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RIVER WATER QUALITY MONITORING USING STATISTICAL PROCESS CONTROL IN DUNGUN RIVER BASIN, TERENGGANU, MALAYSIA

(Pemantauan Kualiti Air Sungai Menggunakan Kawalan Proses Berstatistik di Lembangan Sungai Dungun, Terengganu, Malaysia)

TENGKU NURUL AIMI BALQIS TENGKU MALIM BUSU* & NOR AISHAH AHAD

ABSTRACT

Water pollution keeps rising due to the industrialisation and urbanisation in Malaysia. This matter needs to be given serious attention to avoid further contamination of the river water. Therefore, the quality of river water should be measured to avoid water pollution. This study was carried out to determine river water quality whether the water is safe for aquatic life or not at Dungun River Basin, Terengganu, based on the chemical parameters, which are the pH value and the Total Dissolved Solids (TDS). The water sampling was conducted at three separate sites along the river, and the distance between each station is approximately 2 km. Box plot, scatter plot, and control chart are being used in the analysis. The box plot results show that the water pH value and TDS level are normally distributed with no outliers. The scatter plot shows that the pH value and TDS level have a weak positive relationship with the correlation value of 0.4063. The control chart shows the pH value and TDS level are stable and within control. However, apart from the physical, chemical, and microbiological parameters, water quality must be accessed to ensure a high quality of drinking water. Based on the National Water Quality Standard (NWQS), the result shows that pH was classified as Class IV, while TDS was classified as Class IIA. Therefore, the river water required conventional treatment, but it still can be used for irrigation.

Keywords: river water quality; statistical process control; control chart

ABSTRAK

Pencemaran sungai terus meningkat disebabkan oleh perindustrian dan pembandaran di Malaysia. Perkara ini perlu diberi perhatian serius untuk mengelakkan berlakunya pencemaran air sungai. Oleh itu, kualiti air sungai harus diukur untuk mengelakkan pencemaran air. Kajian ini dilakukan untuk mengetahui kualiti air sungai sama ada airnya selamat untuk hidupan air atau tidak di Lembangan Sungai Dungun, Terengganu, berdasarkan parameter kimia, iaitu nilai pH dan jumlah pepejal terlarut (JPT). Pensampelan air dilakukan di tiga lokasi terpisah di sepanjang sungai dan jarak antara setiap stesen adalah sekitar 2 km. Plot kotak, plot serakan, dan carta kawalan digunakan dalam analisis. Hasil plot kotak menunjukkan bahawa nilai pH air dan tahap JPT adalah tertabur normal dengan tanpa data pencilan. Plot serakan menunjukkan nilai pH dan tahap JPT mempunyai hubungan positif yang lemah dengan nilai korelasi 0.4063. Carta kawalan menunjukkan nilai pH dan tahap JPT stabil dan terkawal. Namun, selain dari parameter fizikal, kimia, dan mikrobiologi, kualiti air mesti dicapai untuk memastikan air minuman berkualiti tinggi. Berdasarkan Piawaian Kualiti Air Kebangsaan (PKAK), hasil menunjukkan bahawa pH dikelaskan sebagai Kelas IV, sementara JPT dikelaskan sebagai Kelas IIA. Oleh itu, air sungai ini memerlukan rawatan konvensional tetapi masih dapat digunakan untuk pengairan.

Kata kunci: kualiti air sungai; kawalan proses berstatistik; carta kawalan

1. Introduction

In the 20th century, concerns about drinking water quality began because water is essential for humans' health and is used for various household activities such as drinking, bathing, cooking, and cleaning. Thus, a minimal supply of safe and clean drinking water is vital in sustaining life. Most of the human body is water which comprises up to 60% of the human adult body. According to Mitchell *et al.* (1945), 83% water from the lung, 73% water from the heart and brain, 79% water from muscles, 79% water from the kidney, 64% water from the skin, and 31% water get from bones.

Water that is consumed and used comes from two primary sources, which are groundwater and surface water. Groundwater is also called subsurface water below the land's surface, where it flows in and fills empty spaces in the rocks or soils. The rocks where groundwater is stored and distributed are called water reservoirs. Groundwater needs to be pumped to the surface of the Earth from a reservoir for use. The surface water is found in large areas, such as rivers, lakes, oceans, or that flows in streams overland. The quality of surface water influences the productivity and vitally of surrounding human societies in rivers (Sun *et al.* 2019). Water is possibly the most essential and valuable of Earth's natural resources, especially when it is suitable for human consumption and groundwater (Sancho *et al.* 2016).

Based on The United Nations World Water Development report in 2003, water-borne diseases are one of the common causes of illness and death, especially in poorly developed countries. Consumption of contaminated water might cause gastro-intestinal illness, including diarrhea. Besides that, malaria and schistosomiasis infected humans through the insects and snails that breed in aquatic ecosystems. Meanwhile, lack of hygienic water for washing and bathing could lead to scabies and trachoma diseases. As of 2000, the estimated mortality rate was 2,213,000 due to water-related diseases, with the majority of those affected are children under five.

Rivers and their catchments are part of natural heritage, which is very significant. Over the ages, rivers have been used by mankind to the point that few of them are still in their natural condition (Ngoye & Machiwa 2004). Rivers play a significant role in the economic, social, cultural, religious, domestic human consumption of water supply for drinking, irrigation for agriculture, transportation and infrastructure, hydroelectric power plants, and a livelihood to the people (Samsudin *et al.* 2017b).

