Application of Total Quality Management (TQM) Tools To Compact Sewage Treatment Plant (STP)

Mohammed Ahmed Mohammed Elbshir[1], Asaad Khalid Alghamdi[2]and Osama Mohammed Elmardi Suleiman Khayal[3]

[1] Mechanical Engineering Dept, Faculty of Engineering Al-Baha University, Saudi Arabia

[2] Postgraduate, MSc in Renewable Energy Engineering Al-Baha University, Saudi Arabia

[3] Department of Mechanical Engineering, Faculty of Engineering and Technology, Nile Valley University, Atbara – Sudan and Elsheikh Abdallah Elbadri University, Berber – Sudan

Abstract

In wastewater treatment plants, water passes through several stages or treatment processes, all of which consume expensive electricity and chemicals.

This research applied one of the tools of total quality management (TQM), which is control maps, through which the performance of the entire system is monitored, and this allows solving problems in the system and studying the development and improvement of the system.

When applying control maps to a wastewater treatment plant, focus was placed on the specifications of raw water (input) and produced water (output). Five quality characteristics of raw water and fifteen quality characteristics of treated water were selected. An X-chart mean map and an R-chart range map were generated for each feature and then the process capability was calculated.

Sample variances were evaluated and process capabilities were compared with specification variances. This helps in deciding on operations and leads to improvement of the system.

Keywords: STP, Sewage Treatments, MBR plant, Total Quality Management (TQM), Control Charts, Process capability.

مستخلص

في محطات معالجة مياه الصرف الصحي تمر المياه عبر عدة مراحل أو عمليات معالجة وكلها تستهلك الكهرباء والمواد الكيميائية باهظة الثمن.

طبق هذا البحث إحدى أدوات إدارة الجودة الشاملة (TQM) وهي خرائط الرقابة والتي من خلالها يتم مراقبة أداء النظام بأكمله وهذا يسمح بحل المشاكل في النظام ودراسة تطوير وتحسين النظام.

عند تطبيق خرائط التحكم على محطه معالجة مياه الصرف الصحي تم التركيز على مواصفات المياه الخام (المدخلات) والمياه المنتجة (المخرجات). تم إختيار خمس خصائص جوده للمياه الخام وخمسة عشر للمياه المعالجة. تم إنشاء خريطة متوسطات (X- chart) وخريطة مدى (R-chart) لكل خاصية ثم تم حساب مقدرة العملية.

تم الحكم علي تباين العينات وتمت مقارنة مقدرات العمليات مع تفاوتات المواصفات. هذا يساعد على إتخاذ قرار بشأن العمليات ويؤدي إلى تحسين النظام.

1.Introduction

Clean water that is fit for use is unfortunately not available to all. It has been reported that more than one billion of people have no access to safe drinking water. This accounts for a large number of water-related diseases and even deaths. People even children walk for several kilometers to collect clean water. Cleaning of water is a process of removing pollutants before it enters a water body or is reused.

This process of wastewater treatment is commonly known as “Sewage Treatment” and it takes place in several stages. Sewage is wastewater released by homes, industries, hospitals, offices and other users. It also includes rainwater that has run down the street during a storm or heavy rain. The water that washes off roads and rooftops carry harmful substances with it. Sewage is a liquid waste. Most of it is water, which has dissolved and suspended impurities [1] – [8].

Wastewater is water used more than once and not suitable for use again, it has been mixed with impurities, bacteria, and chemicals, like the water resulting from washing clothes, dishes, showering, and others. It is collected in plants for treatment and re-used in some human activities such as irrigation, industry, and cooling systems.

Wastewater treatment plants are many in terms of technologies but all of them consume very expensive electricity and chemicals. The types of wastewater treatment plants are:

- Extended Aeration.
- Oxidation Ditch.
- Rotating Disc System / Rotating Biological Contractor (RBC)
- Membrane Bio Reactor (MBR) - This research will focus on this type of wastewater treatment plants.

Figure 1 below shows Membrane Bio Reactor (MBR) plant.

Figure 1: Membrane Bio Reactor (MBR) plant

The Membrane Bio Reactor (MBR) system is developed with the aim of domestic use based on biological membranes technology. MBR filter is an activated sludge system that does not need a conventional settling tank and allows the concentration of solids which results in a large volumetric suspension with a total volume of 0.01.

The water passes through several treatment stages, starting from pumping the water from the equilibrium tank to the automatic separation system, which consists of medium and fine filters to separate any suspended or portable materials that may harm the treatment, and after that, the treated wastewater is removed from the water treatment tank. It is then deployed in the network of air distributors in the station, which oxidizes the organic materials with compressed air, then the process of membrane filtration of the treated water is carried out to get rid of any suspended organic materials [9] – [14].

2. Objectives of the Research

This research applied one of the Total Quality Management (TQM) tools, (which is Control Charts) in treatment plants, through which the performance of the entire system is monitored. This allows to solve the problems in the system and study the development and improvement of the system.
Applying total quality tools to a sewage treatment system raises the quality and efficiency:

- To make decisions regarding product specifications, production process, and recently produced items.
- To determine the processes capability.
- To improve quality (e.g., new procedures and methods).

The results of this research are expected to improve the performance of the system, ease of monitoring and management, and the ability to make the right decisions.

