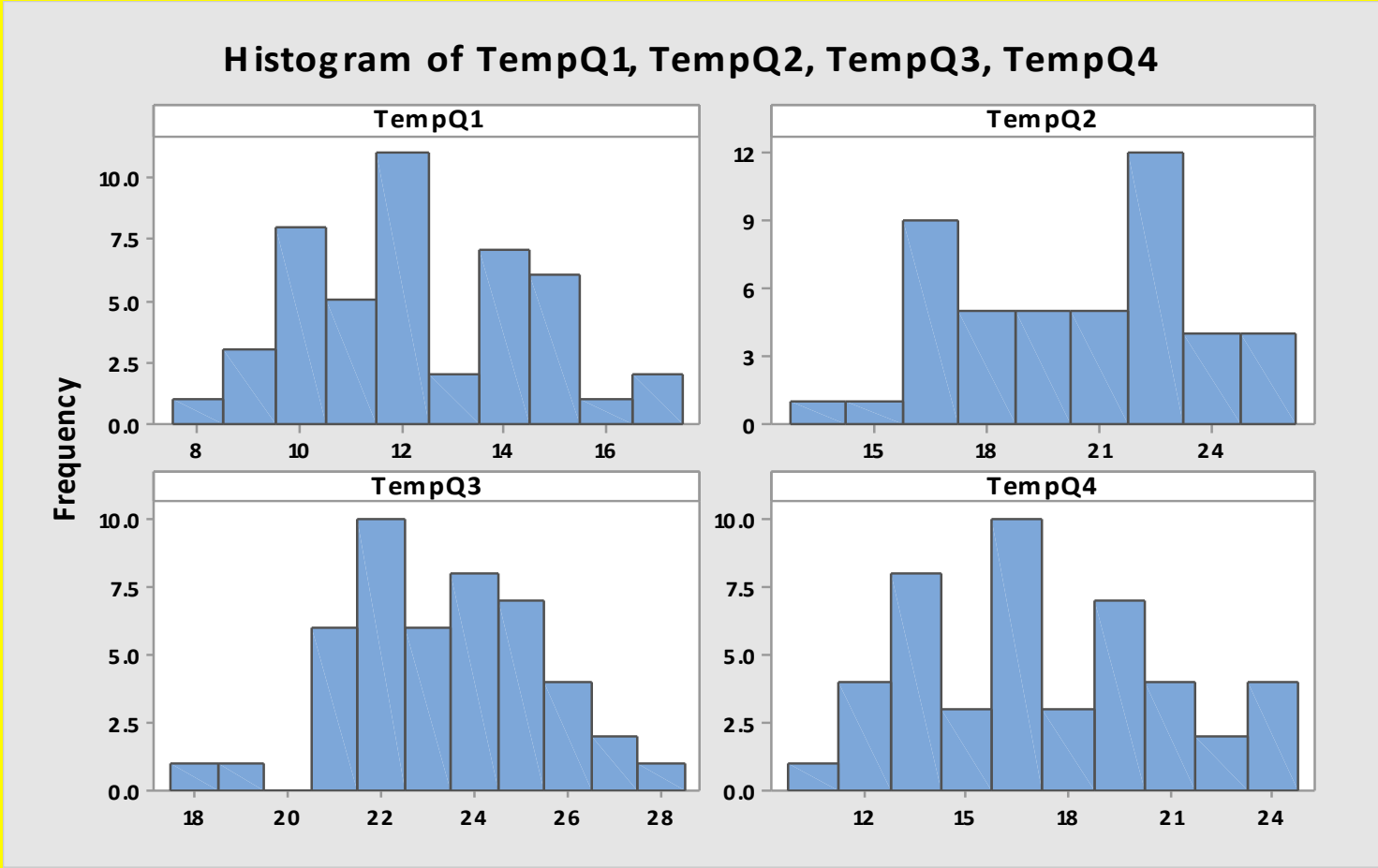


Time Series Plot



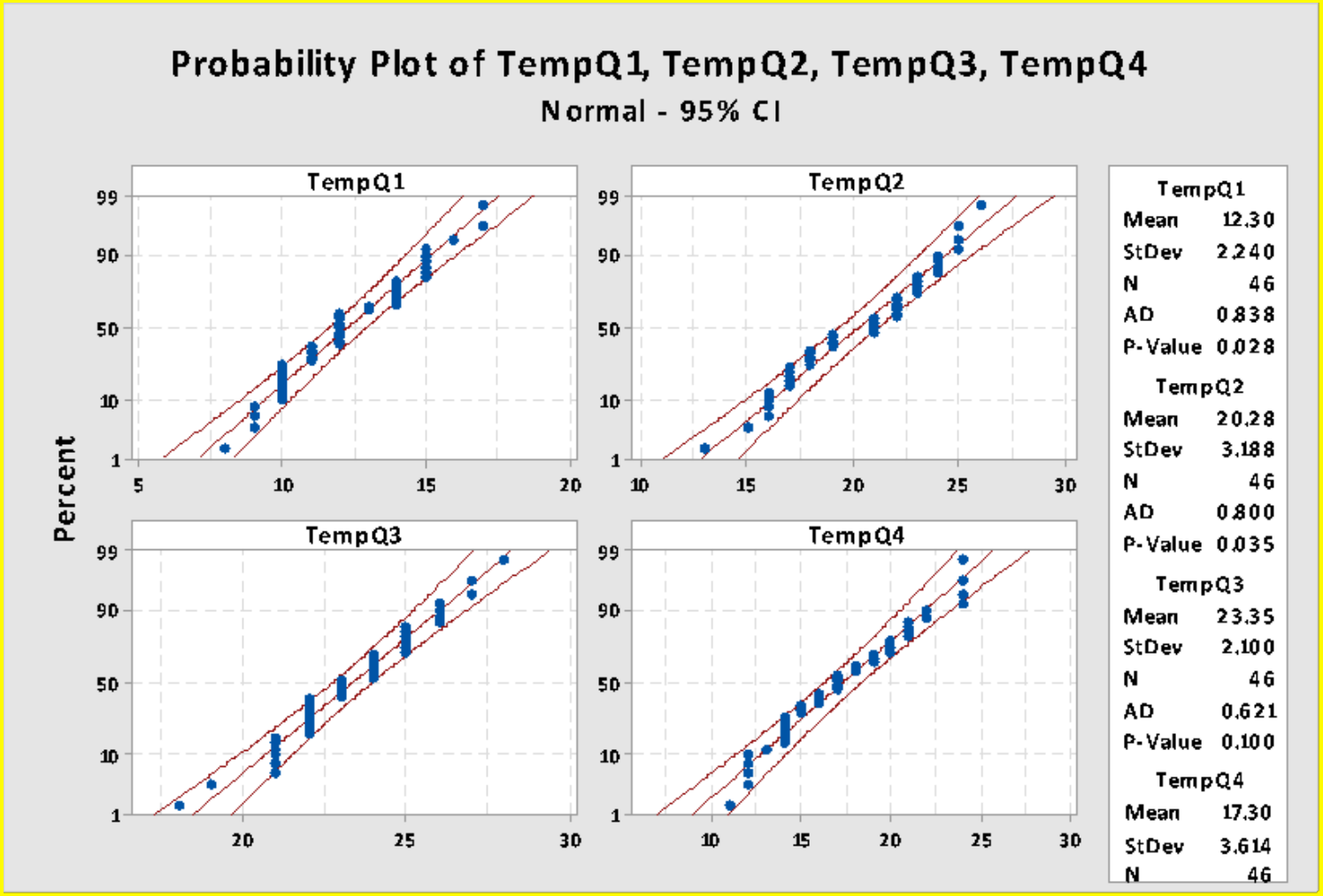
The graphs above show an increase in the temperature values from the middle of the second quarter and the recordings were high. These high recordings continued for next 6months after the second quarter. It is only in the middle of last quarter that the readings started to come down. The highest reading recorded was in the third quarter which is 28 and the lowest was in the first week of first quarter which is 8.

Histogram

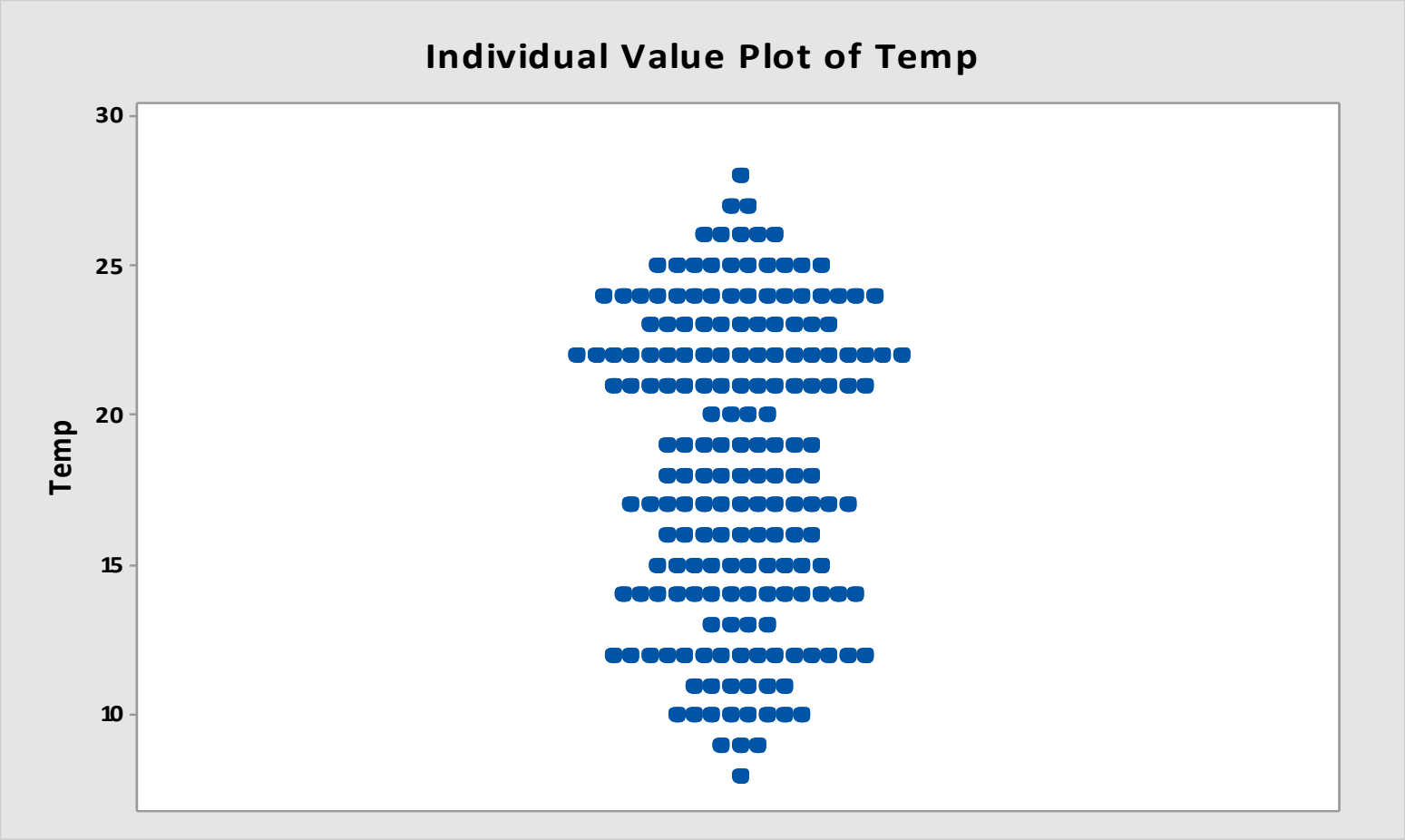


Has repeated readings and there are no sudden increases and decreases. However 4th quarter has more variations.

Probability plot

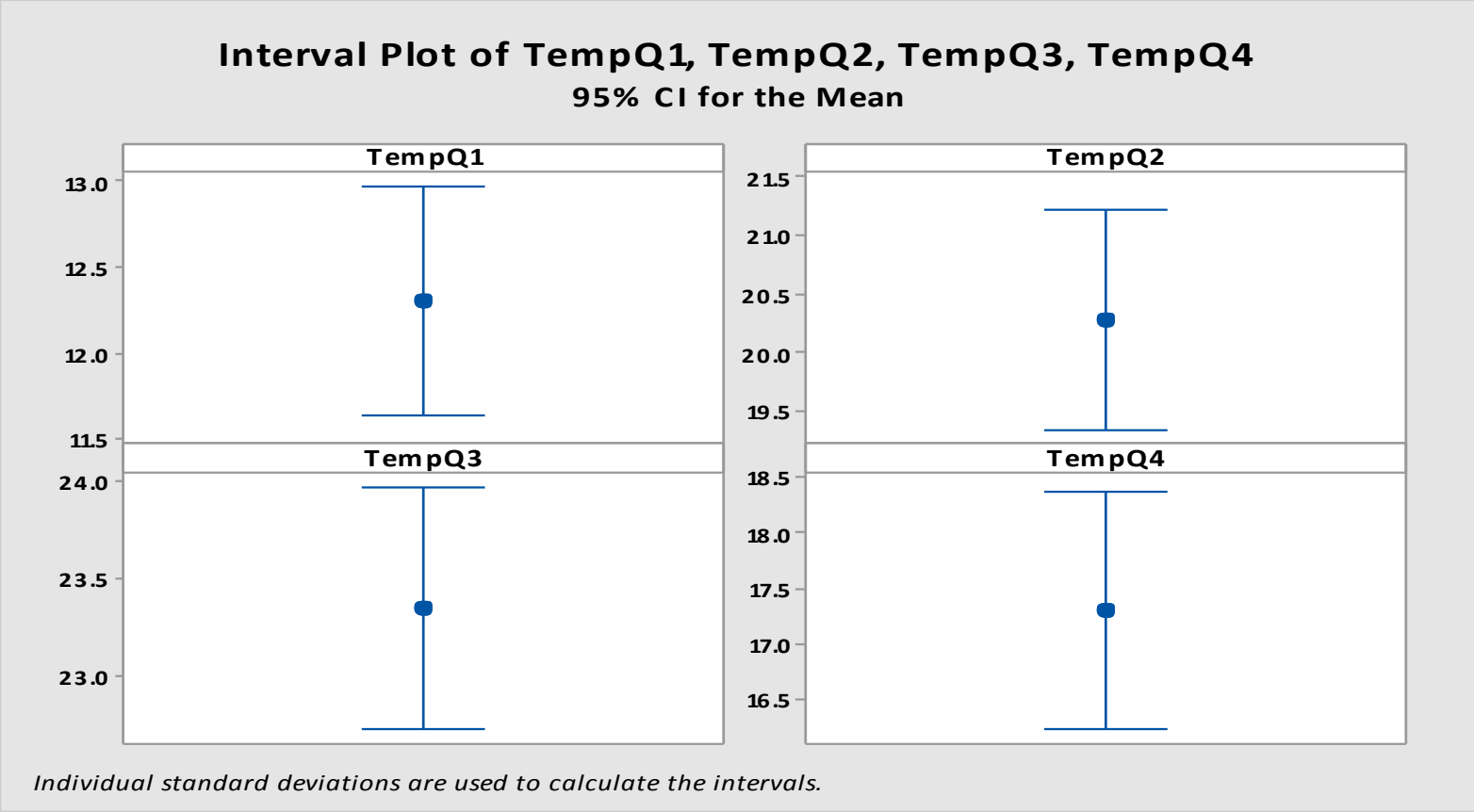


Individual Value Plot



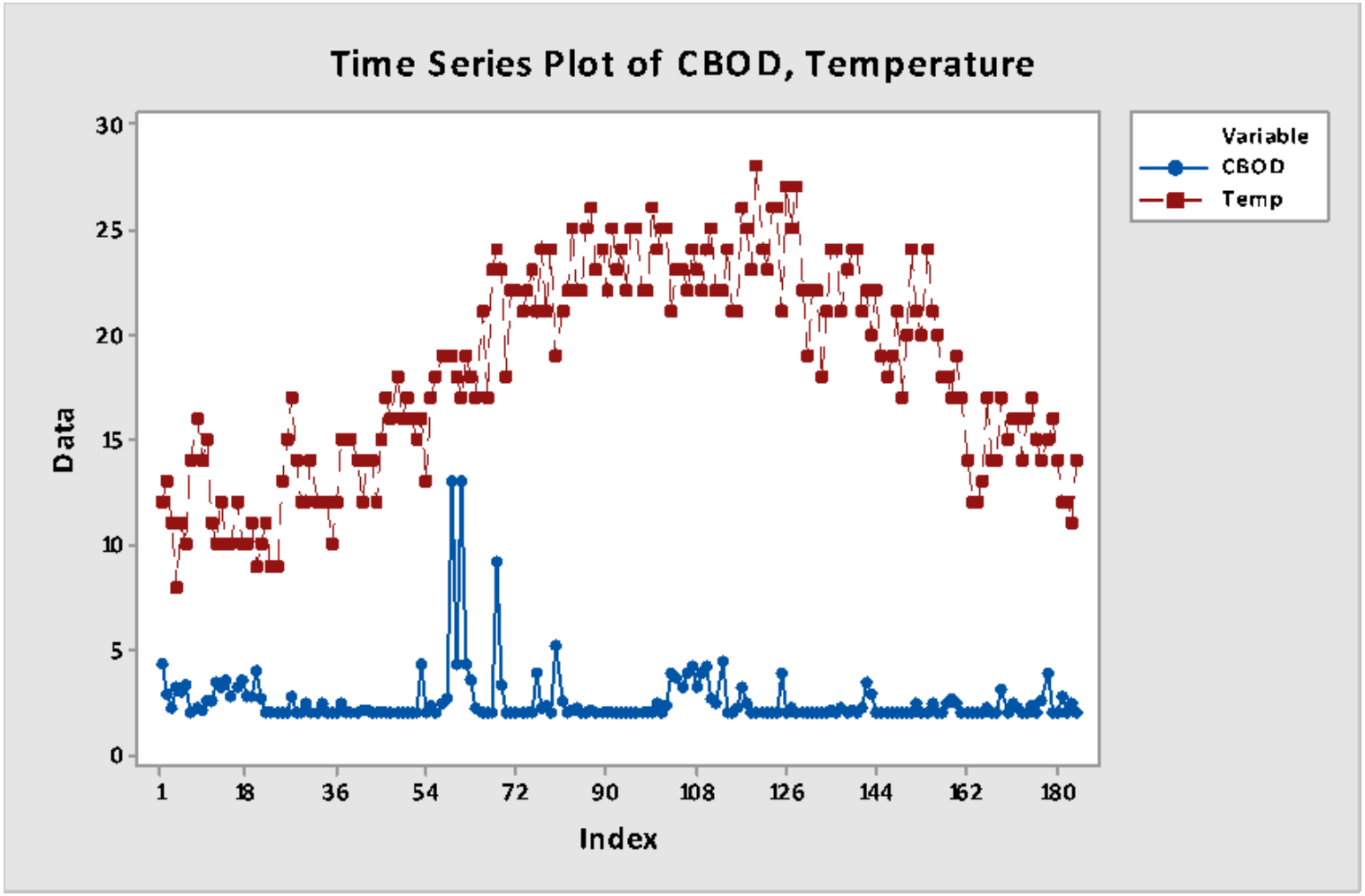
. The third quarter had the highest temperature recorded which was only for one time.