The increment of the human population and the expansion of river and coastal industry caused the pollutant inputs to increase and reduce the river water quality (Suratman *et al.* 2015). As stated in the yearly report by the Department of Environment (DOE), two anthropogenic factors that lead to river pollution in Malaysia are urbanisation and land use development. As a result, there are changes in the hydrological regime and increment of soil erosion (Department of Environment 2008). Other than that, the degradation of river water quality is due to agricultural waste disposal, industrial byproducts, and untreated domestic sewage into the river systems (Suratman *et al.* 2009). Furthermore, due to a lack of water treatment throughout the basin and excessive anthropogenic activity along the river, river water quality has deteriorated dramatically in developing countries (Sun *et al.* 2019). In terms of water quality, anthropogenic impacts can have negative implications in a short period of time (Yunus & Nakagoshi 2004), whereas water body contamination is the outcome of human activities on the one hand, and heavy urbanisation development on the other (Leščešen *et al.* 2015).

In 2020, Malaysian was hit by the shocking news that occurred in the Selangor River. Dania (2020) has reported that the water pollution in the Selangor rivers occurred at least four times in 2020 and disrupted the water supply for over 1 million consumers each it occurred in the Klang Valley. The river in Selangor detects the raw water resources was contaminated. The latest news about water pollution in the Selangor river is after authorities detected odour pollution with a reading of about 8 TON (Threshold Odour Number) emanating. Selangor Water Management Authority said the pollution traced back to an Indah Water Konsortium facility in Rawang. The pollution was due to the illegal dumping of chemicals into its sewerage system.

Furthermore, river pollution also happened in Pasir Gudang, Johor. Anon (2019a) has reported that the water in Sungai Kim Kim was polluted by chemical waste illegally dumped by an irresponsible factory. Later, Benjamin and Nordin (2019) also reported that many schools had been directed to close due to the toxic fumes' incident in Pasir Gudang. There were 18 schools ordered to be closed due to chemical pollution in Pasir Gudang. This order was being carried out for the children's sake since students experienced dizziness, nausea, and vomiting. At least 15 types of chemicals, including hydrogen cyanide, were identified from areas surrounding Sungai Kim Kim by The Fire and Rescue Department of Malaysia (Anon 2019b). Hydrogen cyanide (HCN), also known as prussic acid, is a type of chemical compound. This chemical could be in the form of gas or liquid, which is colourless, highly poisonous and flammable, besides having an odour of bitter almonds. There is a possibility that the manufacturers of nylons, plastics, and fumigants use hydrogen cyanide in their factory.

There were many cases of water pollution being reported in the past that was also caused by the factory or manufacturing industry. It was reported by Azizi (2018) that the water in Simin River turned blue due to the plastic recycling activities run by the factory at Taman Tuanku Ja'afar Industrial Park in Senawang. Moreover, Bernama (2016) reported that the river water pollution in Sungai Semenyih in the Nilai industrial area was due to the irresponsible activity.

Different contamination sources were identified in the Dungun River including fishing activities, urban and industrial activities, and small-scale agriculture (Hwi *et al.* 2020). Dungun River Basin is situated in Dungun District, Terengganu, Malaysia. The river is the longest in Dungun and facing the South China Sea on the east coast of Peninsular Malaysia. Dungun River is approximately 75 km long. Before discharging into the South China Sea, the watershed receives drainage from its main tributaries, such as the Lok River, Loh River, Perlis River, and Telembuh River (Tahir *et al.* 2008). Based on the data from Jabatan Pengairan Dan Saliran (JPS) Dungun District, the Dungun River are divided into five sub-basins which is Pimpin River, Sura River, Gombang River, Abang River, and Jengai River, with a total catchment area of about 1430km^2 and the land use within the catchment, is predominantly rural and agricultural activities (Tahir *et al.* 2008). This river basin is important because it provides the surrounding areas with wastewater dilution, water supply, aquaculture, and water for irrigation.

The quality of surface and groundwater is identified in terms of its physical, chemical, and biological parameters (Fawaz *et al.* 2013). In fact, several water quality parameters can be used to monitor and assess the water quality of the river system, such as pH, total dissolved solids (TDS), temperature, dissolved oxygen (DO), biological oxygen demand (BOD), total suspended solids (TSS), total phosphorus, ammonia, chemical oxygen demand (COD), total nitrate, cyanide, mercury, and total coliform (Suratman *et al.* 2009). However, this research will only focus on the chemical parameter by testing the pH value and the dissolved substance using a TDS meter.

The total dissolved solids (TDS) meter measured the whole of dissolved solids in water. TDS is useful for the water treatment process in the drinking water that mainly originates from chemicals, raw material, sewage, manufacturing waste, and urban run-off.

The pH value is the best predictor for soft or hard water. As stated in the Cuyahoga River Water Quality Monitoring Program (1991), the optimum pH for river water is around 7.4. A low pH is highly harmful to immature fish and insects, while the extreme pH levels can render a river unlivable to life. The pH also determines whether aquatic life can use it. In heavy metals, their toxicity is measured by the degree to which they are soluble. If the aquatic life is more soluble, the metal will be more toxic at a lower pH value (Michaud 1991).

Finally, the quality of the water can be improved by reducing undesirable variability. The statistical method is the best method to improve water quality because the variability can be expressed in statistical terms only. Statistical Process Control (SPC) helps set the standard, measure, monitor, and correct the quality problem. The SPC also eliminate the variability in the process. It may not eliminate all the variability, but a control chart is an effective tool in reducing variability as much as possible. Therefore, the primary purpose of this research is to determine the water quality in Dungun River Basin, Terengganu, and plot the control chart for water quality. Thus, the needed measures will be taken accordingly to determine water quality from Dungun River Basin, Terengganu, Malaysia.

The next part of this paper discusses the overview of the river water, water quality, relationship between pH and TDS and analysis using statistical process control. Section three discuss the methodology that involved data collection and statistical process control. Data analysis and the result are presented in section four, and finally, the conclusion is conferred in the last section.