3. Research Methodology

When applying the TQM tool (control charts) to the wastewater treatment plant, it was focused on specifications of the raw water (input) and produced water (output). The application is in the following sequence:

1. Select the quality characteristics.
2. Choose the rational subgroups.
3. Collect the data.
4. Determine the trial center line and control limits.
5. Establish the revised central line and control limits.
6. Achieve the objectives.

3.1 Select the Quality Characteristics

The quality characteristics for raw water are, [15] – [22]:
A. Quantity of input water.
B. Biochemical Oxygen Requirement (BOD5).
C. Suspended solids (TSS).
D. Chemical oxygen demand (COD).
E. Ammonia concentration (NH_3/N).
The quality characteristics for treated water are:

A. Quantity of output water.
B. Quantity of output sludge.
C. Biochemical Oxygen Requirement (BOD5).
D. suspended solids (TSS).
E. Chemical oxygen demand (COD).
F. Ammonia concentration (NH3/N).
G. Mixed liquor suspended solids (MLSS).
H. Hydrogen ion concentration PH.
I. Conductivity.
J. Organic nitrogen.
K. Turbidity.
L. Nitrates.
M. Free chlorine.
N. Eggs of worms.
O. Coli bacteria.

3.2 Choose the Rational Subgroup

To make rational control charts, each group contained nine samples, and we have had twenty-seven groups. The mean and range were calculated. This was done for each quality characteristics.
Table 1 below illustrates the Rational Subgroups, [23] – [25].

Table 1: the Rational Subgroups

#	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9	R	X
subgroup 1	16.2	17	18	17.2	18.9	19	18.5	19.2	19.6	3.4	18.2
subgroup 2	17	18.3	17.5	18.1	17.1	19.2	18.2	19.6	17.2	2.6	18.0
subgroup 3	18	16	15.9	18	17	17.4	15.9	19.2	17.4	3.3	17.2
subgroup 4	17.2	18	16	16.3	15.9	16.8	16.9	17.6	18.6	2.7	17.0
subgroup 5	16.9	18.6	17.4	16	18	16.3	19.6	15.9	17.4	3.7	17.3
subgroup 6	17.5	18.6	17.7	17	18	19	15.9	18	17.4	3.1	17.7
subgroup 7	17	19.6	19	18	16.6	17.2	19	16	19	3.6	17.9
subgroup 8	19	20	18	17	18	16	16.3	17.2	19.5	4	17.9
subgroup 9	17.5	19.1	16.6	16.2	16.5	16	13.5	16	18.2	5.6	16.6
subgroup 10	18.7	19.4	16	18	16.6	17.2	18.2	16.9	18	3.4	17.7
subgroup 11	16.9	15.9	17.6	18	17.2	19	18	17.4	16.3	3.1	17.4
subgroup 12	17	18.5	18	17.6	17.9	18.6	17.5	17	15.9	2.7	17.6
subgroup 13	15.6	17.5	17	19	20	19.6	18.6	17.7	16.6	4.4	18.0
subgroup 14	17.6	18.8	17.4	17.4	19	15.9	19.3	17.7	18.6	3.4	18.0
subgroup 15	15.9	16	16.8	15.9	18.8	18.9	19.6	16	17.7	3.7	17.3
subgroup 16	17.4	18.6	15.9	17	18	19.6	15.9	17.6	18.8	3.7	17.6
subgroup 17	27.2	18.8	18.6	19.9	18.5	17.4	17.4	18.8	17.4	9.8	19.3
subgroup 18	17.1	16.6	18.6	19.6	19	18	17	16.1	17.5	3.5	17.7
subgroup 19	18.9	27.2	15.9	18	15.6	18	15.9	19.6	17.4	11.6	18.5
subgroup 20	18	18.6	17.5	17.1	27.2	15.9	18	17	18.9	11.3	18.7
subgroup 21	15.9	17.4	15.9	19	18.6	17.1	16.9	17.6	17.39	3.1	17.3
subgroup 22	18.6	18	19	17	18.8	17.36	19.5	18.5	17.5	2.5	18.3
subgroup 23	16.3	17.6	17	16.1	18.6	19.6	17	16.9	18.6	3.5	17.5
subgroup 24	17.6	15.9	18.6	17.7	18.6	16.9	15.9	17.6	18	2.7	17.4
subgroup 25	17.2	19	18	17.4	16.3	17	18.5	18	17.6	2.7	17.7
subgroup 26	17.9	18.6	17.5	17	15.9	15.6	17.5	17	19	3.4	17.3
subgroup 27	20	19.6	18.6	17.7	16.6	17.6	18.8	17.4	17.4	3.4	18.2
										4.2	17.8

3.3 Collect the Data

Data for raw water (input) and treated water (output) were collected from the beginning of January until the end of August (eight months), as shown in Table 2 below.
The data for raw and treated water are: Biochemical Oxygen Requirement (BOD5), suspended solids (TSS), Chemical oxygen demand (COD), and ammonia (NH_3/N).
Data for treated water only: mixed liquor suspended solids (MLSS), PH, conductivity, organic nitrogen, turbidity, nitrates, free chlorine, eggs of worms, and coli bacteria. Also, data on the amount of incoming and treated water and the amount of sludge were collected, [26] and [27].
Table 2 below shows the collected data for January.
Table 2: the collected data for January