Interval Plot

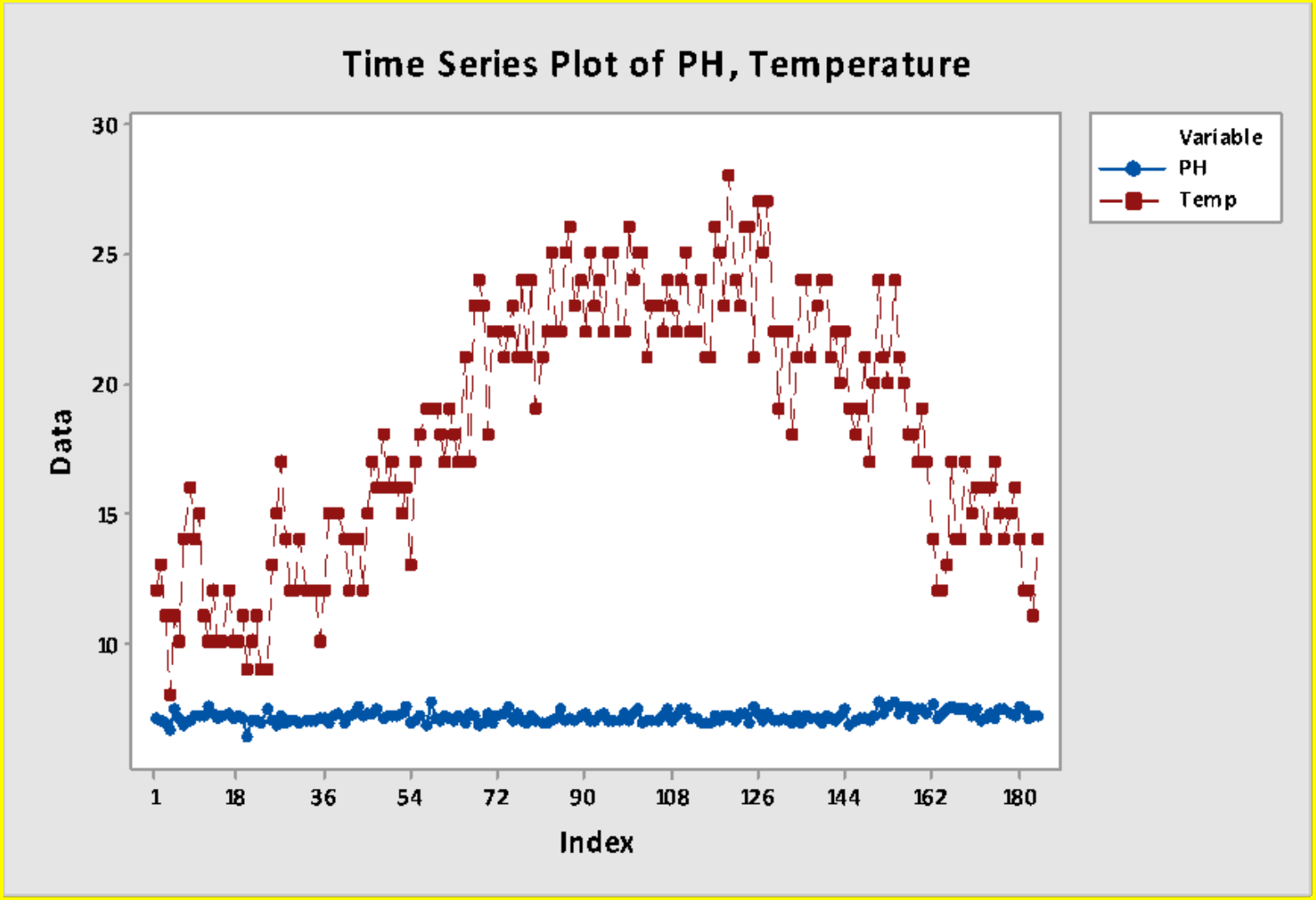


The intervals range differently for different quarters. The range is high in the last quarter as it has more variation and high standard deviation.

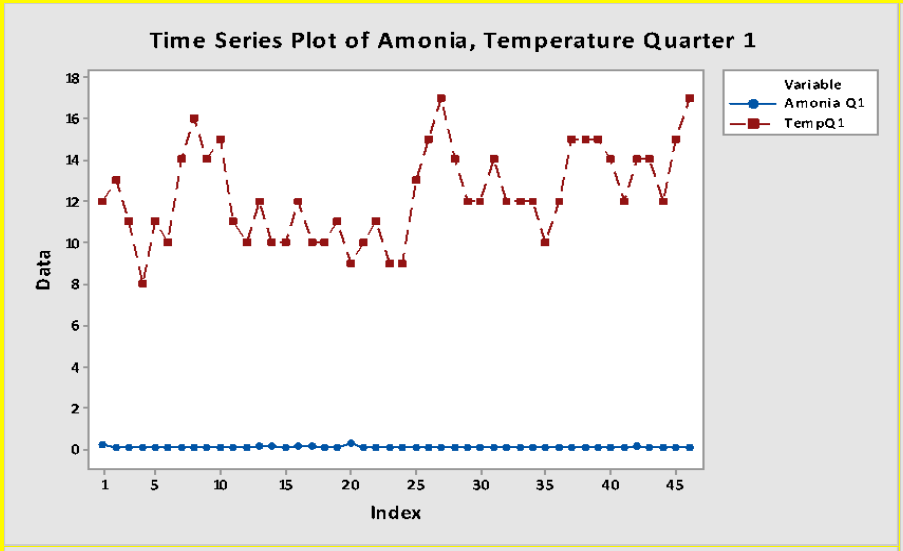
Temperature VS CBOD

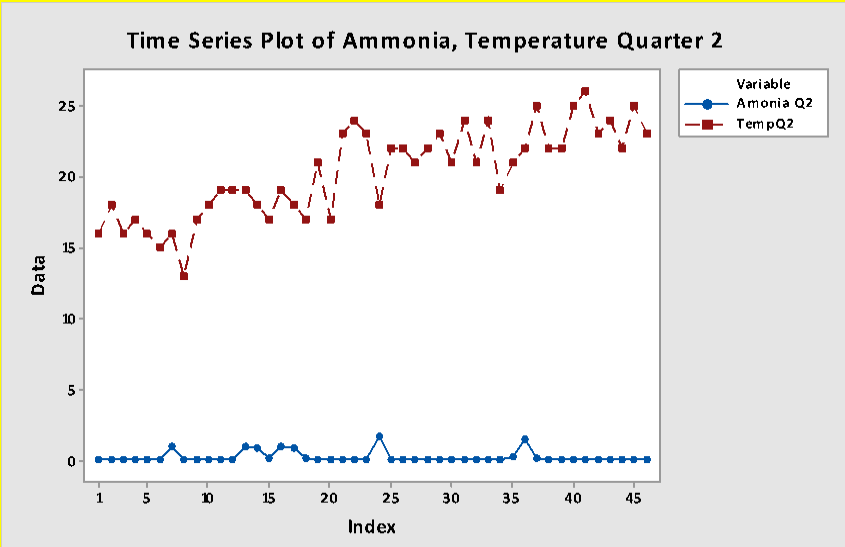


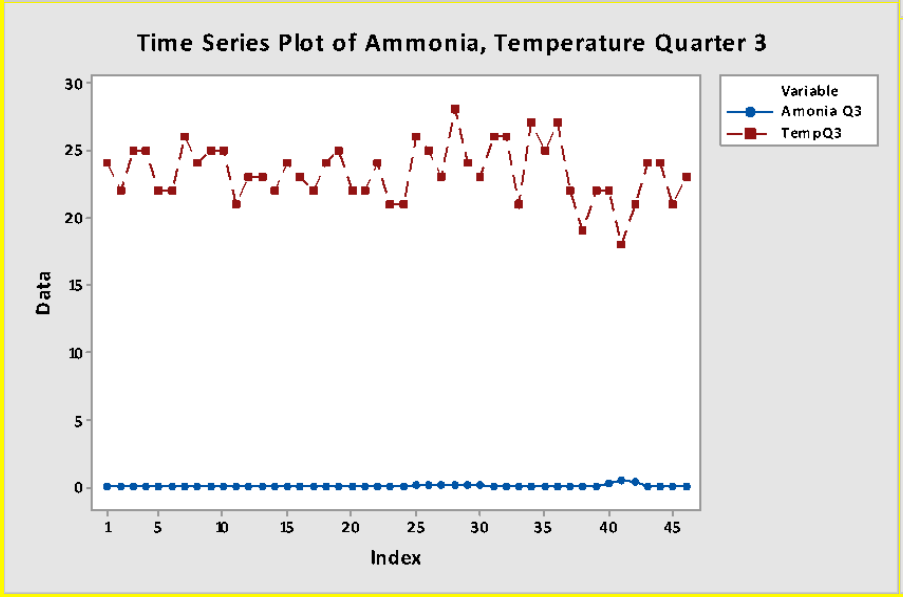
PH vs Temperature

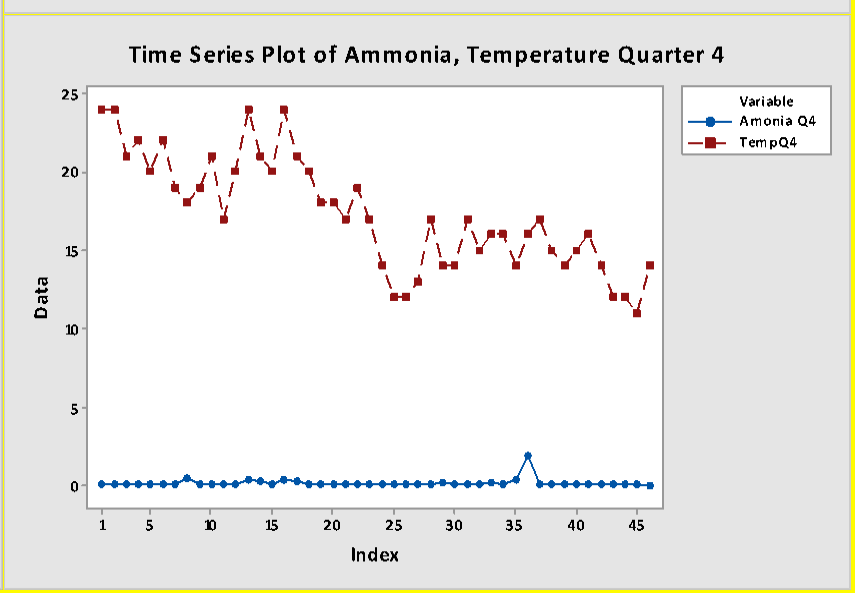


Ammonia VS Temperature

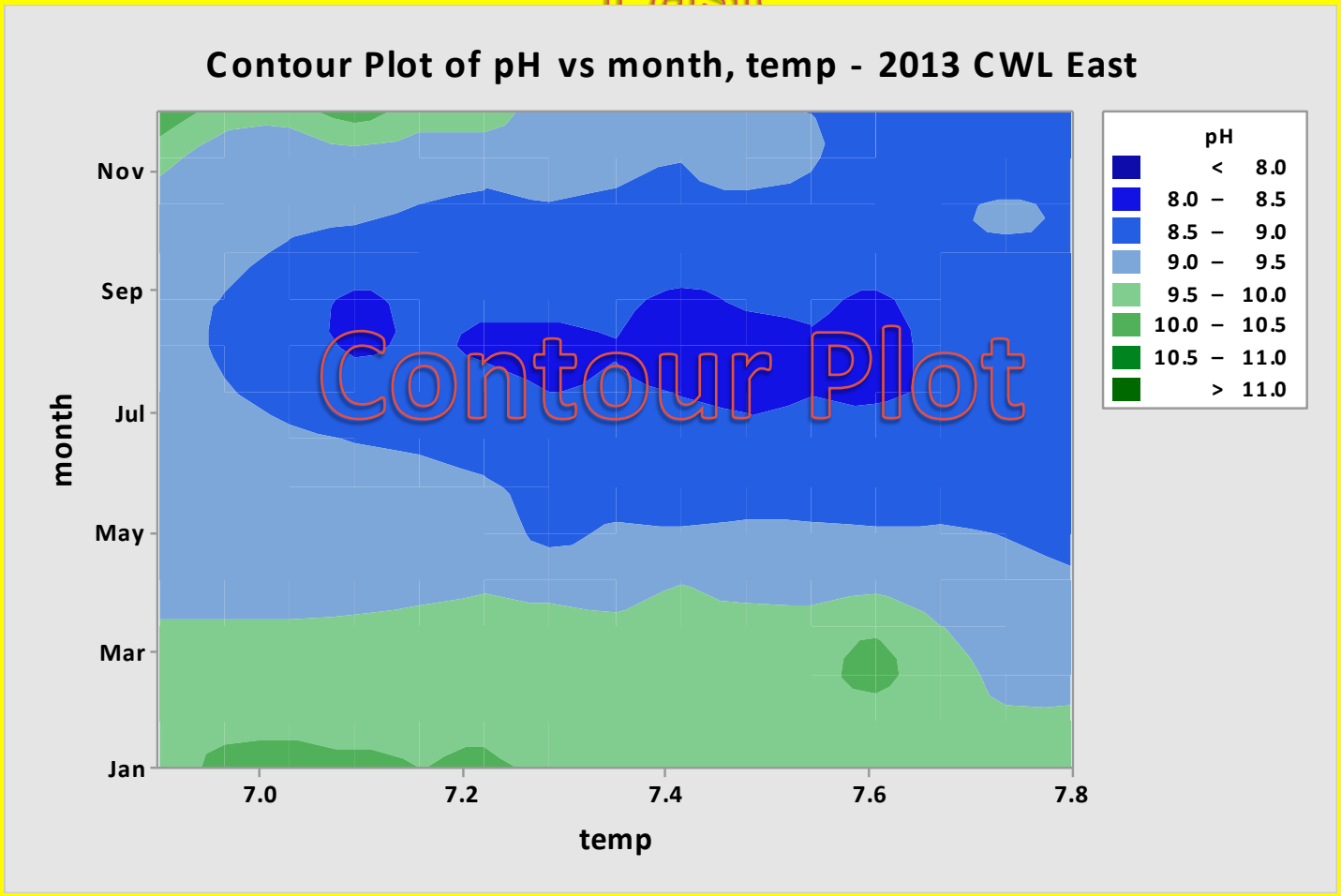








Contour Plot of pH vs month temperature for previous year 2013 East

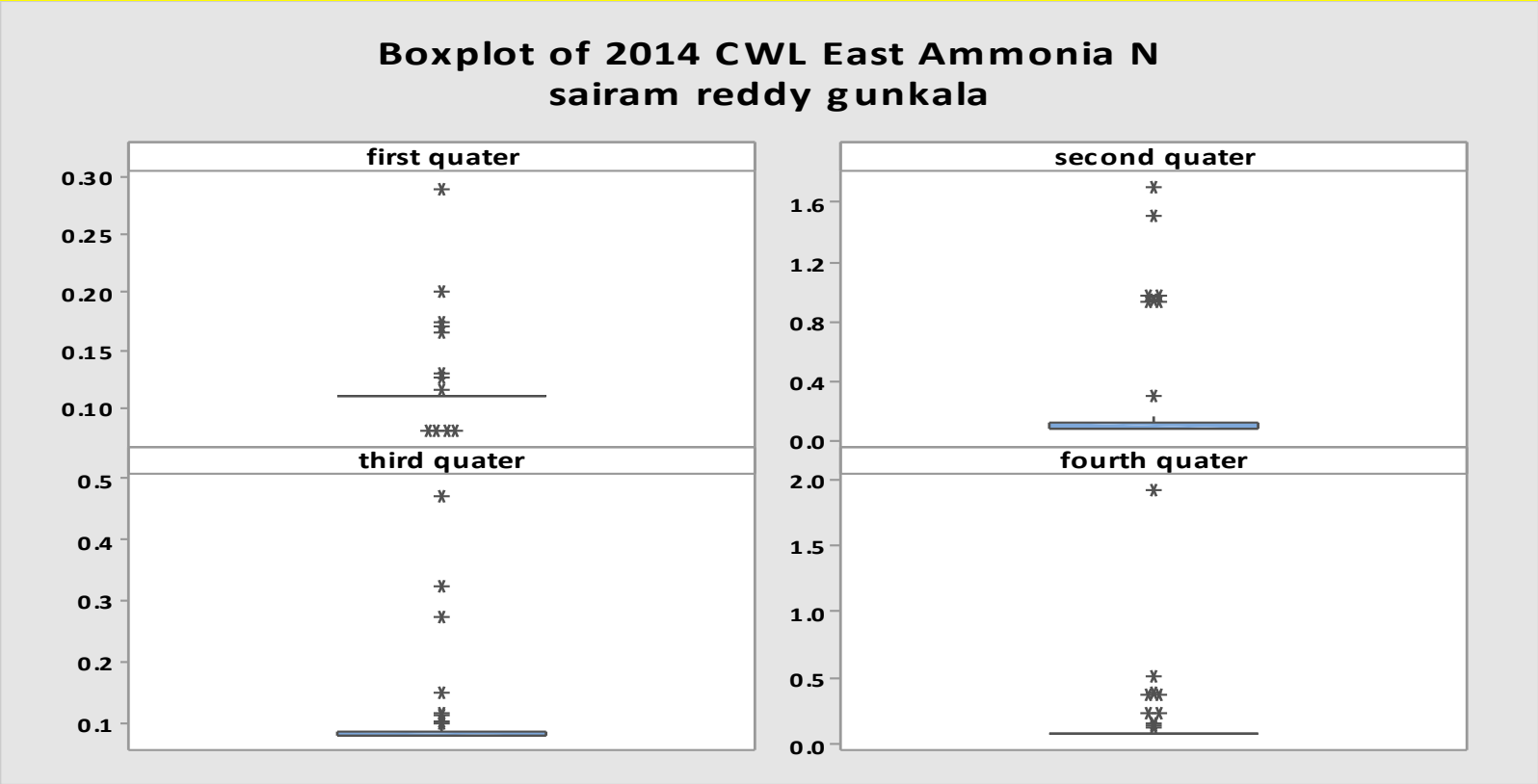


Ammonia Nitrogen

- This section provides a detailed analysis of the 2014 effluent results for the ammonia nitrogen (NH3-N) for the City Water and Light in the east plant
- The ammonia nitrogen at east plant is analyzed three times per week and is sampled as a 6-hour composite that is flow weighted.
- The monthly average limit for nitrogen in water is 4mg/l(ppm)