2. Overview

2.1. *River water*

Quality of river water and the prevention of contamination must be tackled urgently, as 98 percent of the total water usage comes from rivers. 70 percent of the countries' water supplies are for the agriculture industry (Huang *et al.* 2015). Concentrations of the river's pollutants increase since more acts of river water pollution are done by human beings. As a result of new contaminants, less good quality water can be used, and water treatments' high costs lead to water 'quantity scarcity'. Water scarcity is when there is a reduction of freshwater resources due to pollution, lack of rainfall, or droughts to meet the standard water demand (Liu *et al.* 2017; Mekonnen & Hoekstra 2016). Besides, marine life, biodiversity, and recreational activities are greatly affected by the degradation of the water's environmental health and the surrounding environment.

In Malaysia, while the industrialisation process led to economic growth, there are risks and costs of environmental pollutions. Many cases reported that factories or industries disposed of toxic and hazardous waste into the marine ecosystem, leading to water pollution (Samsudin et al., 2017b). Due to untreated sewage disposal and industrial waste disposal directly into the rivers, aquatic systems worldwide are heavily contaminated. There are many kinds of contaminants, including solvents, greases, oils, plastics, plasticisers, pesticides, heavy metals, phenols, and suspended solids, both organic and inorganic. Run-off from stormwater, atmospheric deposition, seepage of groundwater, and discharge from ditches and creeks are the typical pathways on how the contaminants enter river water (Patel & Parikh 2013).

2.2. *Water quality*

There are several ways to describe quality. By definition, the quality is 'inversely proportional to variability' (Smeti *et al.* 2007). This description means that the product quality will increase if the variability in the important criteria of a product decreases (Montgomery 2009). Since water is essential to our nutrition, water quality is a major problem for both human health and the environment (Iglesias *et al.* 2015). In Malaysia, to assess the status and quality of the river water, the Water Quality Index (WQI) and National Water Quality Standards for Malaysia (NWQS) are used by the DOE. For around 25 years, the usage of WQI implemented by DOE in Malaysia works as the basis for environmental water quality assessment. NWQS classifies the beneficial uses of the WQI-based watercourse (Huang *et al.* 2015).

Fishing activities, small-scale agriculture, urban and industrial activities are the sources of pollution in Sungai Dungun. Few studies have been carried out, which showed the contamination and degradation of Dungun River water quality. Various types of pollution, such as plastic, metal, and phosphate-based pollution, are being investigated and explained based on previous studies.

Tahir *et al.* (2008) monitored and analysed the distribution of physical parameters of phosphate-based nutrients, total suspended solids (TSS), and chlorophyll-a in the Dungun River estuary. As a result, it was found that there is variance in the concentrations of orthophosphate and total phosphate with values ranging from 6.3-23.3 µg/l P and 5.5-133.9 µg/l P, respectively. The findings also found that TSS and chlorophyll-a give effects on the distribution of phosphate-based nutrients. In addition, the distribution of phosphate nutrients might be influenced by physical and anthropogenic factors, as indicated by the high phosphate concentrations in the mid-estuary area.

In the latest study, analysis regarding microplastics (MPs) abundance, distribution, and composition in Dungun River was carried out (Hwi *et al.* 2020). From the water collected from 5 sampling sites along Dungun River, gravimetric and digital image processing and chemical composition detected by attenuated total reflectance Fourier infrared were used to classify MPs. In all sampling sites, MPs were identified with the range of concentration within 22.8 to 300.8 items/m3. Almost all of the MPs identified were black and transparent. Fibres accompanied by fragments were the most common morphotypes. The main polymer types of MPs discovered were polypropylene (C3H6), polyacrylonitrile (C3H3N), and semi-synthetic fibre known as rayon. Besides that, seven different metal content types were identified, either inherited or absorbed by the MPs.

2.3. *Relationship between pH and Total Dissolved Solids (TDS)*

There is a relationship between water pH value and total dissolved solids (TDS) level as well. Hence it is believed that pH paper and TDS metre tends to reveal the potential water quality of Dungun River Basin. The correlation between pH value and TDS count can tell that the water quality is good or not.

Furthermore, according to the study in Bangladesh by Rubiat *et al.* (2017), TDS correlates positively with conductivity and pH is affected. In this context, the higher TDS level leads to higher conductivity and lower pH towards acidity. According to WHO, TDS is often used to describe the small quantities of organic matter and organic salts that exist in solution. Magnesium, calcium, sodium, and potassium are the primary constituents. Early studies revealed an inverse relationship between the occurrence of certain chronic diseases, such as cancer, cardiovascular disease, coronary heart disease, and TDS concentrations in drinking water (Burton & Cornhill 1977).

2.4. *Analysis using statistical process control*

Statistical process control (SPC) makes uses of statistical techniques to improve a process's quality. SPC is a useful method for detecting problems, reduce variability to improve the capacity and showing process stability (Conceição *et al.* 2018). The variable is divided into two types which are special cause and common cause. The special cause (also known as the assignable cause) can be recognised and removed because the special cause is not an intrinsic process characteristic. Examples of special causes are errors in calculations, tool wear, operator error, resetting of machines, and errors in measurements. The presence of special causes of variation indicates that the process is out-of-control. If there are no special causes of variability in the process, a process is said to be in-control. While the common causes variability (also known as chance causes) is the natural variability that cannot be avoided and occurs in any process. For example, changes in temperature, humidity fluctuations, electrical fluctuations, natural resource variations, and deterioration of equipment performance. The natural variability is the cumulative effect of unavoidable chance causes of variation (Smeti *et al.* 2007).

3. Methodology

3.1. *Data collection*

This study is exploratory in nature. This exploratory study is used for a more specific investigation to formulating a problem and is versatile enough to give a chance to consider all parts of the issues. It focuses on exploring thoughts and ideas. The main source of data for this study is the primary data.