Month Report													January								
chemical results																		Quantity			
BOD₅		TSS		COD		NH3/N		MLSS	pH	CONDUCTIVITY	organic nitrogen	TURBIDITY	Nitrates	free chlorine	eggs of worms	coli bacteria	sludge m3	treated water m3	raw water m3	Date	
output	input	output	input	output	input	output	input														
4.2	760	3.9	560	16.2	940	5	79	9190	6.9	1255	4.1	2	7.3	1.2	0.1	1.4	3	63	66	01/01/22	
4	430	3.8	520	17	920	4.1	80	9215	6.9	1360	4	2.1	7.1	0.9	0.1	1.3	3	57	60	02/01/22	
4.1	480	3.7	560	18	905	3.9	80	9230	6.7	1390	4.2	2.1	7.2	0.8	0.1	1.4	4	92	96	03/01/22	
4	415	3.8	520	17.2	925	4.6	78	9230	6.7	1390	4.2	2.1	7.2	1.1	0.1	1.4	2	46	48	04/01/22	
4.2	472	3.9	560	18.9	960	4.7	79	9190	6.8	1255	4.1	2	7.3	1	0.1	1.4	5	103	108	05/01/22	
4.1	480	3.7	560	19	905	4.6	80	9230	6.9	1390	4.2	2.1	7.2	0.9	0.1	1.4	4	74	78	06/01/22	
4.2	470	3.9	560	18.5	950	3.9	79	9190	6.8	1255	4.1	2	7.3	1	0.1	1.4	6	150	156	07/01/22	
4	465	2.5	560	19.2	890	3.8	80	9312	6.6	1400	4.4	2	7.4	0.8	0.1	1.4	2	94	96	08/01/22	
4.2	450	3.9	560	19.6	940	4.4	79	9190	6.8	1255	4.1	2	7.3	1.1	0.1	1.4	5	115	120	09/01/22	
3.7	450	3.9	560	17	940	4.6	79	9190	6.8	1255	4.1	2	7.3	0.9	0.1	1.4	6	134	140	10/01/22	
4.1	440	3.7	550	18.3	900	4.9	74	9220	6.6	1388	4	2.1	7.6	1.1	0.1	1.4	6	138	144	11/01/22	
4.2	745	3.9	560	17.5	950	4.1	79	9190	6.8	1255	4.1	2	7.3	0.8	0.1	1.4	2	46	48	12/01/22	
4	465	2.5	560	18.1	890	4	80	9330	6.6	1400	4.4	2	7.4	0.8	0.1	1.4	8	184	192	13/01/22	
4.1	480	3.7	560	17.1	905	4.7	80	9230	6.7	1390	4.2	2.1	7.1	0.9	0.1	1.4	5	121	126	14/01/22	
4.1	440	3.7	560	19.2	900	5	74	9220	6.6	1388	4	2.1	7.6	1.1	0.1	1.4	6	132	138	15/01/22	
3.9	470	3.3	520	18.2	960	5	81	10253	7.3	1290	3.9	1.9	7.1	0.9	0.1	1.5	2	46	48	16/01/22	
4	465	2.5	560	19.6	890	4	80	9350	7	1400	4.4	2	7.4	0.8	0.1	1.4	5	109	114	17/01/22	
3.9	465	2.5	560	17.2	890	4.1	80	9455	6.6	1400	4.4	2	7.4	0.7	0.1	1.4	3	57	60	18/01/22	
4.2	450	3.9	560	18	930	4.3	79	9190	6.8	1255	4.1	2	7.3	1	0.1	1.4	4	92	96	19/01/22	
4	465	2.5	560	16	890	4.8	80	9350	6.6	1400	4.4	2	7.4	0.8	0.1	1.4	5	108	113	20/01/22	
4.1	480	3.7	560	15.9	905	4.9	80	9230	6.7	1390	4.2	2.1	7.2	0.8	0.1	1.4	2	46	48	21/01/22	
4	450	3.9	560	18	925	4.8	79	9190	6.8	1255	4.1	2	7.3	0.9	0.1	1.4	5	109	114	22/01/22	
3.9	415	3.8	520	17	925	5	78	9230	7	1390	4.2	2.1	7.2	0.7	0.1	1.4	5	109	114	23/01/22	
4	465	2.5	560	17.4	890	5.1	80	9312	6.6	1400	4.4	2	7.4	0.8	0.1	1.4	9	180	189	24/01/22	
4.1	480	3.7	560	15.9	905	4.2	80	9230	6.7	1390	4.2	2.1	7.2	0.8	0.1	1.4	2	46	48	25/01/22	
4	415	3.8	520	19.2	925	4.3	78	9230	6.7	1390	4.2	2.1	7.2	0.9	0.1	1.4	3	105	108	26/01/22	
4	465	2.5	560	17.4	890	4.7	80	9350	7	1420	4.4	2	7.4	0.8	0.1	1.4	4	92	96	27/01/22	
4.1	440	3.7	560	17.2	900	4.6	74	9220	6.6	1388	4	2.1	7.6	1.1	0.1	1.4	5	97	102	28/01/22	
4.1	480	3.7	560	18	905	4.9	80	9230	6.9	1390	4.2	2.1	7.2	1	0.1	1.4	5	115	120	29/01/22	
4	470	3.9	560	16	956	3.9	79	9190	6.8	1255	4.1	2	7.3	1	0.1	1.4	5	103	108	30/01/22	
4.2	470	3.9	560	16.3	940	3.8	79	9190	6.8	1255	4.1	2	7.3	1.2	0.1	1.4	4	115	120	31/01/22	

3.4 Determine the Trial Center Line and Control Limits

In practice calculations are simplified by using the following equations where A_2, D_3 and D_4 are factors that vary with the subgroup size and are found in Table B of the Appendix, [28] – [31].