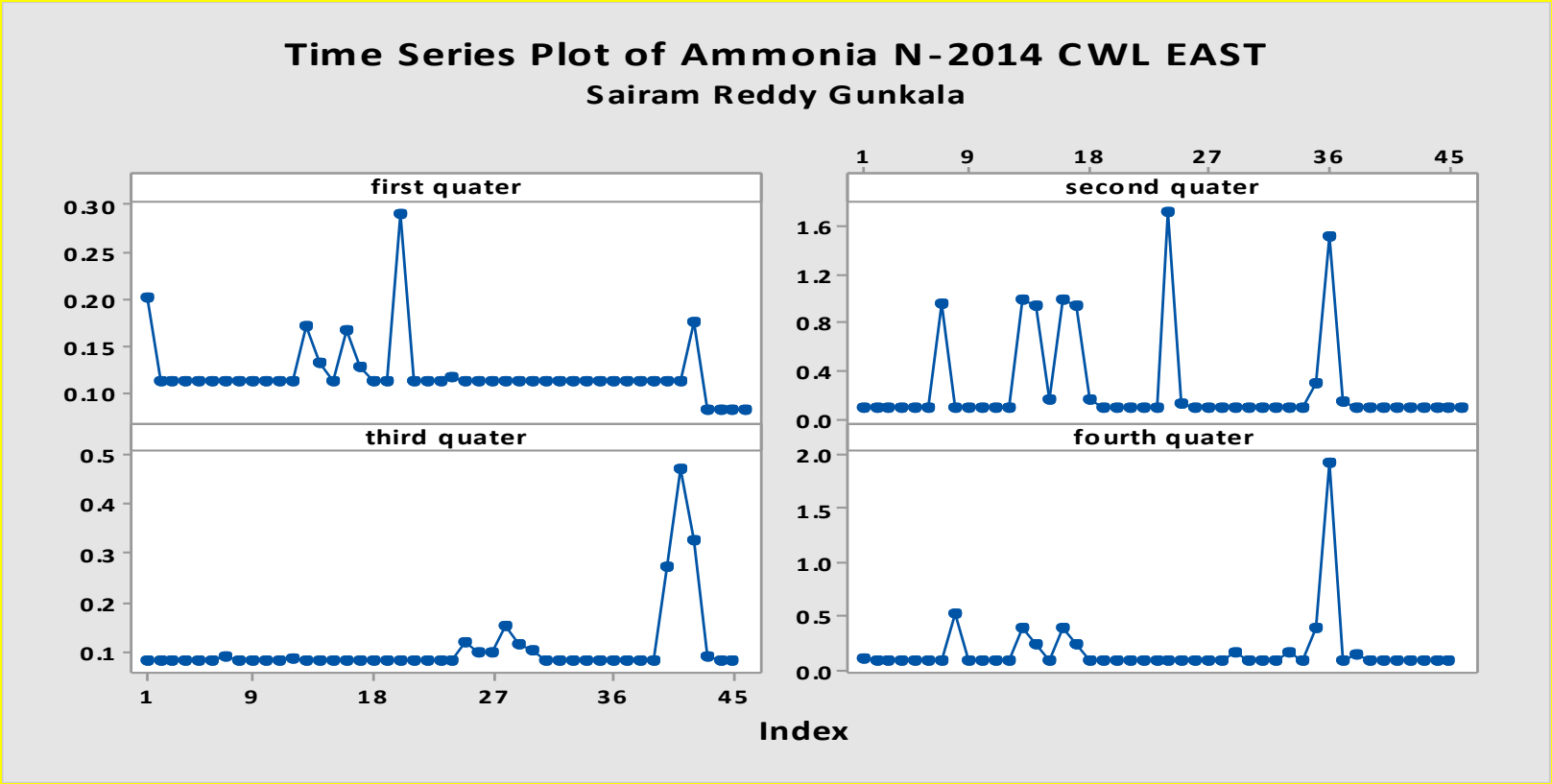
Box Plot

- The graph below depicts group of data from January to December 2014 displayed in four quarters in the graph the spacing between the different part of the box help indicate the degree of dispersion and skewness in data. During the first quarter there is no dispersion in the data where has there is maximum amount of dispersion and skewness in data in second and fourth quarter.



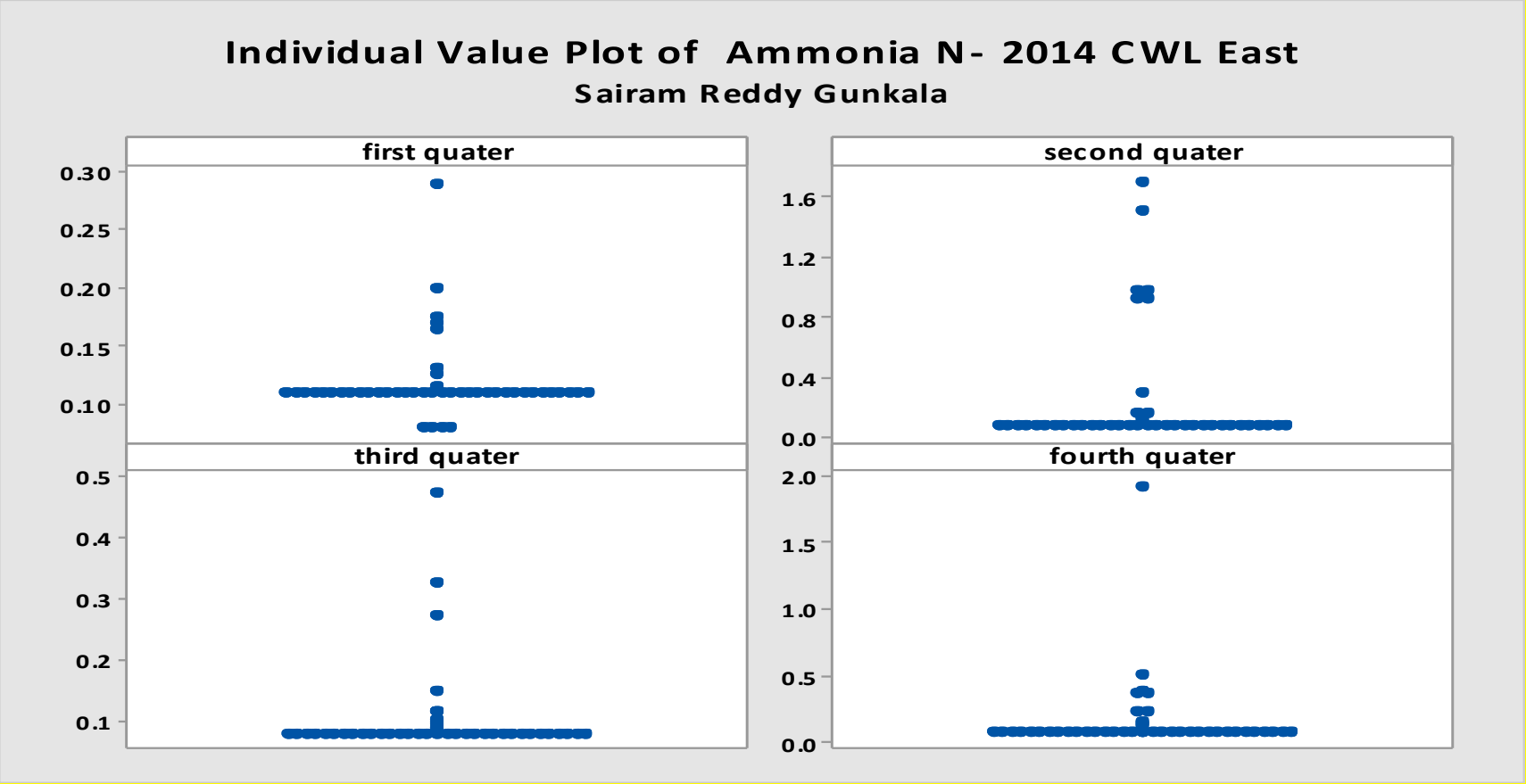
Time Series Plot

- A time series plot is a graph that you can use to evaluate patterns and behavior in data over time.
- Data has lot of fluctuations in second quarter and maximum deviation in fourth quarter



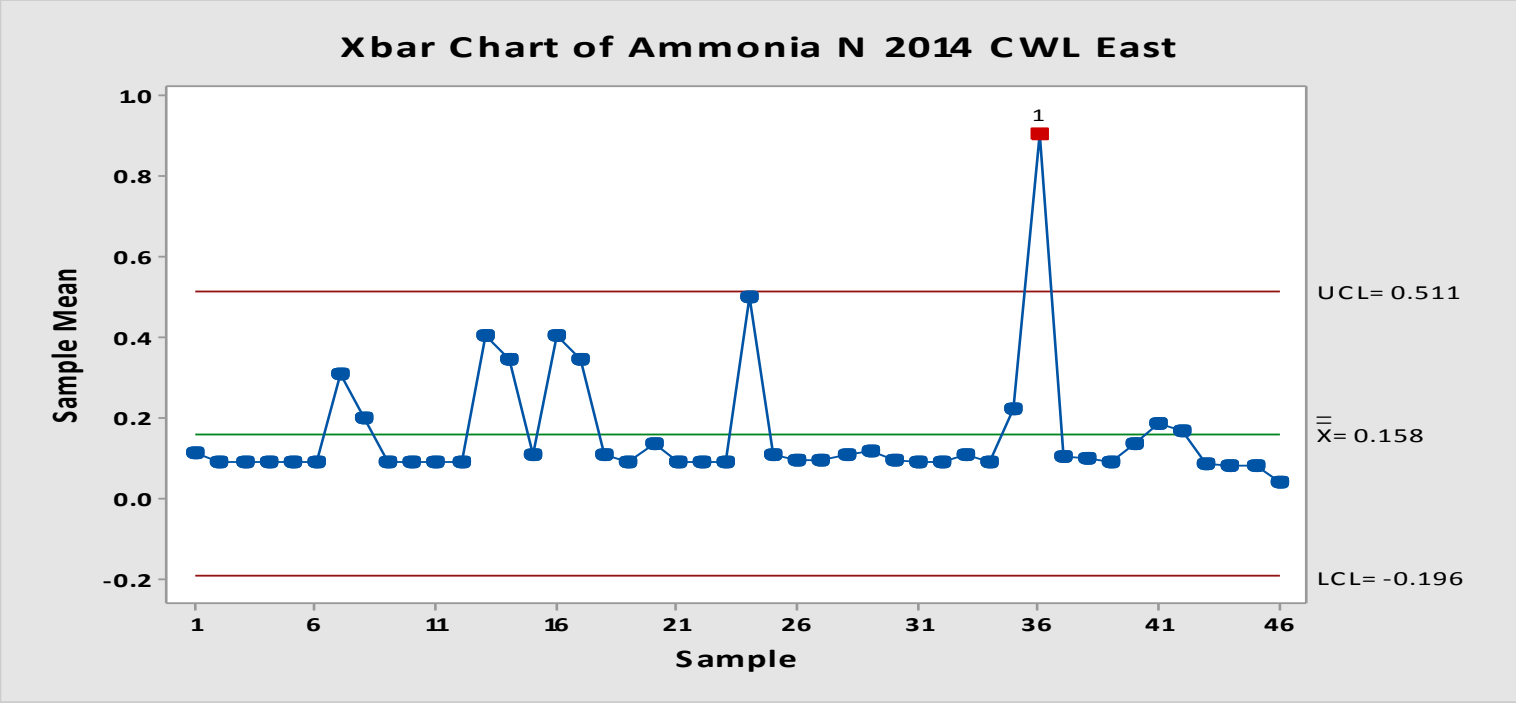
Individual Value Plot

- Individual value plots to identify possible outliers and other values of interest.
- At 0.11 there are high number of plots maximum deviations and fluctuations are present in the second and fourth quarter



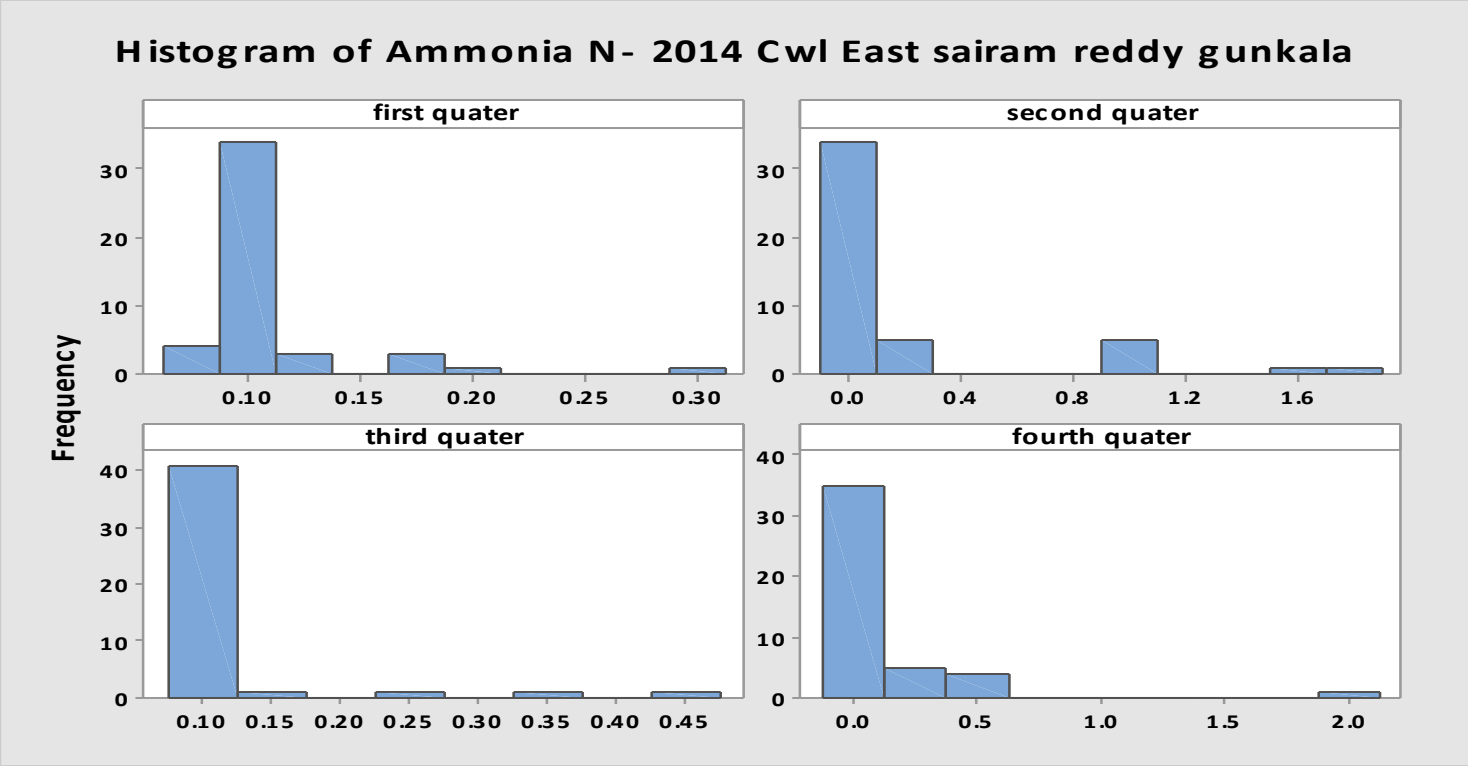
Xbar chart

- Since the effluent limit for ammonia nitrogen under investigation is based on quarterly average maximum of 0.158, which is the approximate number of daily ammonia nitrogen analyses performed in a quarterly. There is only one point out of control limit.