3.1.1. Research area

Water sampling was carried out at three separate sites along the Dungun River Basin, Terengganu, Malaysia. The water sampling sites where the distance between each station was 2km approximately were shown in Figure 1. Moreover, to determine the sampling site's location, a Global Positioning System (GPS) was used. Table 1 shows the longitude (*N*) and Latitude (*E*) for the three sampling sites.

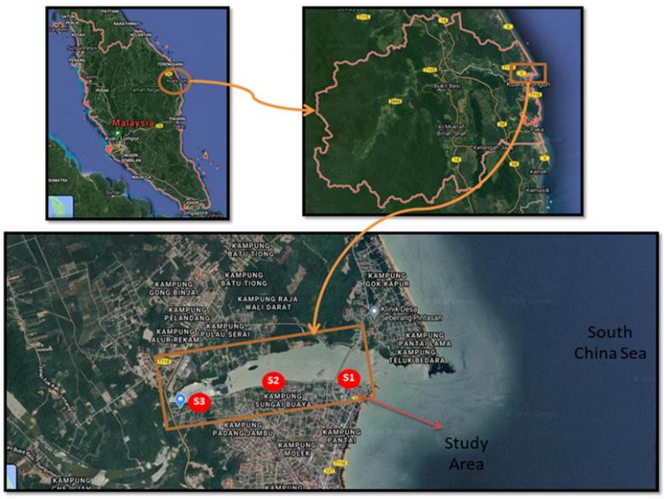

Figure 1: Sampling sites location along Dungun River Basin are labelled with red circles

Table 1: List of the three sampling sites in Dungun River Basin

Station	Longitude (*N*)	Latitude (*E*)
S1	4°46′45.3″	103°25′32.7″
S2	4°46′43.7″	103°24′30.3″
S3	4°46′37.8″	103°24′01.0″

3.1.2. Method of data collection

Data collected must be relevant and representative to make an appropriate generalisation regarding the issue faced. For this study, self-investigation by taking samples was chosen as the method of data collection. 300 ml of water sample was taken from each of the selected river water using a clean glass cup in an hourly interval, 12 hours of the interval between each other. The water sample was collected every day, between 7 am and 7 pm, continuously for two weeks. The data collected are in term of time series data, whereby there is 28 number of subgroups (m=28) with each sample size of 3 (n=3). Instead of using attribute data, this research only focuses on the variable data because the water quality in the river is easier to be measured using variable data. Other than that, this research's variables are water pH value and Total Dissolved Solids (TDS) level.

3.1.3. Water quality parameter

3.1.3.1. pH

Patel and Parikh (2013) mentioned that most aquatic species are being affected because their metabolic activities are pH dependent. The optimal pH range for sustainable aquatic life is pH 6.5-8.2. Aquatic species can also be affected by the water pH because nutritive chemicals' solubility is toxic (Ali 2010). The significant measure to test the contamination level in the watershed areas and the aquatic system's water quality is by testing the pH value (Kumar *et al*. 2018). According to World Health Organization (WHO), even though it is hard to define the optimum value of water pH value as it can be affected by the construction materials used in the supply system and water structure, the standard range for water pH is between 6.5 until 9.5. Wilkes University's study pointed out that pH value is not a measure of the strength of an acidic or simple solution and cannot limit the water supply. However, the WHO's report revealed that pH value is one of the most critical water-quality operational parameters. At the same time, attention should be paid to pH control at every water supply stage to ensure adequate water disinfection and clarification. To be more specific, the standard pH value of river water from the NWQS for Malaysia is illustrated in Table 2, and the explanation for each class is shown in Table 3.

3.1.3.2. Total Dissolved Solid (TDS)

TDS metre measured all concentrations of the dissolved substance in water. In water, total dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, phosphates, and nitrates of calcium, magnesium, sodium, potassium and manganese, organic matter, salt, and other particles (Mahananda *et al*. 2010). At high flows, the TDS level tends to be diluted by surface run-off, and for most rivers, there are inverse correlations between discharge rate and TDS (Charkhabi & Sakizadeh 2006). Besides, the water is typically measured in units of the mass of chemical (milligrams, mg or micrograms, ug) per volume of water (litre, L, l) to measure the chemical concentration in water (Boguski 2006). Since the TDS metre measures TDS level in the measurement unit of ppm (parts per million), which is measured in 1000ml of water, thus the ppm value obtained is converted to mg/l (milligrams per litre). The value of 1 ppm is equal to 1 mg/l approximately. As to interpret the mg/l value, by referring to the NWQS for Malaysia, TDS level classification and the classification explanations are illustrated in Table 2 and Table 3, respectively.

Table 2: National Water Quality Standard (NWQS) for Malaysia

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Total Dissolved Solid (TDS)	mg/l	500	1000	-	-	4000	-
pH	-	6.5-8.5	6.0-9.0	6.0-9.0	5.0-9.0	5.0-9.0	-

Table 3: Water Classes and Uses

CLASS	USES
Class I	Conservation of the natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Susceptible aquatic species.
Class IIA	Water Supply II - Conventional treatment required. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use with body contact.
Class III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above

3.2. *Statistical process control*

Statistical process control (SPC) is an effective problem-solving technique that is useful to improve the capability and stability in the process by reducing variability. SPC may not eliminate the variability entirely, but the control chart is the best method for reducing variability as much as possible. The control chart also can illustrate the quality level of the specified variables in real time as time passes (Saudi *et al.* 2018).

A control chart (also known as Shewhart chart) is a graphical way of presenting data over time. It plots the value of the quality characteristic along the vertical axis, and the horizontal axis represents the sample, or subgroups, from which the quality characteristics are found. There are three horizontal lines in the control chart. The process's variation is represented by the upper and the lower control limits, whereas the other horizontal line is the centreline that indicates the process average.