COD Output Trial Charts:

Trial Central Lines:

$$\bar{\bar{x}} = \frac{\sum_{i=1}^{g} \bar{x}_i}{g} \quad \text{and} \quad \bar{R} = \frac{\sum_{i=1}^{g} R_i}{g}$$

Where $\bar{\bar{x}}$: average of subgroup averages

$\bar{x}_i$: average of each subgroup

g: number of subgroups

$\bar{R}$: average of subgroup ranges

R_i: range of each subgroup

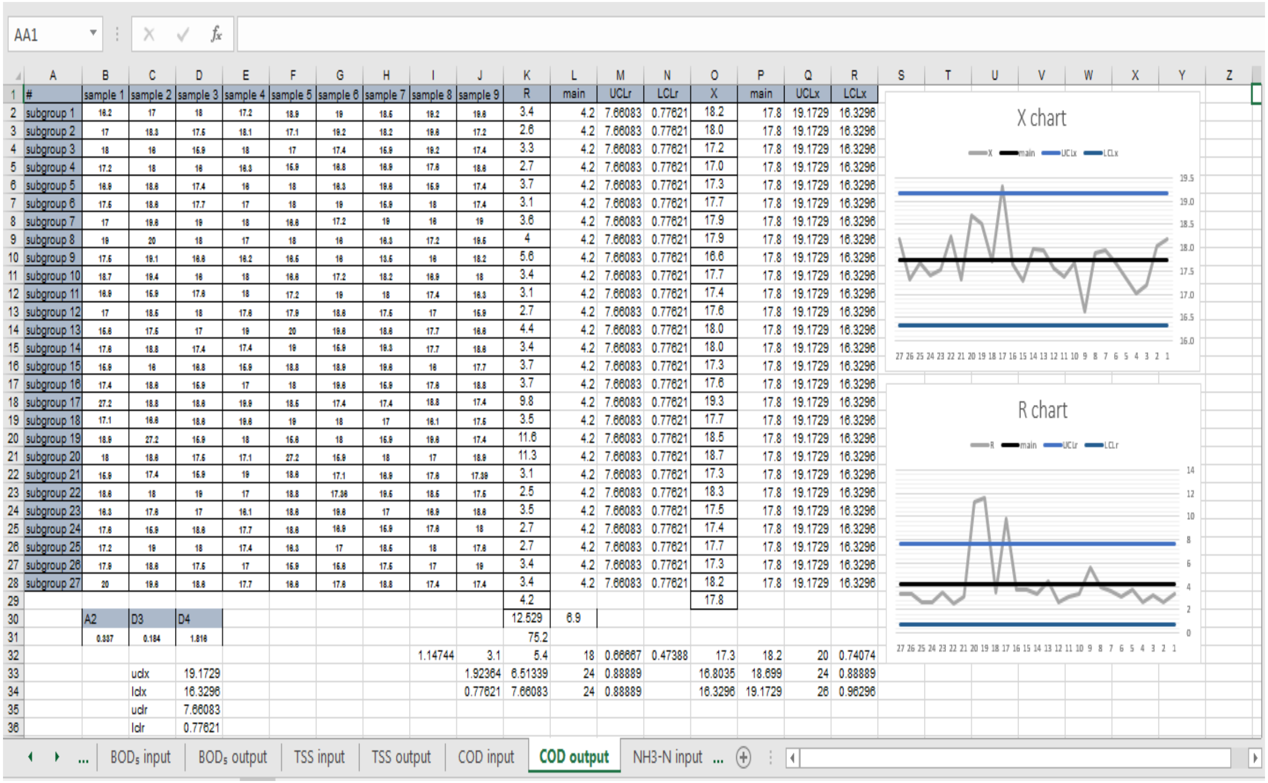
$\bar{\bar{x}} = 17.8$ and $\bar{R} = 4.2$

Trial Control Limits:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} = 19.2$$
$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} = 16.3$$
$$UCL_R = D_4\bar{R} = 7.66$$
$$LCL_R = D_3\bar{R} = 0.77$$

Table 3 below shows the trial charts calculations on Excel.