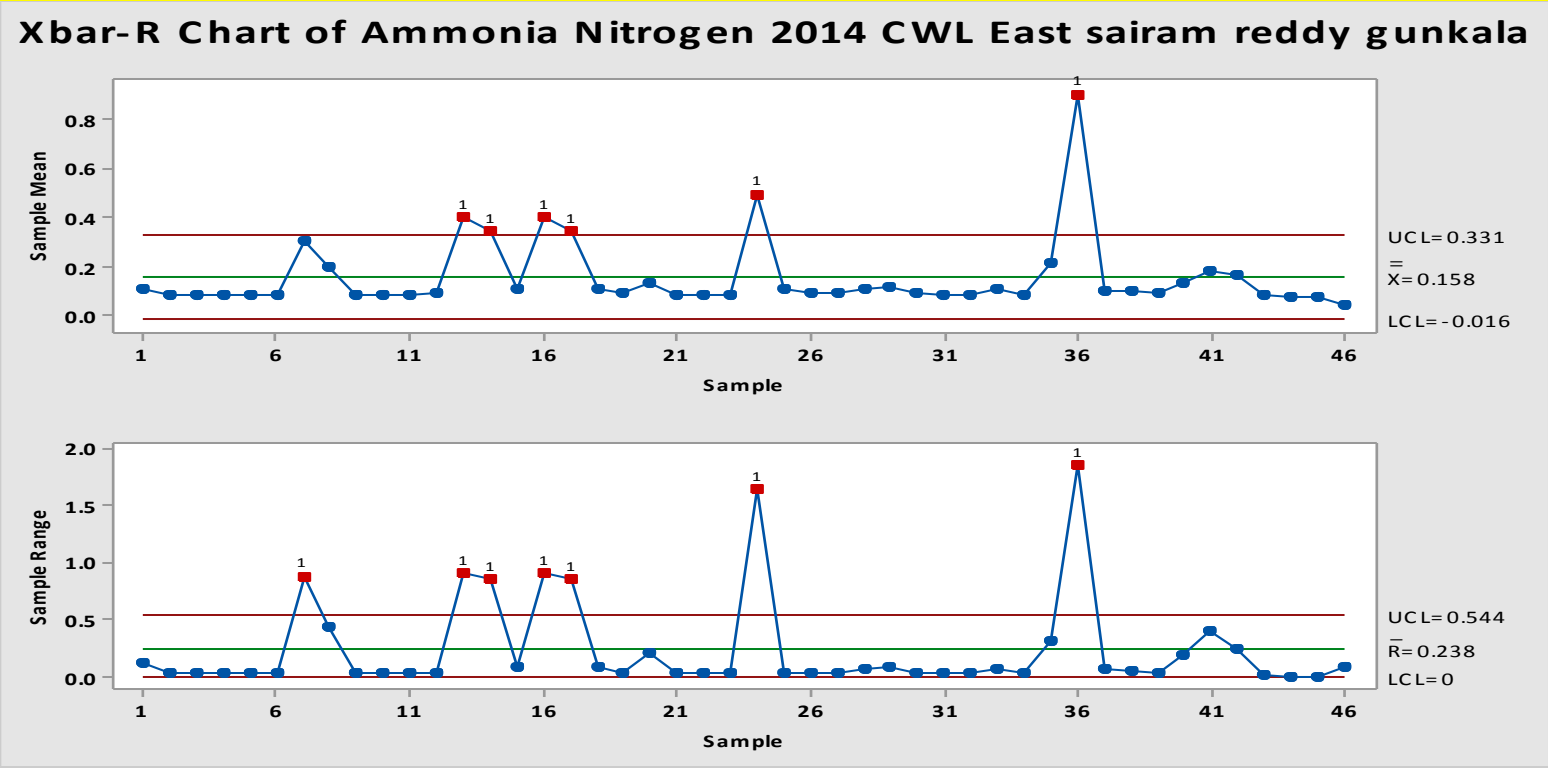
Histogram

- A histogram is a bar graph of raw data that creates a picture of the data distribution. The bars represent the frequency of occurrence by classes of data. A histogram shows basic information about the data set, such as central location , width of spread , and shape. Use histograms to assess the system's current situation and to study results of improvement actions.



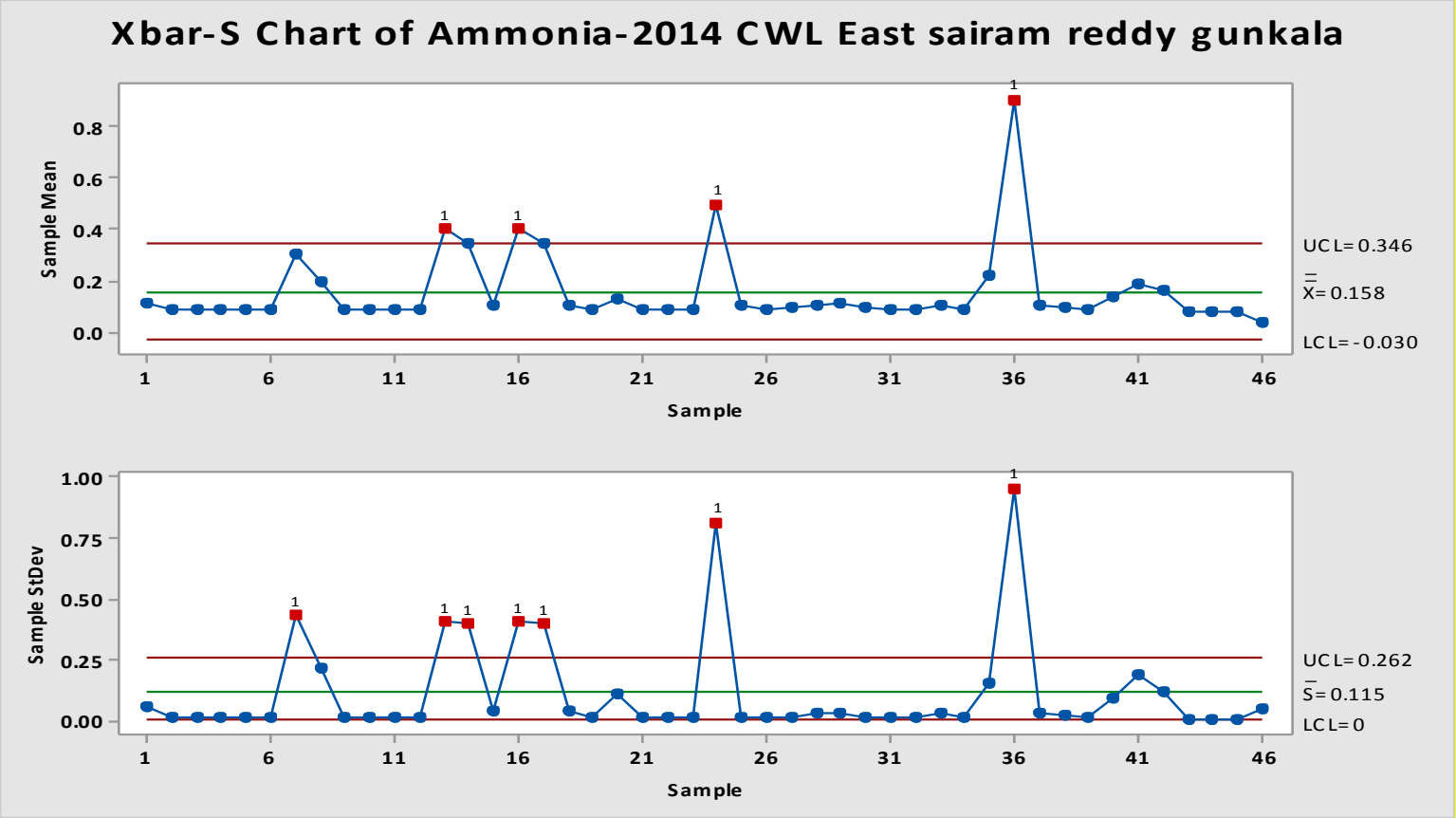
Xbar R chart

- An Xbar-R chart plots the process mean and process range over time for variables data in subgroups



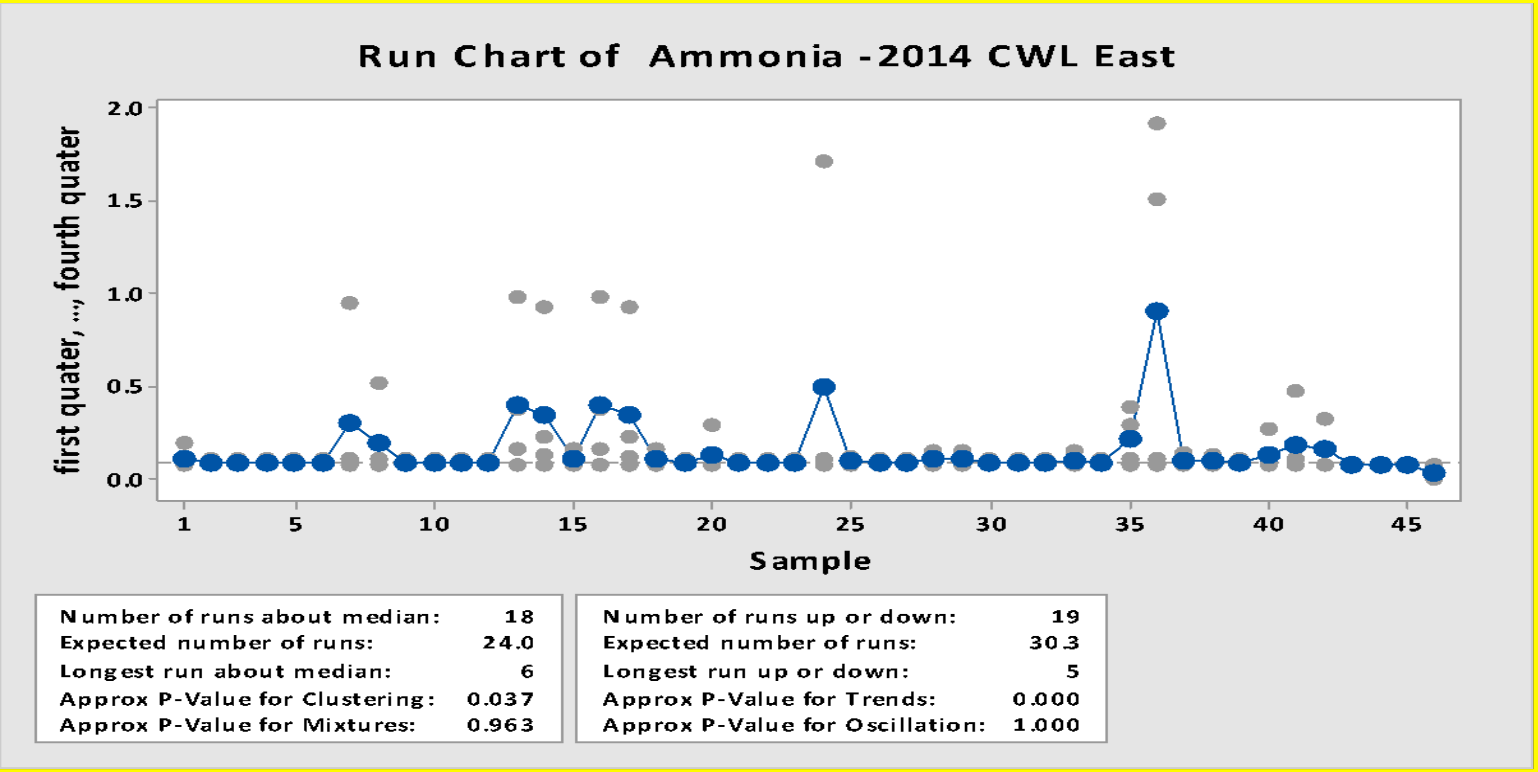
Xbar-S chart

- An Xbar-S chart plots the process mean (Xbar chart) and process standard deviation (S chart) over time for variables data in subgroups.



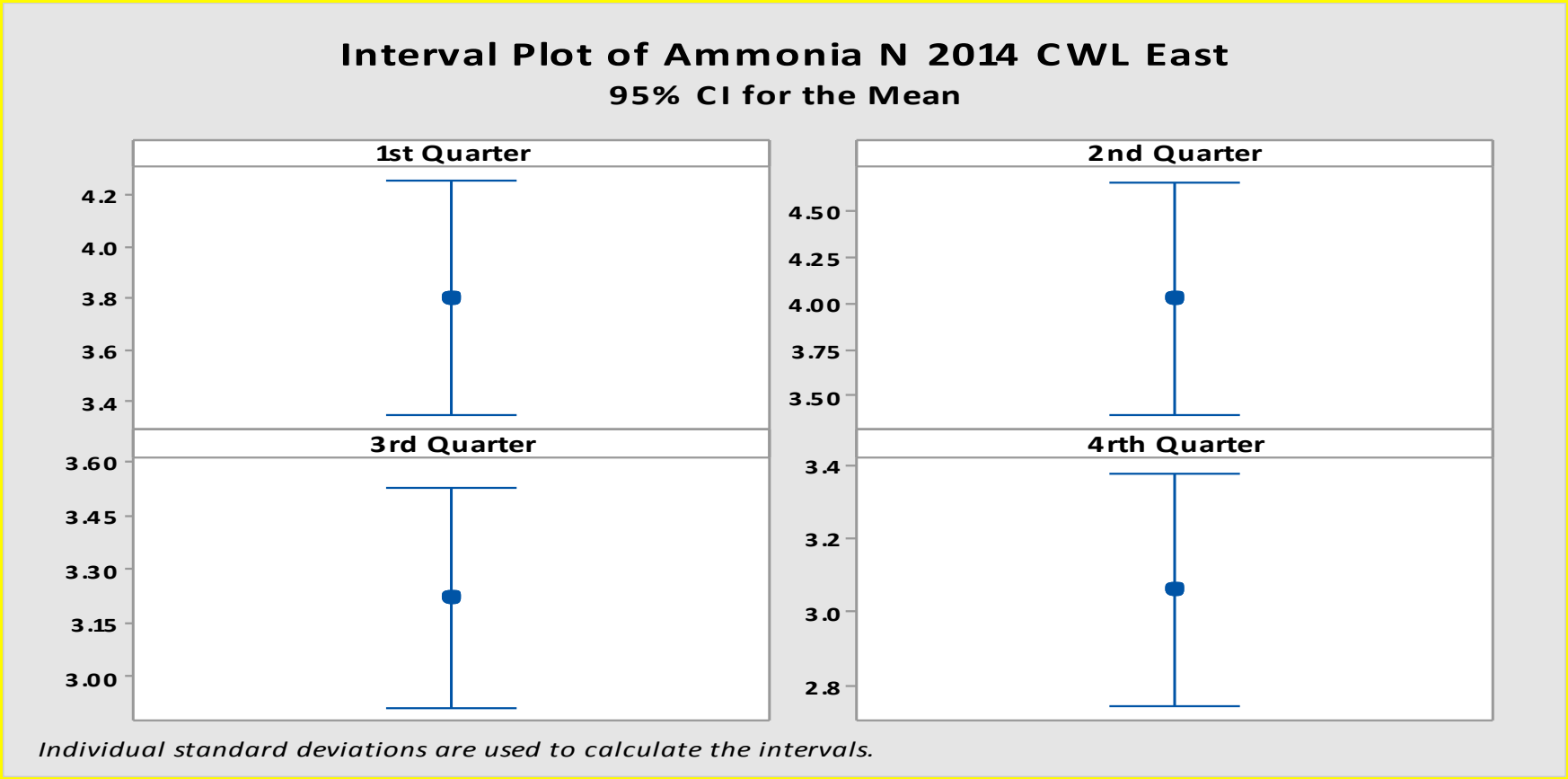
Run Chart

- A run chart plots the individual observations in the order that they were collected. The black points represent the individual values. The blue points represent subgroup medians.