The control chart is divided into two types: control chart for variable and control chart for the attribute. Control charts for variables can be used when the quality characteristics are quantitative (or can be counted). It usually is important to track both the mean value of their variability and quality characteristics. The variability provides an idea of the process dispersion, while the mean indicates the central tendency of a process. Next, the control chart for attributes can be used when the quality characteristics are not quantitative (or can't be counted). Typically, it will be classified as defective (nonconforming units) or non-defective (conforming units). It measures the defects in a sample and counts the number of defects per item.

Therefore, instead of using a control chart for attribute, the researcher prefers to use the control chart for variable because this chart typically leads to more efficient control procedures and offers more process output information than the control chart for attribute.

3.2.1. Control chart for variable

To keep a process in control, a change in the process mean and standard deviation are needed. The proportion of parts that do not meet specifications will be changed. Therefore, the variable control chart is divided into three types: $\bar{x}$ chart, *R* chart and *S* chart.

Mainly, $\bar{x}$ and *R* charts are a mixture of control charts used to monitor the process average as the mean and variability as the range when measuring small subgroup size ($n \leq 10$) at regular intervals from a process. The $\bar{x}$ and *R* charts are coupled together in SPC as an example of control charts with a subgroup of two or more. The stability and predictability of the process will be determined by both charts (Samsudin *et al.* 2017a). To construct a mean chart and range chart, the process average, $\bar{\bar{x}}$ and the average range, $\bar{R}$ need to be constructed first. The $\bar{\bar{x}}$ and $\bar{R}$ can be computed in Eq. (1) and Eq. (2), respectively (Samsudin *et al.* 2017b).

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots + \bar{x}_m}{m} \tag{1}$$

where $\bar{\bar{x}}$ = process average
m = number of subgroups
$\bar{x}$ = mean of the sample in each subgroup

$$\bar{R} = \frac{R_1 + R_2 + \cdots + R_m}{m} \tag{2}$$

where $\bar{R}$ = average range
m = number of subgroups
R = range of the sample in each subgroup

The control chart is only accountable when the upper control limit, the central line, and the lower control limit have been defined, facilitating determining whether the process is stable or not (Besterfield 2009). In general, the formulae to construct the control limits on the $\bar{x}$ chart are defined in Eq. (3) (Montgomery 2009).

$$\begin{aligned} &\text{Upper Control Limit (UCL)} = \bar{\bar{x}} + A_2\bar{R} \\ &\text{Centreline (CL)} = \bar{\bar{x}} \\ &\text{Lower Control Limit (LCL)} = \bar{\bar{x}} - A_2\bar{R} \end{aligned} \tag{3}$$

where $\bar{\bar{x}}$ = process average
$\bar{R}$ = average range
A_2 = factor obtained from the table (see Appendix)

Nevertheless, the range method is often used in constructing the control limit chart where the process variability is controlled by plotting the sample range *R* values on a control chart. The centreline, upper control limit, and lower control limit for the *R* chart can be computed as follows in Eq. (4) (Montgomery 2009).

$$\begin{aligned}&\text{Upper Control Limit (UCL)} = D_4\overline{R}\\&\text{Centre line (CL)} = \overline{R}\\&\text{Lower Control Limit (LCL)} = D_3\overline{R}\end{aligned} \tag{4}$$

where $\overline{R}$ = average range
D_4 = factor obtained from the table (see Appendix)
D_3 = factor obtained from the table (see Appendix)

The application of $\overline{x}$ and *R* charts consists of 3 phases: control limits, revise control limits and the new control limits (generally tighter than the first control limits). The central line is proven for $\overline{x}$ and *R* charts by using Eq. (5) and Eq. (6).

$$\overline{\overline{x}} = \frac{\sum_{u}^{s} 1\overline{x}k}{s} \tag{5}$$

$$R = \frac{\sum_{u}^{s} 1\overline{R}k}{s} \tag{6}$$

where $\overline{\overline{x}}$ = average of the subgroup average
$\overline{x}k$ = average of the kth subgroup
$\overline{R}$ = average of the subgroup range
$\overline{R}k$ = average of the kth subgroup

The chart in control limits is constructed on ±3σ (standard deviations) from the central value. This is illustrated based on the following Eq. (7) and Eq. (8) (Montgomery 2009).

$$\begin{aligned}UCL_{\overline{\overline{x}}} &= \overline{\overline{x}} + 3\overline{\overline{x}}\\LCL_{\overline{\overline{x}}} &= \overline{\overline{x}} - 3\overline{\overline{x}}\end{aligned} \tag{7}$$

$$\begin{aligned}UCL_{\overline{R}} &= \overline{R} + 3\overline{R}\\LCL_{\overline{R}} &= \overline{R} - 3\overline{R}\end{aligned} \tag{8}$$

where $\overline{\overline{x}}$ = average of the subgroup average
$\overline{x}k$ = average of the k^{th} subgroup

According to Besterfield (2009), in SPC, the most critical phase is the formation of the revised control limits and central line. The standard values for the central lines are modified to unleash the best approximation for the available data. When the analysis indicates 'good controls' on the preliminary data, $\bar{\bar{x}}$ and $\bar{R}$ are being considered as descriptive of the process and placed as the standard values for $\bar{x}_0$ and R_0 once (Besterfield 2009; Montgomery 2009). If it did not have out-of-control points on both sides of the central line are shown, and the variation did not have the uncommon pattern, the control limit is classified in a better control process. At this stage, only the out-of-control points are evaluated for the process stability determination (Montgomery 2009; Besterfield 2009). In the process, the points of out-of-control can be discarded if there is an assignable cause. The out-of-control is most caused by the chance that may arise as a part of natural variation. Therefore, the data in the system may remain.