Table 3: the Trial Charts Calculations on Excel



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	#	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9	R	main	UCLr	LCLr	X	main	UCLx	LCLx
2	subgroup 1	18.2	17	18	17.2	18.9	19	18.5	19.2	19.8	3.4	4.2	7.66083	0.77621	18.2	17.8	19.1729	16.3296
3	subgroup 2	17	18.3	17.5	18.1	17.1	19.2	18.2	19.8	17.2	2.6	4.2	7.66083	0.77621	18.0	17.8	19.1729	16.3296
4	subgroup 3	18	16	16.9	18	17	17.4	16.9	19.2	17.4	3.3	4.2	7.66083	0.77621	17.2	17.8	19.1729	16.3296
5	subgroup 4	17.2	18	16	16.3	16.9	16.8	16.9	17.8	18.8	2.7	4.2	7.66083	0.77621	17.0	17.8	19.1729	16.3296
6	subgroup 5	16.9	18.8	17.4	16	18	16.3	19.8	16.9	17.4	3.7	4.2	7.66083	0.77621	17.3	17.8	19.1729	16.3296
7	subgroup 6	17.5	18.8	17.7	17	18	19	16.9	18	17.4	3.1	4.2	7.66083	0.77621	17.7	17.8	19.1729	16.3296
8	subgroup 7	17	19.8	19	18	16.8	17.2	19	16	19	3.6	4.2	7.66083	0.77621	17.9	17.8	19.1729	16.3296
9	subgroup 8	19	20	18	17	18	16	16.3	17.2	19.5	4	4.2	7.66083	0.77621	17.9	17.8	19.1729	16.3296
10	subgroup 9	17.5	19.1	16.8	16.2	16.5	16	13.5	16	18.2	5.6	4.2	7.66083	0.77621	16.6	17.8	19.1729	16.3296
11	subgroup 10	18.7	19.4	16	18	16.8	17.2	18.2	16.9	18	3.4	4.2	7.66083	0.77621	17.7	17.8	19.1729	16.3296
12	subgroup 11	16.9	15.9	17.8	18	17.2	19	18	17.4	16.3	3.1	4.2	7.66083	0.77621	17.4	17.8	19.1729	16.3296
13	subgroup 12	17	18.5	18	17.8	17.9	18.8	17.5	17	15.9	2.7	4.2	7.66083	0.77621	17.6	17.8	19.1729	16.3296
14	subgroup 13	16.6	17.5	17	19	20	19.6	18.8	17.7	16.8	4.4	4.2	7.66083	0.77621	18.0	17.8	19.1729	16.3296
15	subgroup 14	17.8	18.8	17.4	17.4	19	15.9	19.3	17.7	18.8	3.4	4.2	7.66083	0.77621	18.0	17.8	19.1729	16.3296
16	subgroup 15	16.9	16	16.8	15.9	18.8	18.9	19.6	16	17.7	3.7	4.2	7.66083	0.77621	17.3	17.8	19.1729	16.3296
17	subgroup 16	17.4	18.8	16.9	17	18	19.8	16.9	17.8	18.8	3.7	4.2	7.66083	0.77621	17.6	17.8	19.1729	16.3296
18	subgroup 17	27.2	18.8	18.8	19.9	18.5	17.4	17.4	18.8	17.4	9.8	4.2	7.66083	0.77621	19.3	17.8	19.1729	16.3296
19	subgroup 18	17.1	16.8	18.8	19.8	19	18	17	16.1	17.5	3.5	4.2	7.66083	0.77621	17.7	17.8	19.1729	16.3296
20	subgroup 19	18.9	27.2	16.9	18	16.8	18	16.9	19.8	17.4	11.6	4.2	7.66083	0.77621	18.5	17.8	19.1729	16.3296
21	subgroup 20	18	18.8	17.5	17.1	27.2	16.9	18	17	18.9	11.3	4.2	7.66083	0.77621	18.7	17.8	19.1729	16.3296
22	subgroup 21	16.9	17.4	16.9	19	18.8	17.1	16.9	17.8	17.89	3.1	4.2	7.66083	0.77621	17.3	17.8	19.1729	16.3296
23	subgroup 22	18.8	18	19	17	18.8	17.38	19.5	18.5	17.5	2.5	4.2	7.66083	0.77621	18.3	17.8	19.1729	16.3296
24	subgroup 23	18.3	17.8	17	16.1	18.8	19.8	17	16.9	18.8	3.5	4.2	7.66083	0.77621	17.5	17.8	19.1729	16.3296
25	subgroup 24	17.8	16.9	18.8	17.7	18.8	16.9	16.9	17.8	18	2.7	4.2	7.66083	0.77621	17.4	17.8	19.1729	16.3296
26	subgroup 25	17.2	19	18	17.4	16.3	17	18.5	18	17.8	2.7	4.2	7.66083	0.77621	17.7	17.8	19.1729	16.3296
27	subgroup 26	17.9	18.8	17.5	17	16.9	16.8	17.5	17	19	3.4	4.2	7.66083	0.77621	17.3	17.8	19.1729	16.3296
28	subgroup 27	20	19.8	18.8	17.7	16.8	17.8	18.8	17.4	17.4	3.4	4.2	7.66083	0.77621	18.2	17.8	19.1729	16.3296
29											4.2				17.8			
30		A2	D3	D4							12.529	6.9						
31		0.337	0.184	1.816							75.2							
32									1.14744	3.1	5.4	18	0.66667	0.47388	17.3	18.2	20	0.74074
33			uclx	19.1729						1.92364	6.51339	24	0.88889		16.8035	18.699	24	0.88889
34			lclx	16.3296						0.77621	7.66083	24	0.88889		16.3296	19.1729	26	0.96296
35			uclr	7.66083														
36			lclr	0.77621														

3.5 Establish the Revised Central Line and Control Limits

The revised center line and control limits are determined by discarding the points out of control limits that produced from Assignable Causes.

where A, d_2, D_1 and D_2 are factors that vary with the subgroup size and are found in Table B of the Appendix.

The revised chart is used to record the future samples and achieve the objectives.