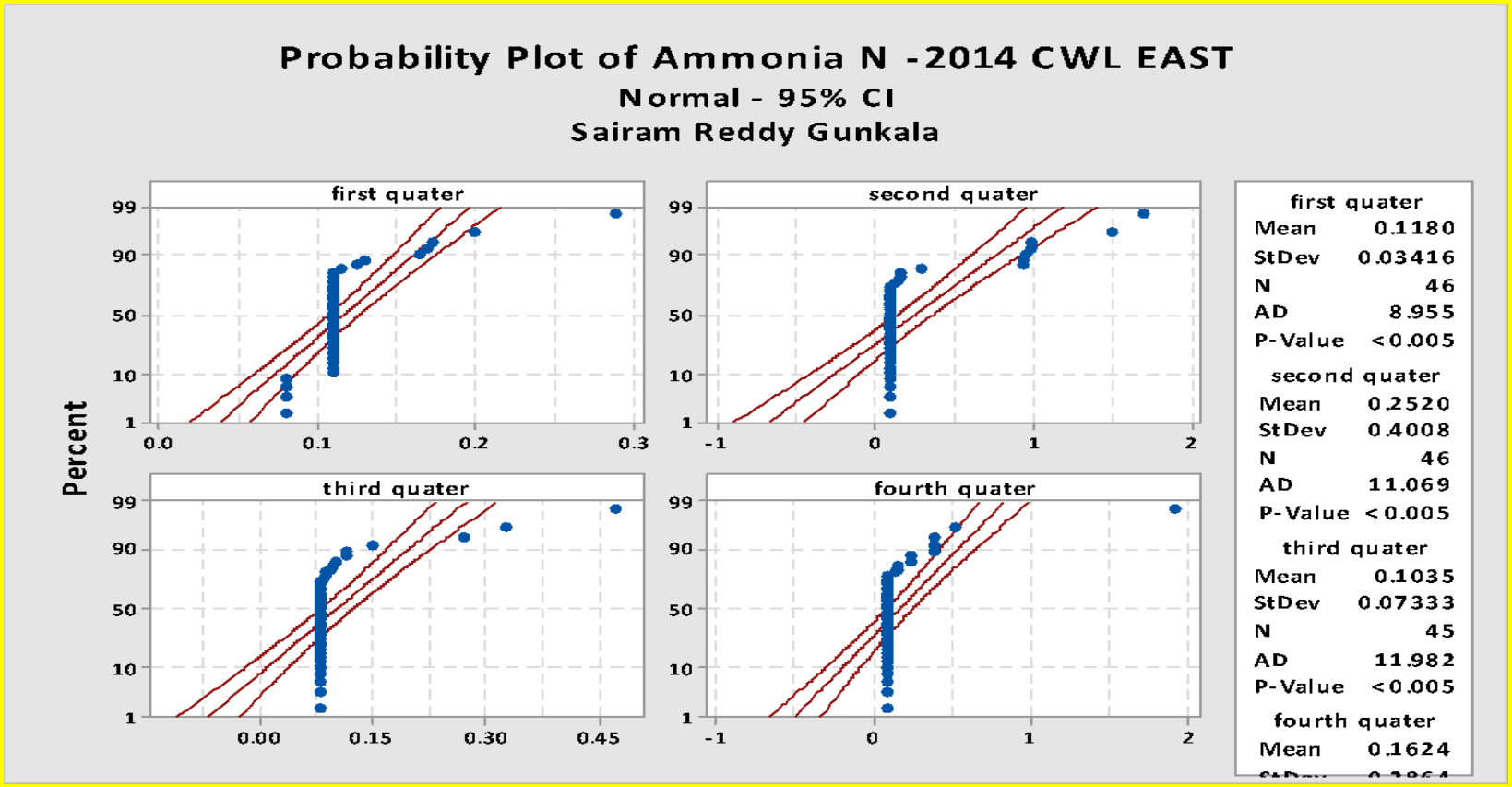
Interval Plot

- An interval plot is a graphical summary of the distribution of a sample that shows the sample's central tendency and variability.

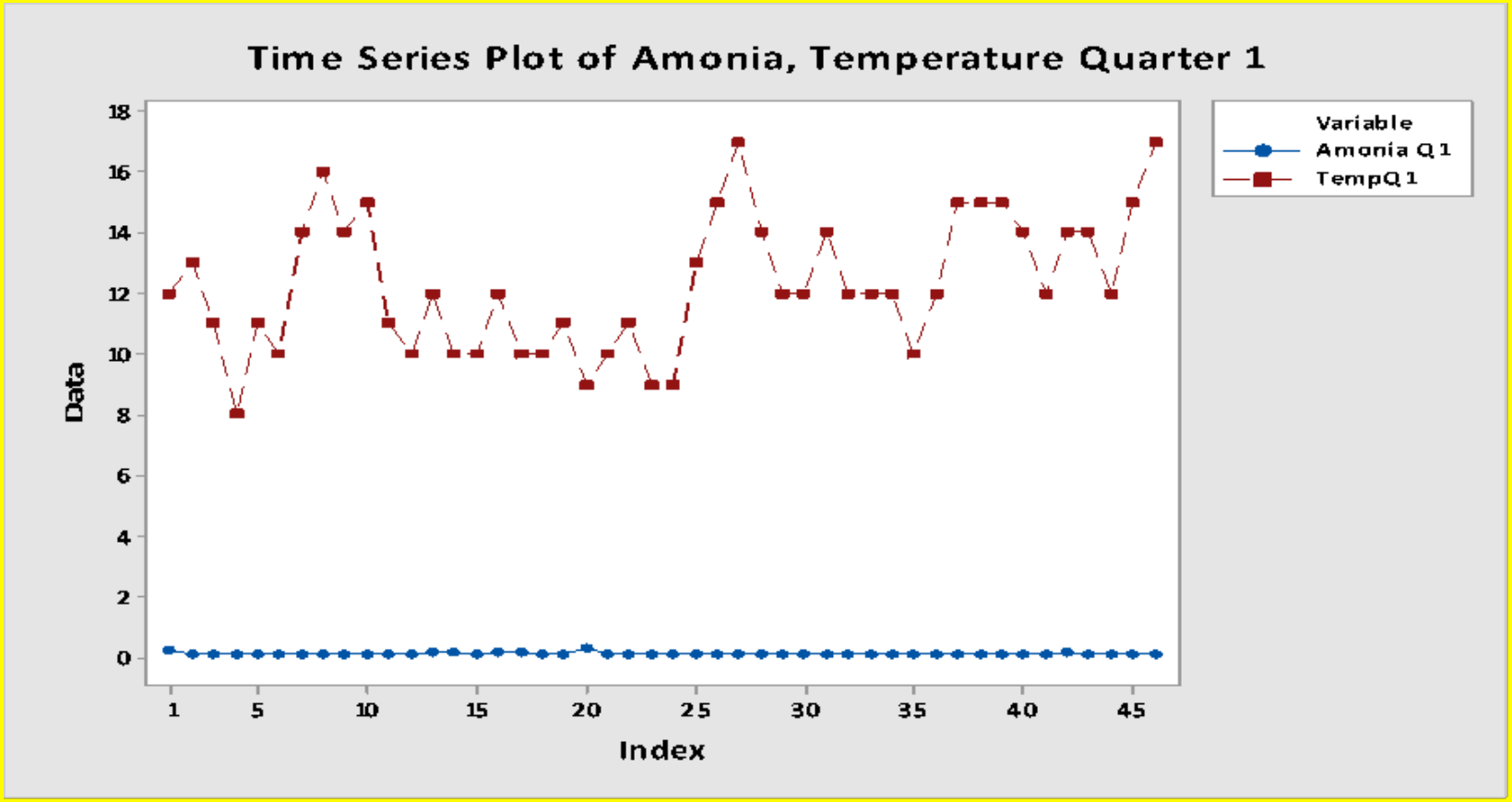


Probability plot

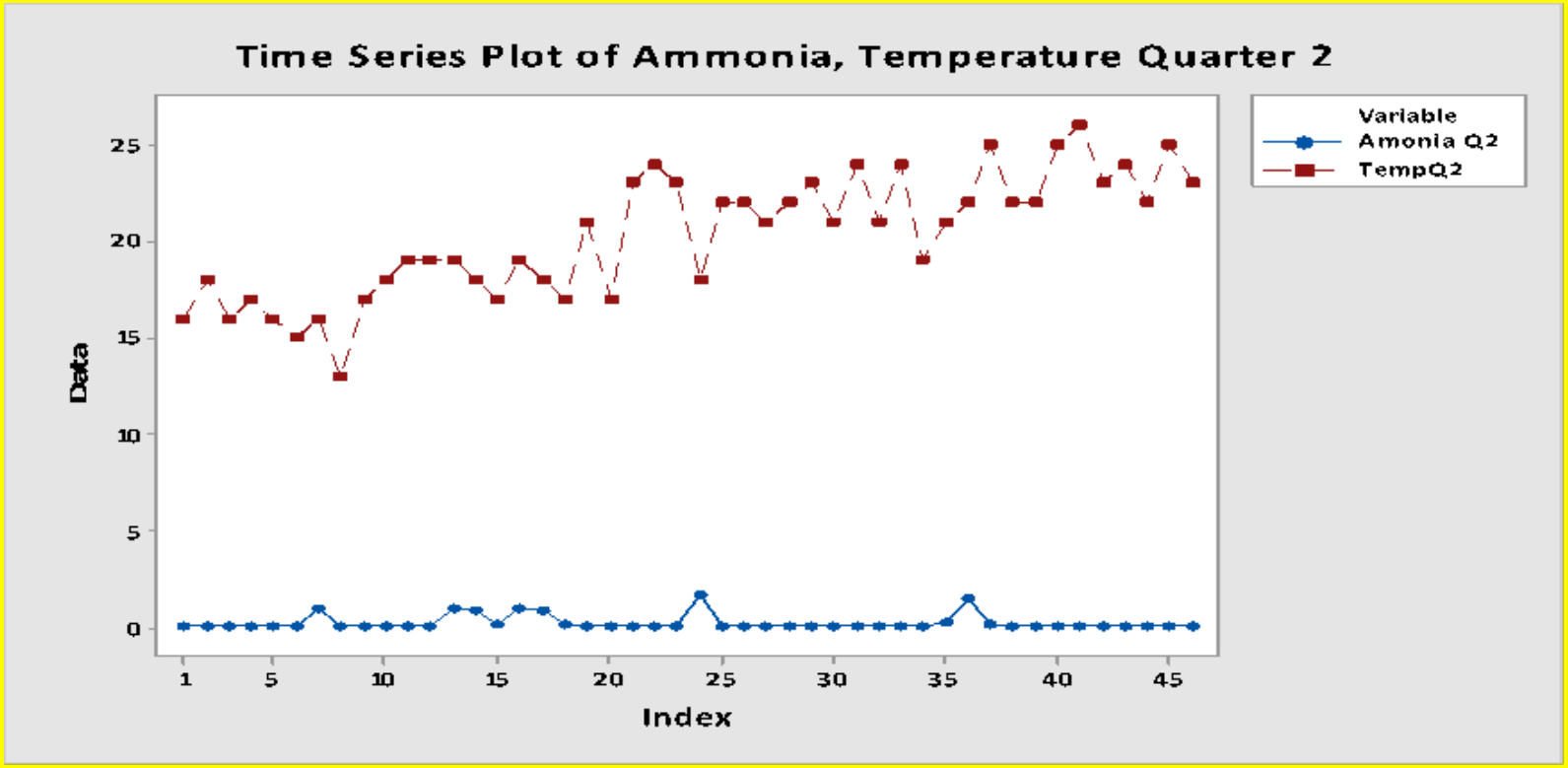
- A probability plot is graph that you can use to evaluate the fit of a distribution to your data, estimate percentiles, and compare different sample distributions.