As specified by Montgomery (2009), when the data is discarded, for the 3rd phase, the new $\bar{\bar{x}}$ and $\bar{R}$ is calculated by using the formulae in Eq. (9) and Eq. (10).

$$\bar{\bar{x}}_{new} = \frac{\sum \bar{x} - \bar{x}b}{s - sb} \tag{9}$$

$$\bar{R}_{new} = \frac{\sum \bar{x} - \bar{R}b}{s - sb} \tag{10}$$

where $\bar{x}b$ = discarded subgroup average
sb = number of discarded subgroups
Rb = discarded subgroup range

4. Data Analysis and Result

The water pH and TDS levels data collected for two weeks started from the 22nd November until the 5th December. The collected data for water pH and TDS levels from each station sample are shown in Table 4 and Table 5.

From Table 4, the pH value of water samples was found to vary between 6 and 9, which indicates that the water was mostly neutral or basic (in the context of water, pH value greater than 7 considered as a base while less than 7 considered as acidic) (Rubiat *et al.* 2017). At each sample, the range of pH values is not more than 3. As stated in Table 2 and Table 3, if the pH values are within 6.0 to 9.0, the NWQS for Malaysia classes the water as Class IIA. It indicates that conventional treatment requires to treats Class II water sources efficiently and the condition of the water is suitable for the sensitive to aquatic species.

The TDS level of water samples obtained from the TDS metre is illustrated in Table 5. Since the NWQS uses the standard unit in mg/l (milligram per litre), the value obtained is converted as the water sample measures TDS level in the measurement unit of ppm (parts per million). The results show that the TDS levels have a considerable difference between station 1 (S1) with station 2 (S2) and station 3 (S3), where the value at S1 mostly exceed 1000mg/l while the value at S2 and S3 are less than 500mg/l. As stated in Table 2 and Table 3, the result for all TDS levels values except for subgroup 7 and 8 at S1 can be classified as Class IIA because the TDS levels exceed 1000mg/l. It indicates that conventional treatment requires to treats Class II water sources efficiently and the condition of the water is suitable for the sensitive to aquatic species. The result for TDS levels at subgroup 7 and 8 in S1, S2 and S3, can be classified as Class I because the TDS levels are less than 1000mg/l. It indicates that the water is used for the conservation of the natural environment, practically no treatment is necessary to treat the water sources. This type of water is suitable for the most sensitive aquatic species. According to Zaki (2010), the Interim National Water Quality Standard (INWQS) for Class I until Class III of the INWQS defines the level of water quality needed to support macro aquatic life, with varying degrees of sensitivity.

Table 4: pH value from each station

Subgroup	Date (Day)	Time	S1	S2	S3	Average	Range
1	22.11.2020	7 am	8.6	8.0	8.0	8.2	0.6
2	(Sunday)	7 pm	9.0	6.0	6.0	7.0	3.0
3	23.11.2020	7 am	8.6	8.0	8.0	8.2	0.6
4	(Monday)	7 pm	9.0	7.6	7.0	7.9	2.0
5	24.11.2020	7 am	8.6	7.0	6.6	7.4	2.0
6	(Tuesday)	7 pm	8.6	7.0	7.0	7.5	1.6
7	25.11.2020	7 am	8.0	7.0	6.6	7.2	1.4
8	(Wednesday)	7 pm	8.6	7.0	7.6	7.7	1.6
9	26.11.2020	7 am	9.0	6.6	7.0	7.5	2.4
10	(Thursday)	7 pm	8.6	7.0	7.6	7.7	1.6
11	27.11.2020	7 am	8.6	7.0	7.6	7.7	1.6
12	(Friday)	7 pm	9.0	7.0	7.0	7.7	2.0
13	28.11.2020	7 am	8.6	7.0	6.6	7.4	2.0
14	(Saturday)	7 pm	9.0	7.0	6.6	7.5	2.4
15	29.11.2020	7 am	9.0	7.0	6.6	7.5	2.4
16	(Sunday)	7 pm	9.0	7.0	7.0	7. 7	2.0
17	30.11.2020	7 am	9.0	6.6	7.0	7.5	2.4
18	(Monday)	7 pm	8.6	7.0	6.6	7.4	2.0
19	1.12.2020	7 am	8.0	6.6	7.0	7.2	1.4
20	(Tuesday)	7 pm	8.6	7.0	6.6	7.4	2.0
21	2.12.2020	7 am	8.0	7.0	7.0	7.3	1.0
22	(Wednesday)	7 pm	9.0	6.6	7.0	7.5	2.4
23	3.12.2020	7 am	9.0	6.6	7.0	7.5	2.4
24	(Thursday)	7 pm	9.0	7.0	7.6	7.9	2.0
25	4.12.2020	7 am	9.0	7.0	6.6	7.5	2.4
26	(Friday)	7 pm	8.0	7.0	6.6	7.2	1.4
27	5.12.2020	7 am	8.0	7.0	6.6	7.2	1.4
28	(Saturday)	7 pm	8.6	6.6	6.6	7.3	2.0