COD Output Revised Charts:

Revised Central Lines:

$$\bar{\bar{X}}new = \frac{\sum \bar{x} - \bar{x}_d}{g - g_d} \qquad \text{and} \qquad \bar{R}_{new} = \frac{\sum R - R_d}{g - g_d}$$

Where: $\bar{x}_d$: discarded subgroup averages

g_d: number of discarded subgroups

R_d: discarded subgroup ranges

$\bar{\bar{x}} = 17.7$ and $\bar{R} = 3.43$

Revised Control Limits:

$$UCL_{\bar{x}} = \bar{x}_0 + A\sigma_0 \qquad \text{and} \qquad LCL_{\bar{x}} = \bar{x}_0 - A\sigma_0$$

$$UCL_R = D_2\sigma_0 \qquad \text{and} \qquad LCL_R = D_1\sigma_0$$

Where: $\bar{x}_0 = \bar{\bar{X}}new$

$R_0 = \bar{R}_{new}$

$\sigma_0 = \frac{R_0}{d_2}$

Revised Control Limits:

$UCL_{\bar{x}} = \bar{\bar{x}} + A\sigma_{\circ}$ =18.8

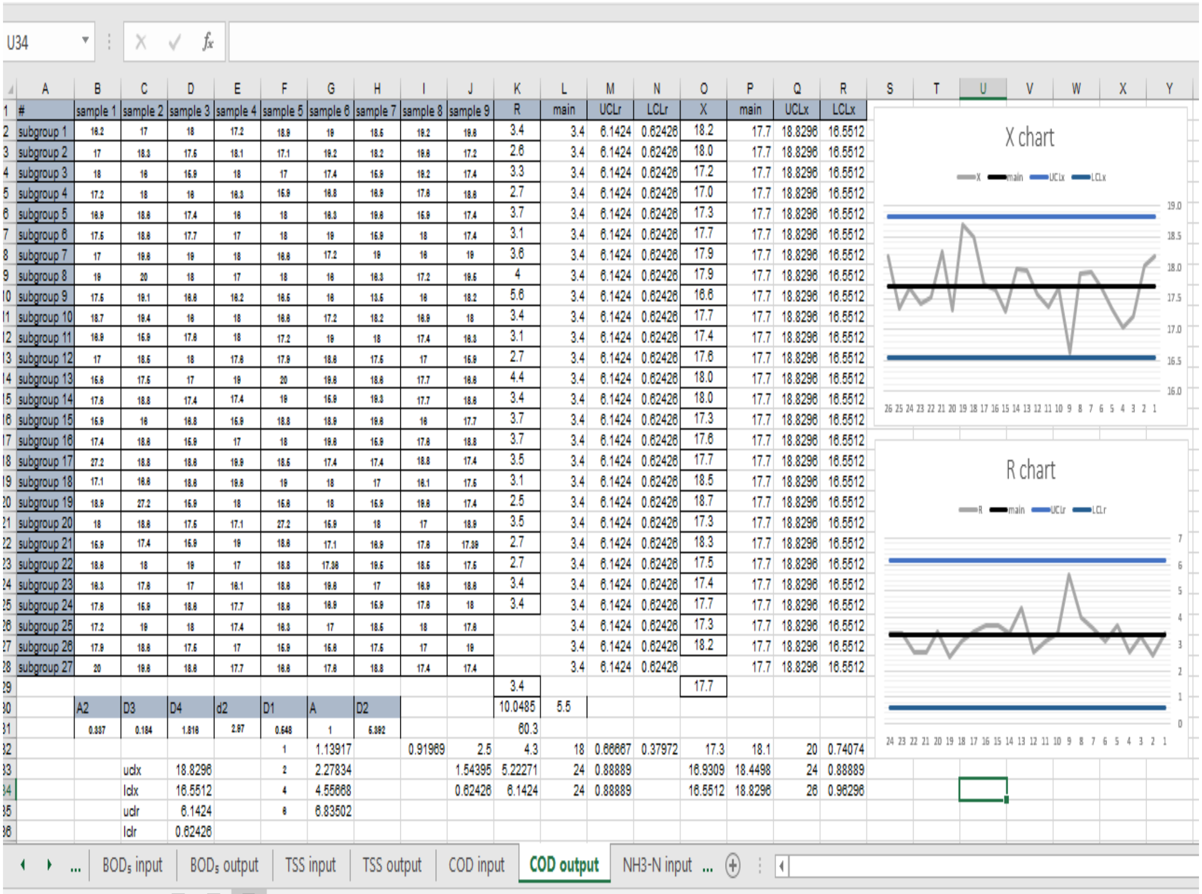
$LCL_{\bar{x}} = \bar{\bar{x}} - A\sigma_{\circ}$ = 16.5

$UCL_R = D_2\sigma_{\circ}$ = 6.1

$LCL_R = D_1\sigma_{\circ}$ = 0.62

Table 4 below shows the revised charts calculations on Excel.

Table 4: the Revised Charts Calculations on Excel



3.6 Achieve the Objectives (The Results)

State of Control:

The % of product that falls within any pair of values is more predictable as shown in Figure 2 (Normal Pattern Variation).

Looking at X and R control charts, calculate the percentage of distribution of samples Table 5.