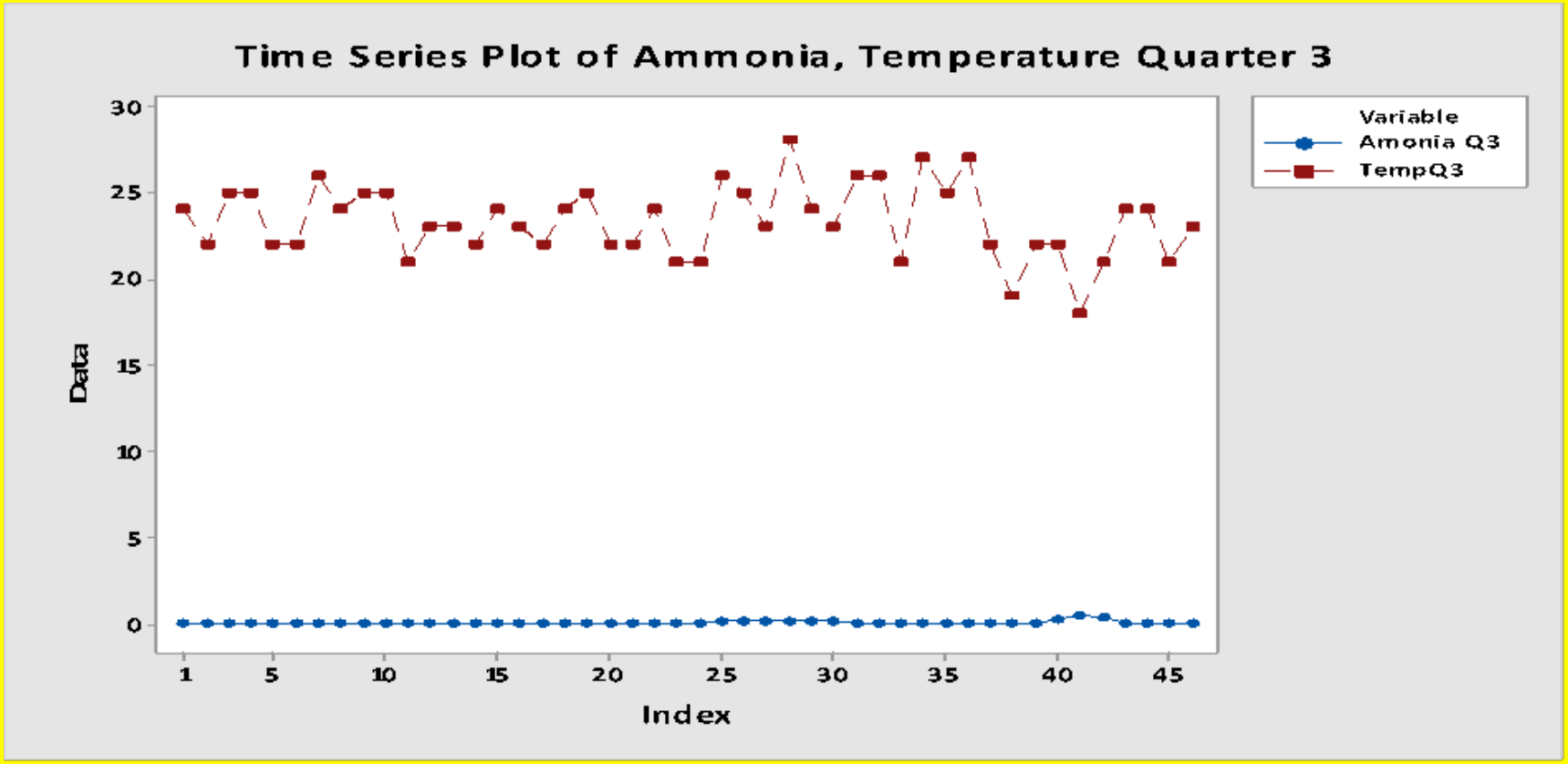
Ammonia vs. Temperature – Quarter 1



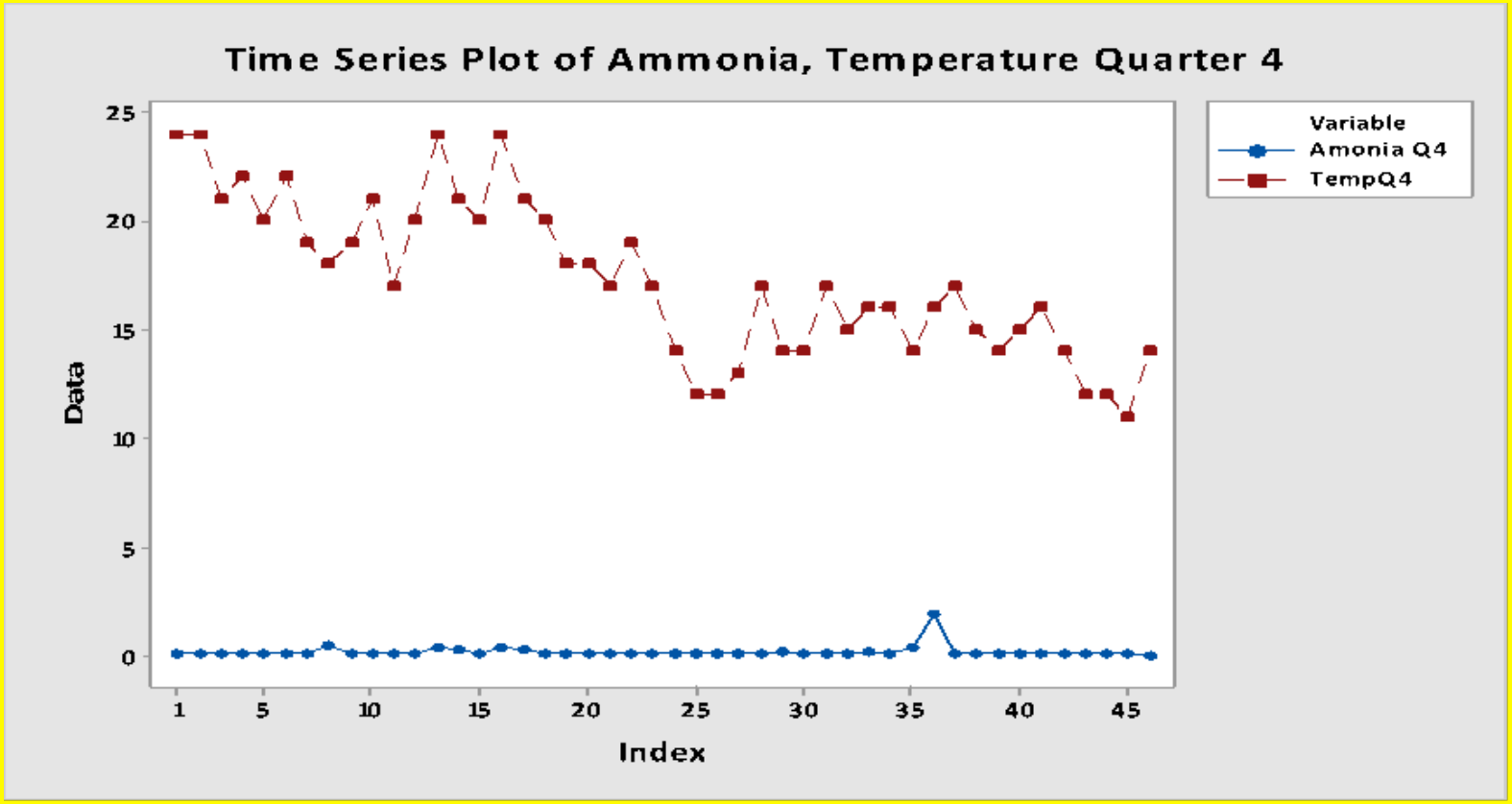
Ammonia vs. Temperature – Quarter 2



Ammonia vs. Temperature – Quarter 3



Ammonia vs. Temperature – Quarter 4

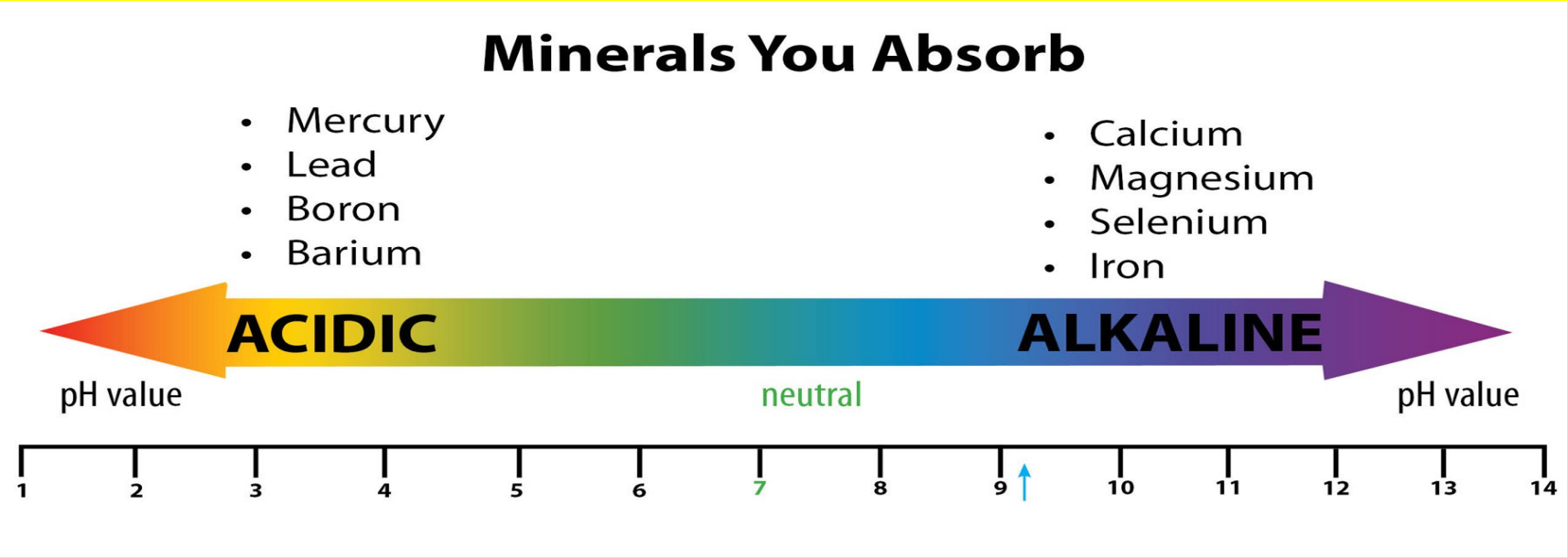


pH Variable

This section includes the analysis of the effluent pH variable.

- The technical definition of pH is the measure of the activity of hydrogen ion(H+).
- The pH of natural waters is between 6.5 and 8.5.
- The limits according to the NPDES permit are between 6 and 9. A measurement that is below 6 (acidic) or above 8.5 (alkaline) can disrupt aquatic life.
- pH variable has a maximum and minimum limit.

Ph Effluent

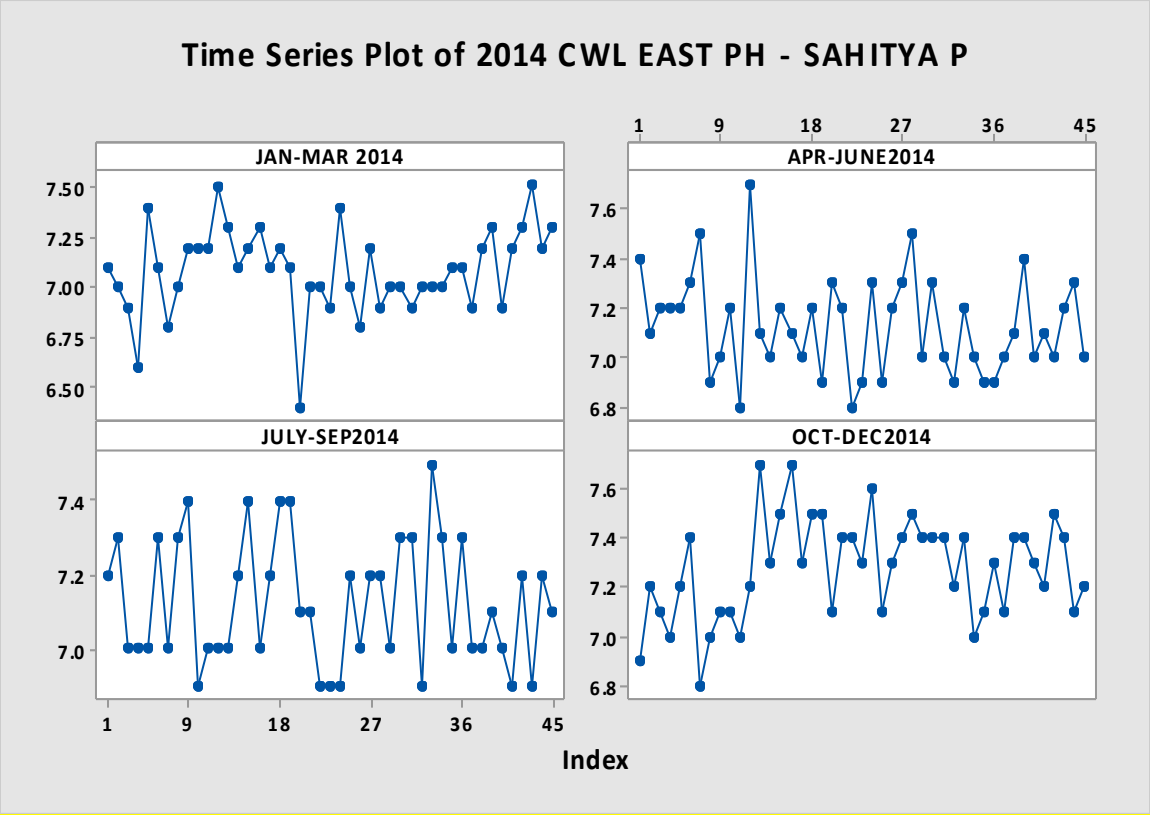

Minerals You Absorb
Mercury
Lead
Boron
Barium
Calcium
Magnesium
Selenium
Iron
ACIDIC
ALKALINE
pH value
neutral
pH value
1
2
3
4
5
6
7
8
9
10
11
12
13
14

EFFLUENT CHARACTERISTICS ANALYZED

- **pH**
  - Measured 3 times per week
  - pH either highly acidic or alkaline can interfere with aquatic life
  - pH per NPDES (6-9)
  - Natural water has a pH 6.5-8.5

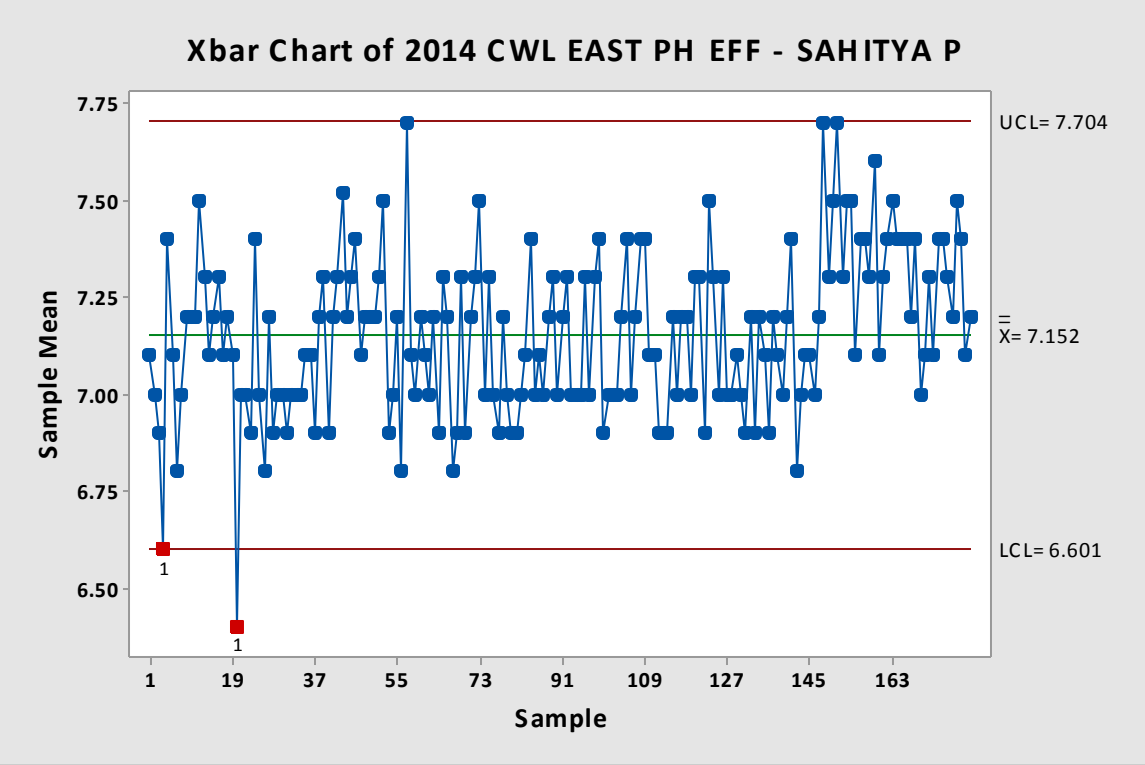
TIME SERIES PLOT

- pH of Effluent
  - Limit Range
    6.50 – 7.50
  - No outliers
  - Very Stable

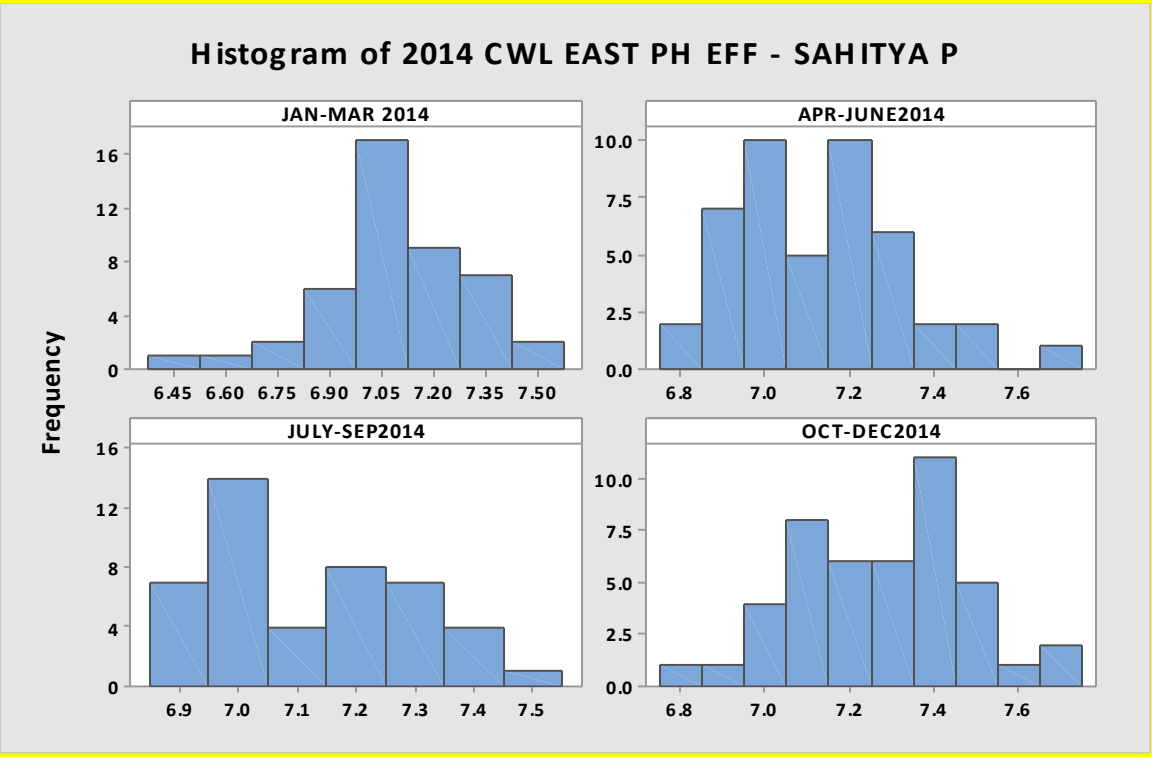


X-BAR CHART

- **pH levels of Effluent**
  - Represents Water Quality
  - In Statistical Control
  - Within permitted level
  - X-bar control charts were developed utilizing subgroups of 15, which is the approximate number of daily pH analyses performed in a month

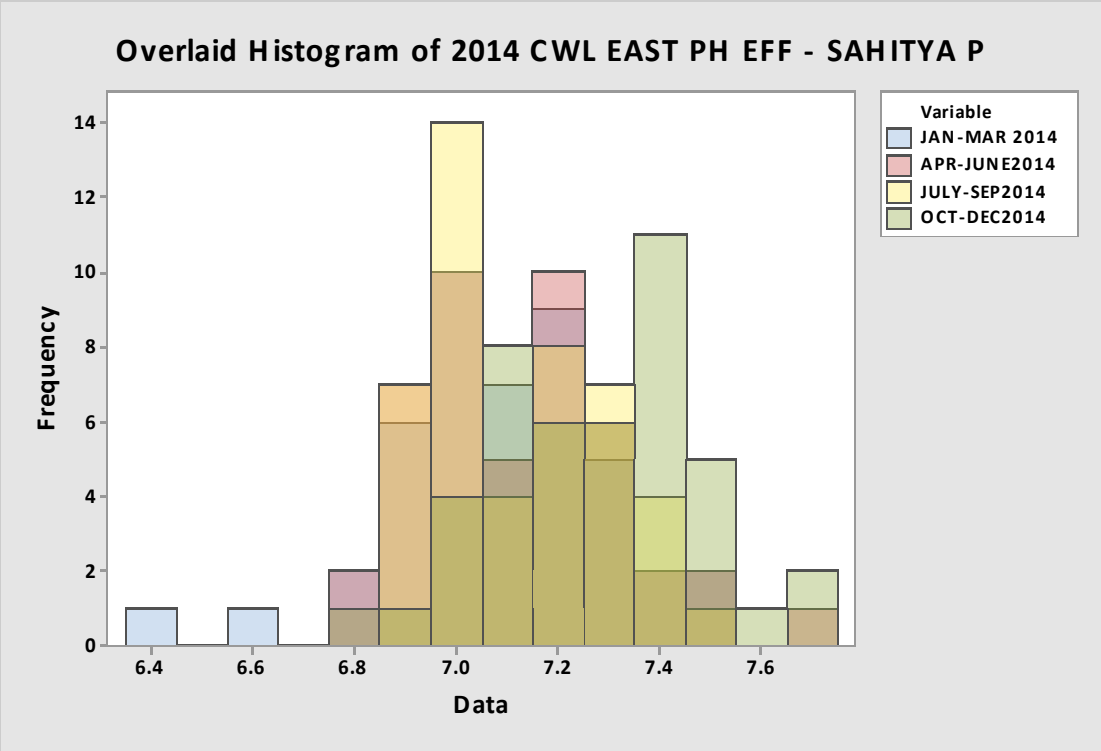


HISTOGRAM PLOT



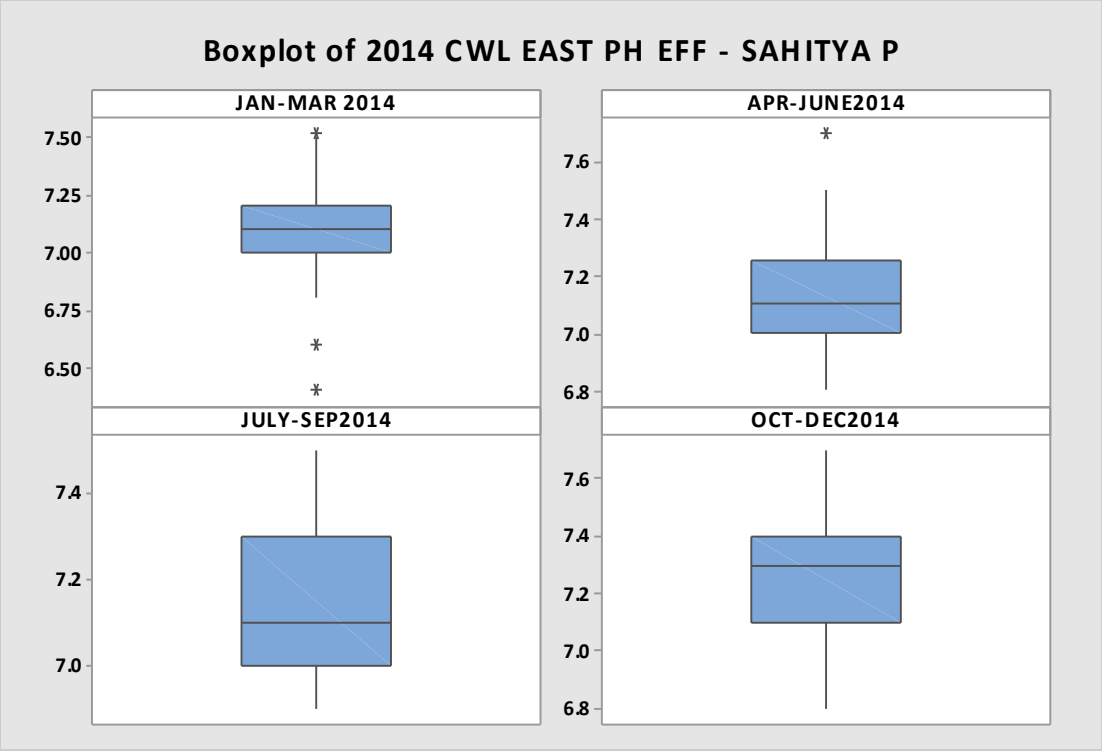
- Normal Distribution Centered around 7.05
- More Values at 7.2 than 7.3