Table 5: TDS levels from each station

Subgroup	Date (Day)	Time	S1	S2	S3	Average	Range
1	22.11.2020	7 am	2500	439	407	1115.3	2093
2	(Sunday)	7 pm	3200	298	115	1204.3	3085
3	23.11.2020	7 am	2430	495	418	1114.3	2012
4	(Monday)	7 pm	3130	121	61	1104.0	3069
5	24.11.2020	7 am	1220	75	147	480.7	1145
6	(Tuesday)	7 pm	2320	52	47	806.33	2273
7	25.11.2020	7 am	407	33	61	167.0	374
8	(Wednesday)	7 pm	959	51	142	384.0	908
9	26.11.2020	7 am	1530	43	62	545.0	1487
10	(Thursday)	7 pm	1350	62	51	487.7	1299
11	27.11.2020	7 am	1030	75	131	412.0	955
12	(Friday)	7 pm	1700	73	60	611.0	1640
13	28.11.2020	7 am	1400	79	124	534.3	1321
14	(Saturday)	7 pm	2010	73	120	734.3	1937
15	29.11.2020	7 am	1950	80	130	720.0	1870
16	(Sunday)	7 pm	1700	76	126	634.0	1624
17	30.11.2020	7 am	2210	65	90	788.3	2145
18	(Monday)	7 pm	1600	77	80	585.7	1523
19	1.12.2020	7 am	1200	94	89	461.0	1111
20	(Tuesday)	7 pm	1440	67	54	520.3	1386

continued…

...continuation

21	2.12.2020	7 am	1200	78	74	450.7	1126
22	(Wednesday)	7 pm	1850	67	56	657.7	1794
23	3.12.2020	7 am	1700	70	91	620.3	1630
24	(Thursday)	7 pm	2150	80	120	783.3	2070
25	4.12.2020	7 am	1800	74	93	655.7	1726
26	(Friday)	7 pm	1270	60	81	470.3	1210
27	5.12.2020	7 am	1610	54	74	579.3	1556
28	(Saturday)	7 pm	2150	72	69	763.7	2081

4.1. *Water quality parameter*

Based on the data collected, one of the descriptive statistics, which is the box plot, can be applied to determine the data distribution, such as whether the data are normally distributed or skewed to any side. Hence, the Box plots constructed for water pH values and TDS levels are shown in Figure 2 and Figure 3.

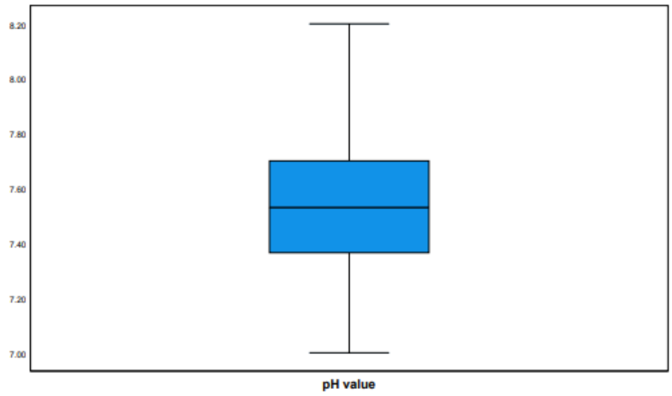

Figure 2: Box plot of water pH values

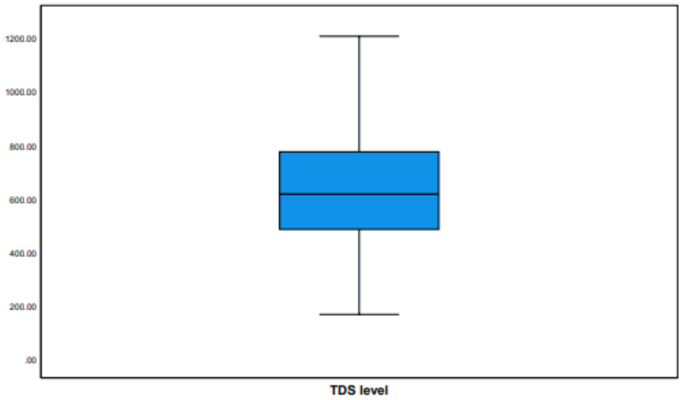

Figure 3: Box plot for TDS levels

From both box plots constructed, it can be said that the data for water pH value and TDS level are normally distributed, with no outliers found. To further investigate the relationship between water pH value and TDS level, a scatter plot as one of the quality tools is applied. A scatter diagram between water pH and TDS level is illustrated in Figure 4.

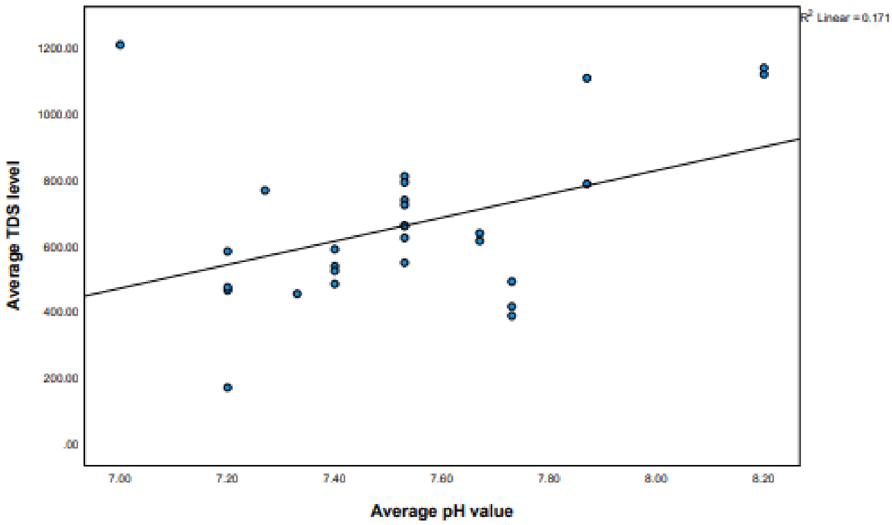

Figure 4: Scatter plot between water pH and TDS level

The scatter plot is constructed by taking the averages of water pH values and TDS levels of each sample. From the scatter plot, there is a positive correlation between water pH and TDS level. The correlation value of 0.4063 indicates that there is a weak positive relationship between water pH and TDS level as well. As such, as the water pH increases, the TDS level tends to increase as well. However, according to the study conducted in Bangladesh by Rubiat *et al.* (2017), TDS correlates positively with conductivity and pH is affected. In this context, the higher TDS level led to higher conductivity and lower pH towards acidity. The difference in the findings between this research and the others might be due to the different locations where the water samples are taken. It is, however, important to consistently monitor the water pH and TDS level; these variables tend to show significant changes when harmful substances are present in the water due to some reasons such as pollution. In fact, pH value and TDS level always act as an early warning sign of contaminated water resources so that immediate actions can be taken.