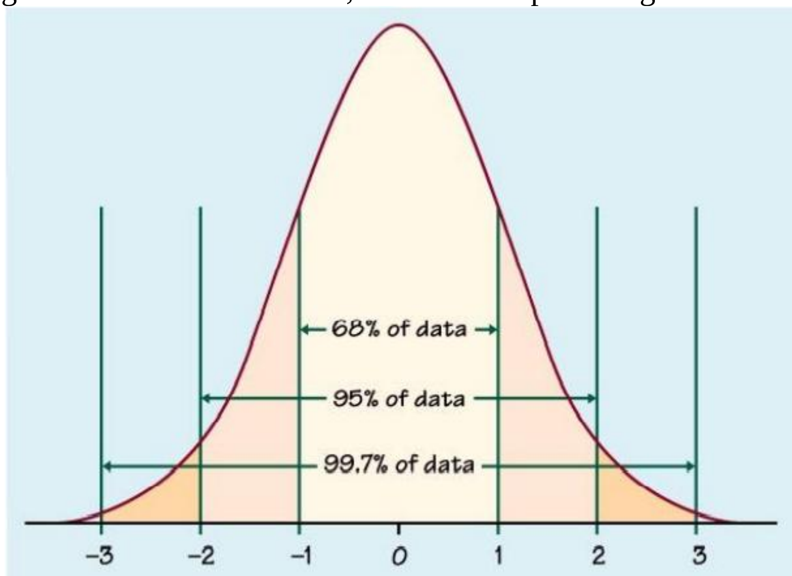


Figure 2: The Normal Pattern Variation

Table 5 below illustrates the Distribution of Samples according to the following categories 2σ, 4σ and 6σ.

Table 5: Distribution of Samples

	2σ	4σ	6σ
Normal Distribution	68%	95%	99%
BOD_5 input - X chart	78%	85%	85%
BOD_5 input - R chart	4%	82%	89%
BOD_5 output - X chart	30%	30%	82%
BOD_5 output - R chart	59%	67%	93%
TSS input - X chart	30%	95%	99%
TSS input - R chart	78%	85%	92%
TSS output - X chart	22%	70%	89%
TSS output - R chart	74%	89%	99%
COD input - X chart	63%	95%	99%
COD input - R chart	93%	97%	99%
COD output - X chart	74%	89%	99%
COD output - R chart	68%	89%	89%
NH3/N input - X chart	68%	85%	99%
NH3/N input - R chart	11%	95%	95%
NH3/N output - X chart	19%	60%	78%
NH3/N output - R chart	4%	74%	82%
MLSS - X chart	8%	82%	85%
MLSS - R chart	0%	0%	82%
Conductivity - X chart	48%	78%	89%
Conductivity - R chart	96%	96%	99%
Sludge quantity - X chart	60%	85%	99%
Sludge quantity - R chart	48%	78%	93%
Treated water quantity - X	48%	85%	99%
Treated water quantity - R	44%	83%	92%
Raw water quantity - X chart	44%	85%	99%
Raw water quantity - R chart	44%	74%	92%

Process Capability and Tolerance:

The process spread will be referred to as the process capability and is equal to 6σ. There are three possible situations which could be summarized as follows:

Case I: When the process capability is less than the tolerance (Desirable)

$6\sigma < USL-LSL$.

Case II: When the process capability is equal to the tolerance (Satisfactory)

$6\sigma = USL-LSL$.

Case III: When the process capability is greater than the tolerance (Undesirable)

$6\sigma > USL-LSL$.

To calculate the standard deviation, use the equation: $\sigma = R/d_2$

Where $d_2 = 2.97$ at n = 9 samples

Table 6 below illustrates the Process Capability and Tolerance.

Table 6: Process Capability and Tolerance

	capability	tolerance	state
BOD_5 input	182	500	Desirable
BOD_5 output	8.3	10	Desirable
TSS input	806	600	Undesirable
TSS output	21.7	10	Undesirable
COD input	1387	1500	Desirable
COD output	75.2	30	Undesirable
NH3/N input	74.6	80	Desirable
NH3/N output	32.1	5	Undesirable
Sludge quantity	63.36	90	Desirable
Treated water quantity	1467.2	1800	Desirable
Raw water quantity	1524.6	1800	Desirable

4. Conclusions

In this research, control charts have been applied to an operating system, which is a wastewater treatment plant in Al-Aqiq city. It appears from the above results that the plant is not in its best condition and many improvements can be made to obtain higher quality with the same current consumption of electricity.

BOD_5 Input:

There is no way to control it as the water source is not controlled and the analysis of a sample takes 5 days.

BOD_5 Output, TSS Output and NH_3/N Output:

The treatment process must be reconsidered, or the test and measurement equipment may need to be calibrated.

MLSS and Conductivity:

They are elements that there is no danger of increasing or decreasing, especially since the purpose of water is irrigation, so it can be ignored.

Regarding tolerance, it appears from the previous results that some equipment and processes must be improved in order to be able to produce according to actual conditions, specifically equipment and processes related to TSS, COD and NH_3/N.