OVERLAID HISTOGRAM PLOT



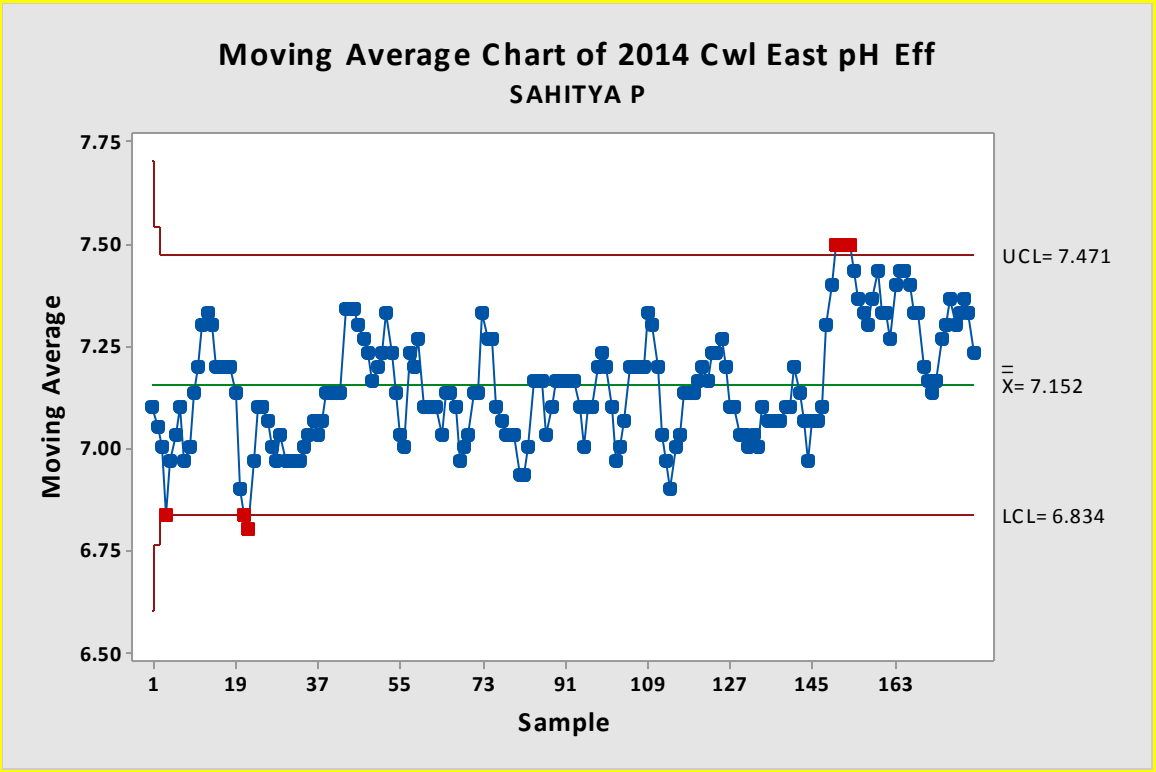
- Normal Distribution
- pH varies with Seasons

BOX PLOT OF pH



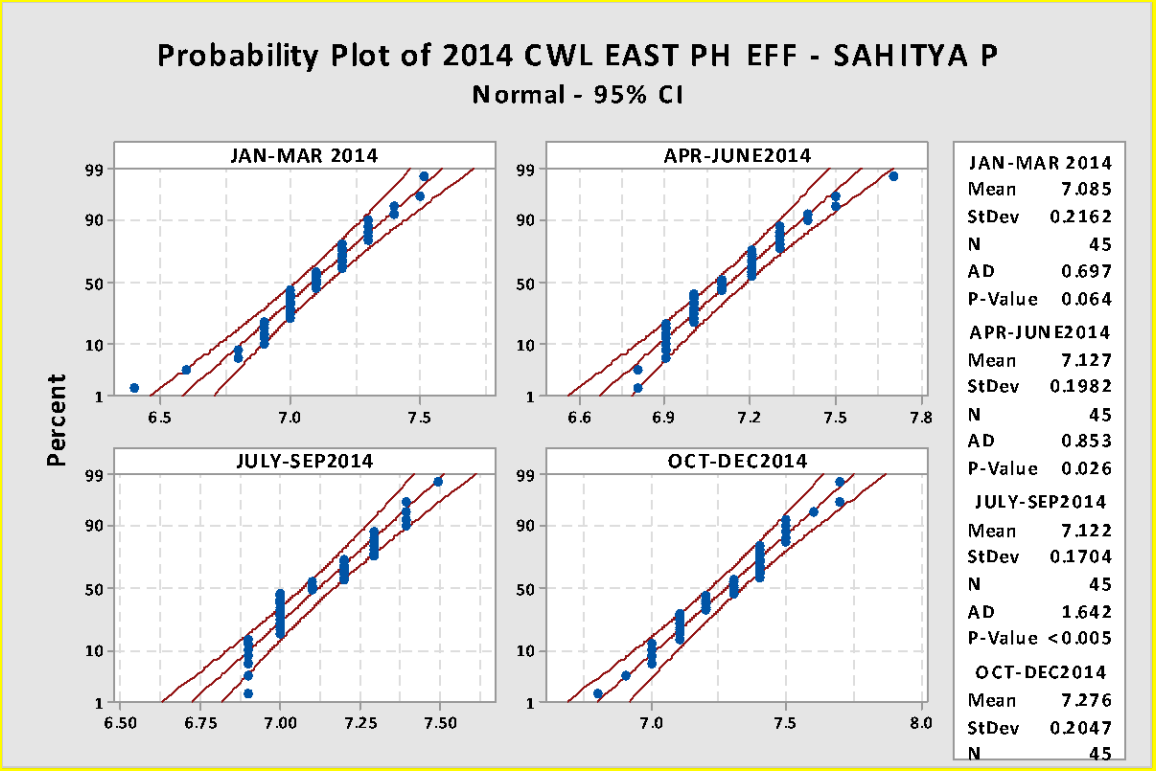
- Normal Distribution
- Most frequent pH value is around 7.2

MOVING AVERAGE PLOT OF PH LEVELS



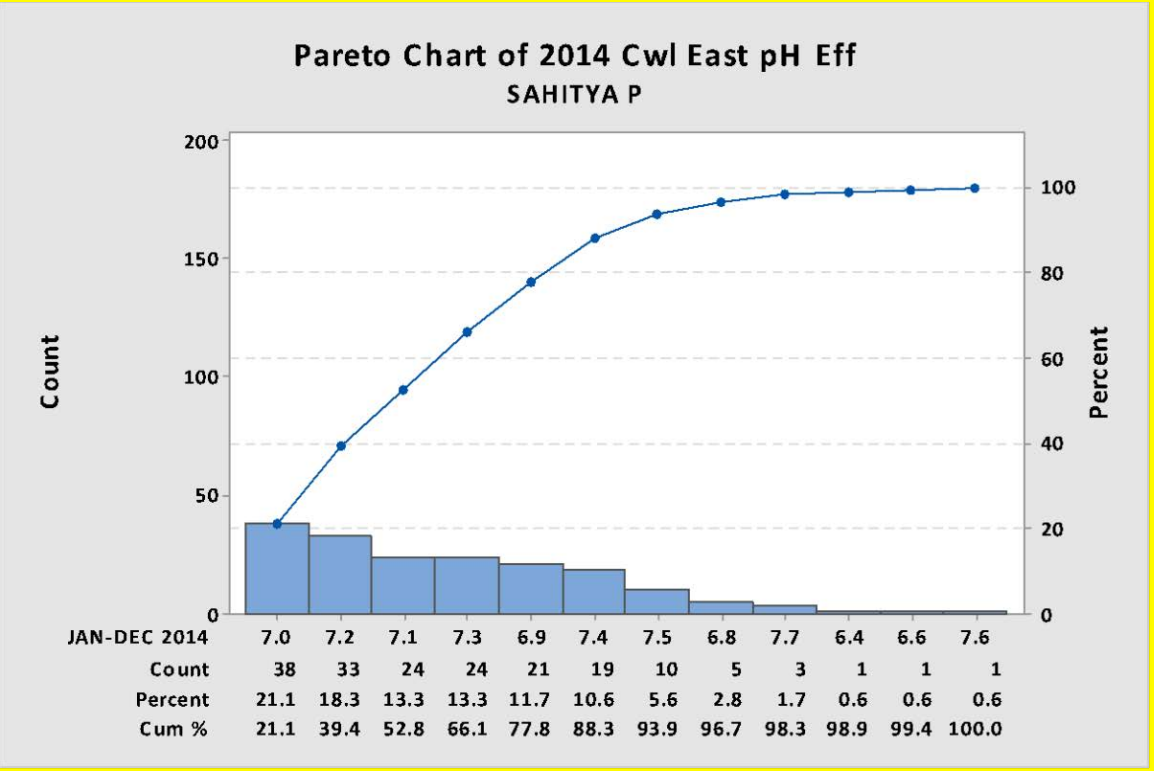
- Upper Control Limit= 7.471
- Lower Control Limit= 6.834
- Spec Values
- Upper = 9
- Lower = 6
- Based on the Plot and the Permitted Levels Process is in Control.
- Mean is 7.152

PROBABILITY PLOT



- Each Month Shows Statistical Control
- Outliers in July-Sep.

PARETO CHART



•The purpose of the Pareto chart is to highlight the most important among a (typically large) set of factors.

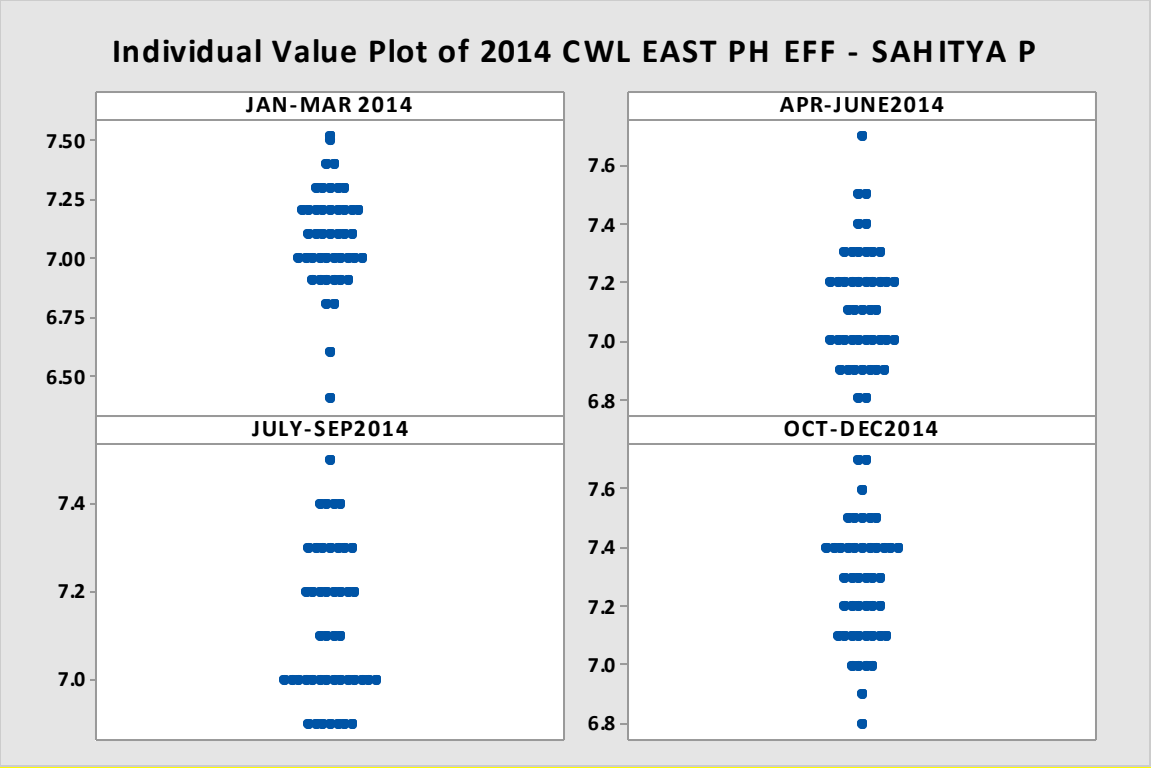
• In quality control, it often represents the most common sources of defects, the highest occurring type of defect, or the most frequent reasons for customer complaints

• pH 7.4 Represents Most Readings

INDIVIDUAL PLOT

- Individual value plots clearly show the characteristics of data distribution.

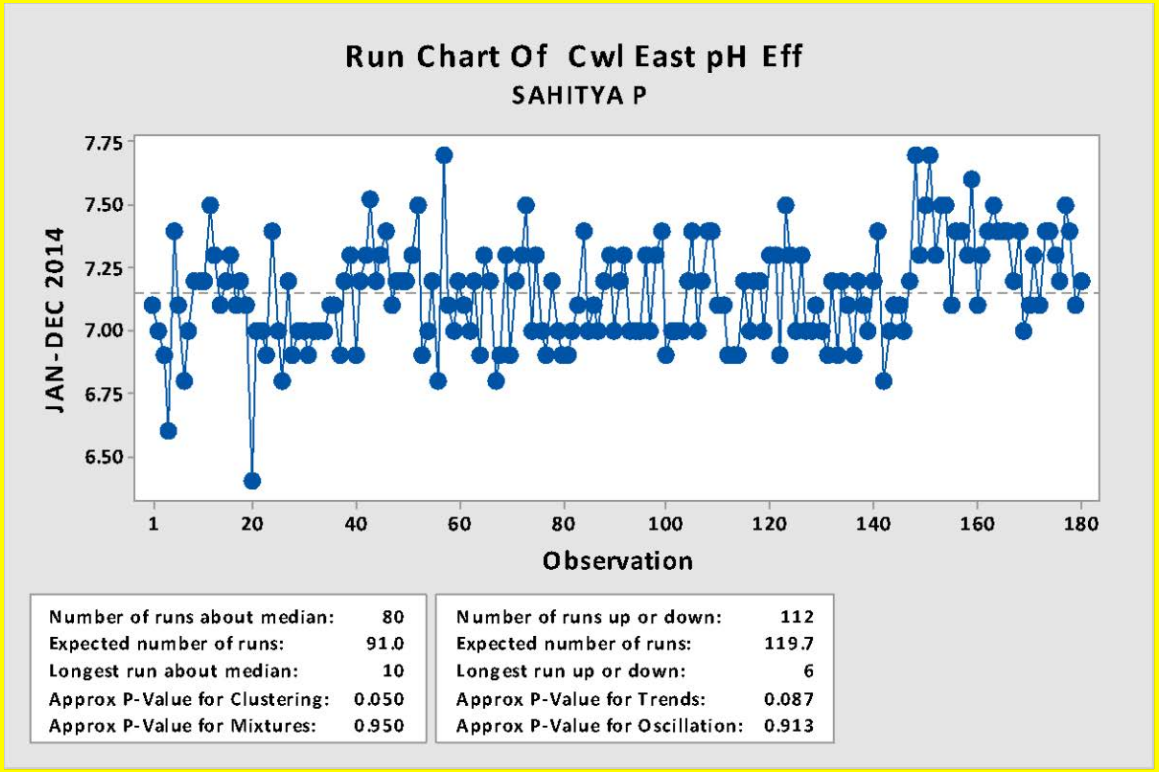
- Most values are in between 7.00 – 7.25



RUN CHART

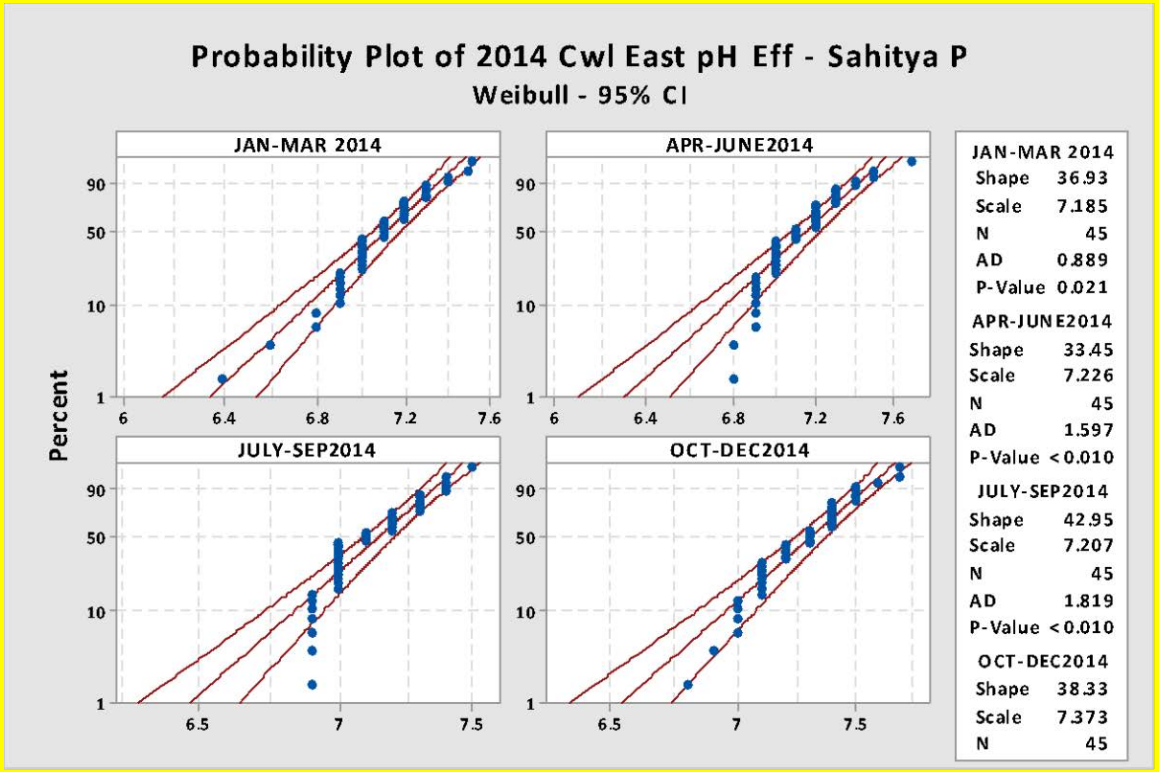
- Graph displays process performance over time.
- Events shown on y-axis are plotted against time period on x-axis.
- Upward downward trends,

  cycles and large abberations.