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Appendices

Table A below illustrates the Raw and Treated Water Specification from the following considerations:
Natural properties.
Organic chemical properties.
Microbial properties.
Properties of chemical compounds.
Chemical properties (heavy elements).
Table A: Raw and Treated Water Specification

Properties		Raw Water mg/L	Secondary Treatment mg/L	Tertiary Treatment mg/L
natural properties	supernatants	0	0	0
	TSS. suspended solids	600	40	10 (a)
	PH	6-9	6-8.4	6-8.4
Organic chemical properties	Biochemical Oxygen Requirement BOD5	500	40	10 (a)
	TURBIDITY	----------	5	5
	GREASE & Oil	100	0	0
	PHENOL	5	0.002	0.002
microbial properties	The number of fecal colic bacilli	----------	100 cells / 100 ml	2.2 cells / 100 ml (b)
	The number of eggs of intestinal worms	----------	----------	1/L
properties of chemical compounds	Nitrates No3-N	----------	10.0	10.0
	Ammonia NH3-N	80	5.0	5.0
Chemical properties (heavy elements)	Aluminum Al	----------	5.0	5.0
	Arsenic As	0.1	0.1	0.1
	Beryllium Be	----------	0.01	0.1
	Boron B	2.0	0.75	0.75
	Cadmium Cd	0.02	0.1	0.01
	free chlorine CL2	----------	(+)0.5	(+)0.5
	total chromium Cr	1.2	0.1	0.1
	Cobalt Co	----------	0.05	0.05
	Copper Cu	1.2	0.4	0.4
	Fluoride F	----------	1	1
	Iron Fe	----------	5.0	5.0
	Lead Pb	1.0	0.1	0.1
	Lithium Li	----------	2.5	2.5
	Manganese Mn	5.0	0.2	0.2
	Mercury Hg	0.05	0.001	0.001
	Molybdenum Mo	0.5	0.01	0.01
	Nickel Ni	2.0	0.2	0.2
	Selenium Se	0.5	0.02	0.02

	Vanadium V	1.0	0.1	0.1
	Zinc Zn	2.6	4.0	4.0

(a) 1. The monthly rate of BOD5 and TSS is not more than 10 mg/L
(a) 2. The weekly rate of BOD5 and TSS is not more than 15 mg/L.
(b) Treated wastewater is considered disinfected to a non-infectious degree and is sufficient for use in unrestricted irrigation if the MPN for fecal coliforms does not exceed 2.2 numbers per 100 milliliters (or equivalent by other measurement methods) as determined by bacterial test results within a week. It also does not exceed 23 per 100 milliliters in any sample (or equivalent from other measurement methods).
(+) Not less than 2.0 mg/L if chlorine is used for disinfection.
Table B below shows the main Factors for Computing Control Chart Limits or Factors useful in the Construction of Control Charts.

Table B: Factors for Computing Control Chart Limits

	Chart for Averages			Chart for standard deviations					Chart for Ranges						
	Factors for Control Limits			Factors for: Central Line	Factors for: Control Limits				Factors for Central Line		Factors for Control Limits				
n	A	A_2	A_3	c_4	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	0	3.267	0	2.606	1.128	0.8862	0.852	0	3.686	0	3.266
3	1.732	1.023	1.954	0.8862	0	2.568	0	2.276	1.693	0.5908	0.888	0	4.357	0	2.574
4	1.500	0.729	1.628	0.9213	0	2.266	0	2.088	2.059	0.4857	0.879	0	4.697	0	2.281
5	1.342	0.577	1.427	0.9400	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.003
7	1.134	0.419	1.182	0.9594	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.206	5.203	0.076	1.924
8	1.061	0.373	1.099	0.9650	0.185	1.815	0.179	1.751	2.847	0.3512	0.819	0.389	5.306	0.137	1.863
9	1.000	0.337	1.032	0.9693	0.239	1.761	0.232	1.707	2.970	0.3367	0.807	0.548	5.392	0.184	1.816
10	0.949	0.308	0.975	0.9727	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.688	5.467	0.223	1.777
11	0.905	0.285	0.927	0.9754	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.813	5.533	0.256	1.744
12	0.866	0.266	0.886	0.9776	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.924	5.593	0.284	1.716
13	0.832	0.249	0.850	0.9794	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.026	5.646	0.307	1.693
14	0.802	0.235	0.817	0.9810	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.119	5.695	0.328	1.672
15	0.775	0.223	0.789	0.9823	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.204	5.739	0.347	1.653
16	0.750	0.212	0.763	0.9835	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.283	5.781	0.363	1.637
17	0.728	0.203	0.739	0.9845	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.357	5.819	0.378	1.622
18	0.707	0.194	0.718	0.9854	0.482	1.518	0.475	1.496	3.640	0.2747	0.738	1.425	5.855	0.392	1.608
19	0.688	0.187	0.698	0.9862	0.497	1.503	0.490	1.483	3.689	0.2711	0.733	1.490	5.888	0.404	1.596
20	0.671	0.180	0.680	0.9869	0.510	1.490	0.504	1.470	3.735	0.2677	0.728	1.550	5.920	0.415	1.585
21	0.655	0.173	0.663	0.9876	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.607	5.950	0.425	1.575
22	0.640	0.167	0.647	0.9882	0.534	1.466	0.528	1.448	3.819	0.2618	0.719	1.661	5.978	0.435	1.565
23	0.626	0.162	0.633	0.9887	0.545	1.455	0.539	1.438	3.858	0.2592	0.715	1.712	6.004	0.444	1.556
24	0.612	0.157	0.619	0.9892	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.761	6.030	0.452	1.548
25	0.600	0.153	0.606	0.9896	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.807	6.055	0.460	1.540
Over 25	$3/\sqrt{n}$	$3/d_2\sqrt{n}$	...	...	*	**	...	...	...	...	...	...	...	...	...