WEIBULL PROBABILITY PLOT

- Purpose is to assess whether data in X, could come from a weibull distribution.
- If data is weibull, the plot is linear.

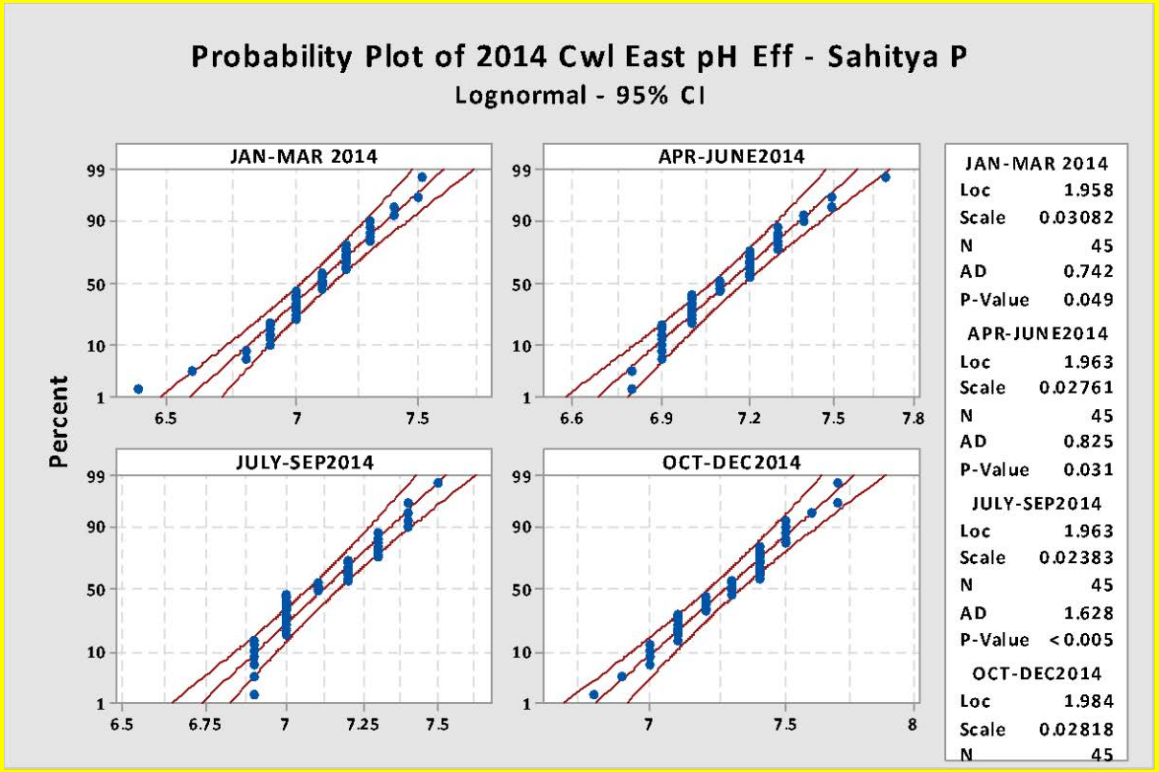


LOGNORMAL PROBABILITY PLOT

- The purpose is to assess whether the data in X, could come from a lognormal distribution.

- If the data is lognormal, the

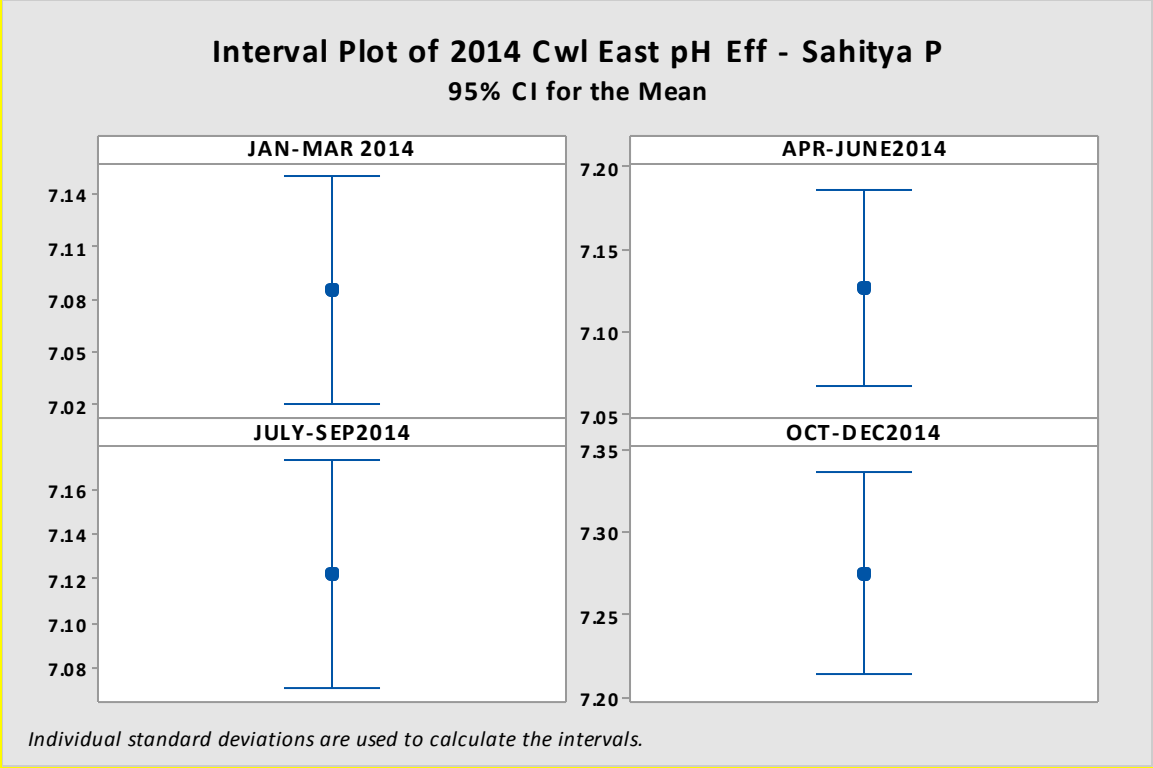
  plot is linear.



INTERVAL PLOT

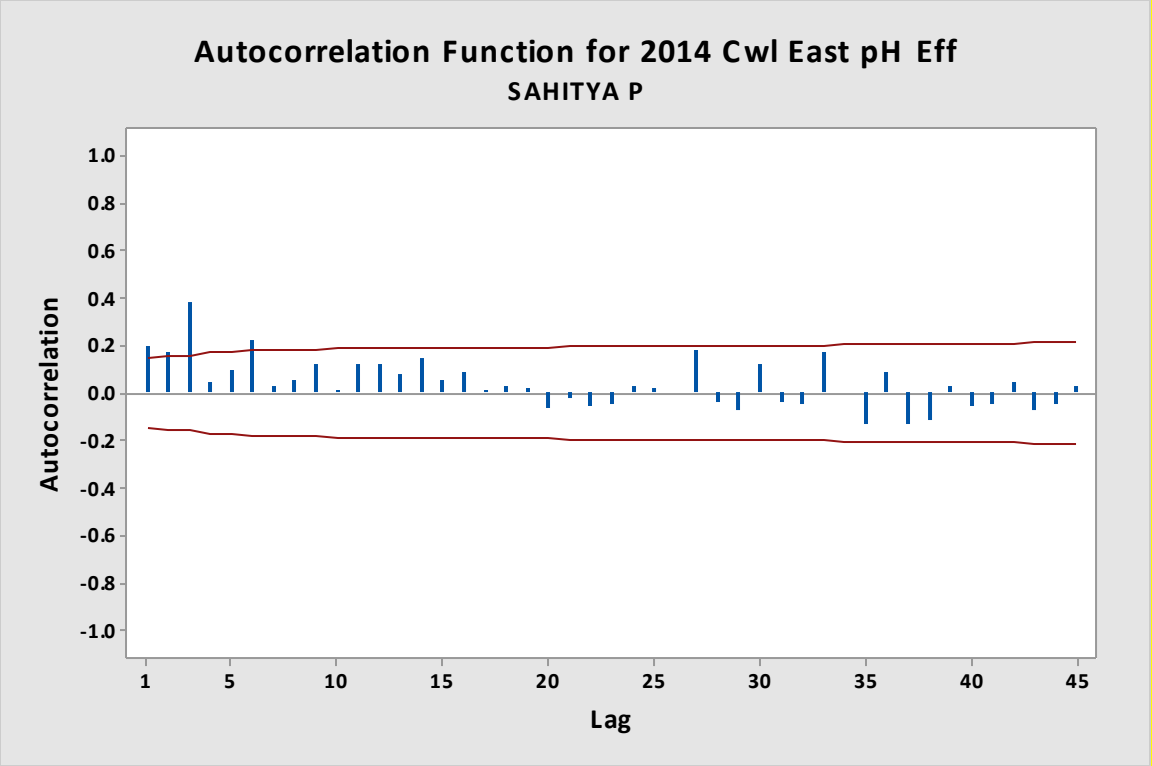
- The interval plot above shows the characteristics of pH value over a period of whole year

- It shows the mean average value for Ph throughout whole year

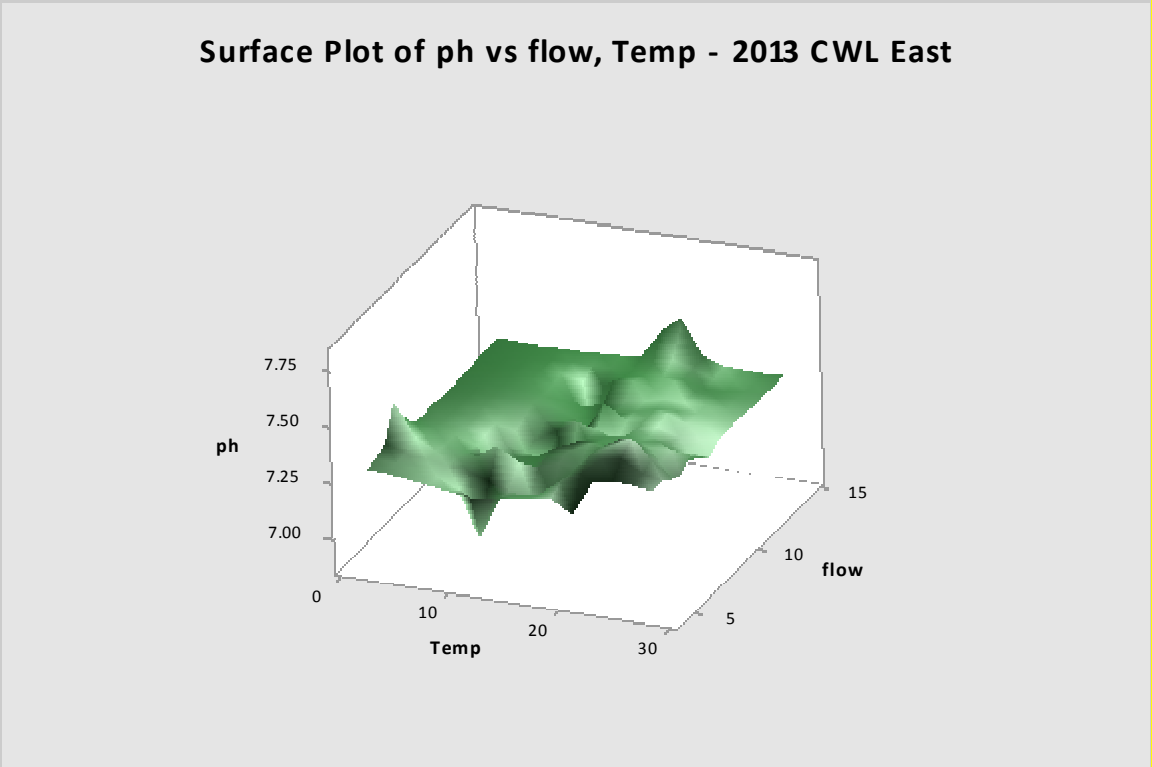


AUTO-CORRELATION PLOT

- By performing an autocorrelation function, it is found out how well observations at different points time correlate with each other
- Also, how they look for a seasonal pattern of an year.

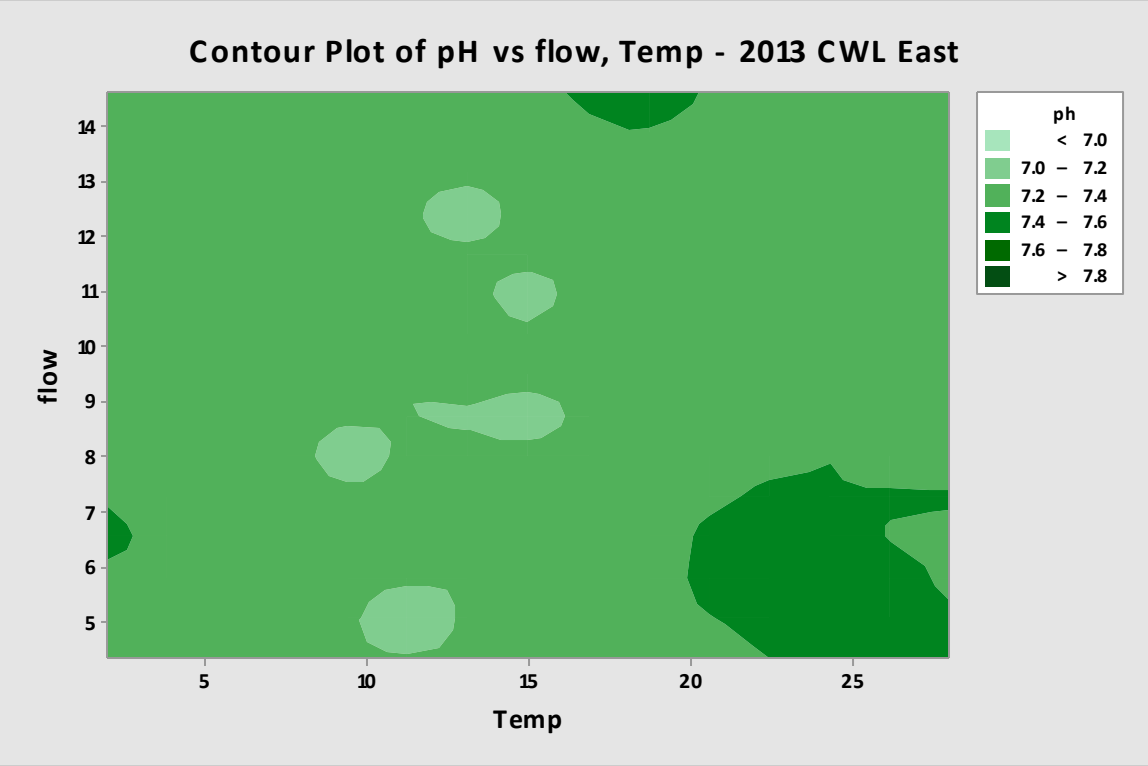


Surface Plot for Previous Year 2013 East



- The above graph plots the values by taking flow, temperature and ph as X-axis, Y-axis and Z-axis.

Contour Plot for Previous Year 2013



- This is a graphical technique for representing 3-D surface.
- Most of the Ph values are at 7.6 and 7.8 around the temperatures in between 20 and 25.

Conclusions & Future Directions

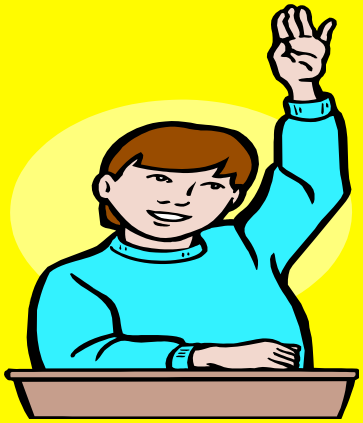
①Energy Conservation at a local water waste treatment plant was illustrated by the applications of statistical quality & process control (SQC/SPC).

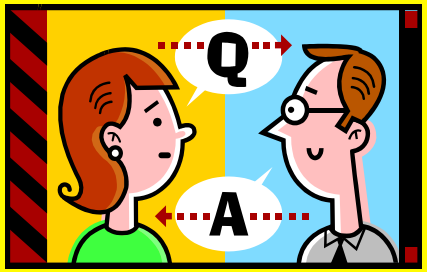
②This energy conservation also directly implies the economical benefits of the annual operating strategic plan of water treatment at this plant as well as pin pointing those areas where these can be improved upon.

③The future directions of this research are to obtain the current and future annual data when available for this water treatment plan and identify if these have been improved upon for improving both energy conservation and economics.

QUESTIONS?

- Dr. Richard Segall
- rsegall@astate.edu





Thank You