4.2. *Control chart for variable*

After analysing the collected data, the river water's baseline capability in Dungun River Basin should be established. As such, a quality tool is further applied as to improve the stability and quality of river water. One of the most significant quality tools is the control chart, which is applied to determine the water's process stability (Schikora 2017). In this case, water pH and TDS level are the main variables of interest in this research. Thus, the variable control chart; $\bar{x}$ chart and R chart, are adopted. The $\bar{x}$ chart and R chart for water pH is illustrated in Figure 5.

Based on the $\bar{x}$ chart and R chart for the water pH of collected water samples, the centreline, lower control limit, and upper control limit for the $\bar{x}$ chart are 7.5, 5.6335, 9.4332, respectively. The pH values in river water were found to be varied from 5.6335 to 9.4332. For the R chart, the centreline, lower control limit, and upper control limit are 1.9, 1.6499, and 4.7803, respectively. According to Montgomery (2009), the $\bar{x}$ chart should never be interpreted when the R chart is out-of-control as the calculation of control limits of $\bar{x}$ chart is relies on the $\bar{R}$ value. Hence, as to attempt the R chart of water pH, there are no out-of-control points, and hence it is considered as under controlled. In addition, moving to the $\bar{x}$ chart, there is no out-of-control point too. There is no special causes variability in the process; thereby, a process is said to be in-control.

Based on the control charts contrasted for TDS Level, Figure 6 shows that the centre line, lower control limit and upper limit for the $\bar{x}$ chart are 656.8, -1040.3, 2353.9, respectively. From the centre line, on average, the TDS value of the river water at Dungun River Basin is around 656.8. As to ensure that the river water is in control for the chemical dimension of water quality, the TDS value must not be beyond 2353.9 or below -1040.3. For the R chart, shows that the centreline, lower control limit and upper control limit are 1658.9, 0 and 4270.1, respectively. As such, the average range of TDS value is 1658.9, while the range of TDS level for each station at Dungun River Basin must not go beyond 4270.1 from time to time. From both the $\bar{x}$ chart and R chart, it can be observed that there is no point fall beyond the control limits. Hence, in the context of the TDS level, the river water is said to be in-control. By referring to the standard set by NWQS, the TDS level range is still in the situation where the water required the conventional treatment and if the TDS level near the upper control limit, the water can still be used for irrigation.

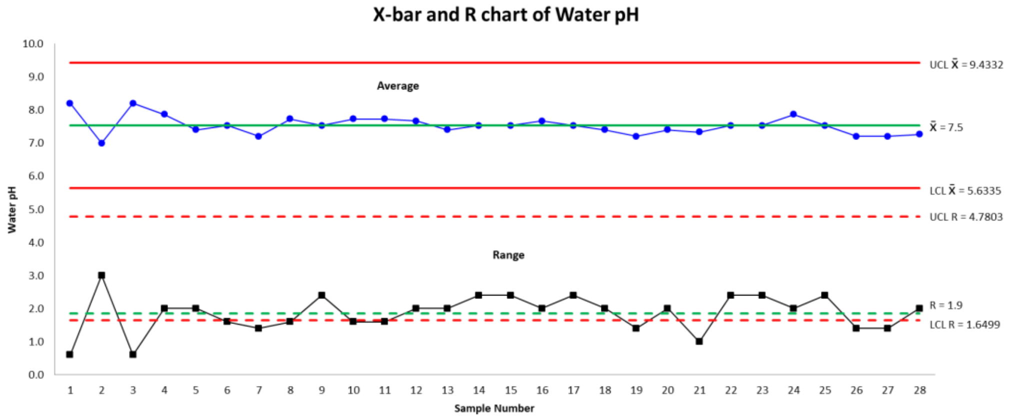

Figure 5: $\bar{X}$ and R chart of water pH values for the collected water sample

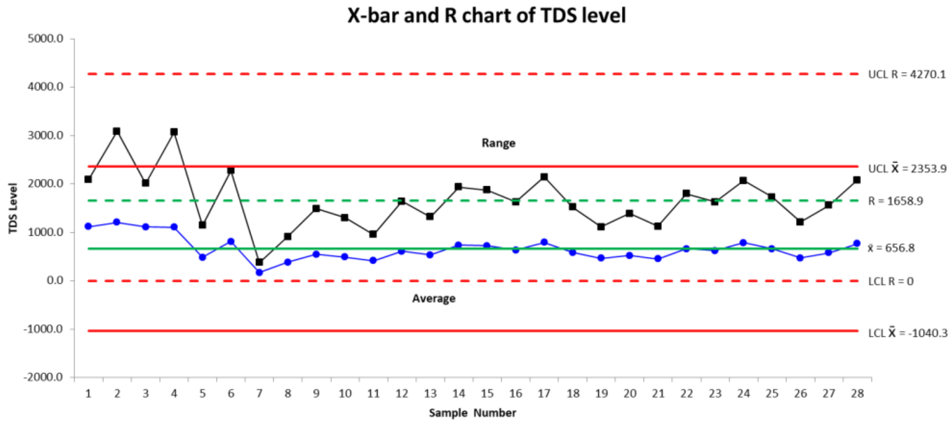

Figure 6: $\bar{X}$ and R chart for TDS levels of collected water samples

5. Conclusion

To fulfil the objective of measuring the water quality parameters, box plots and scatter plots were constructed to determine the distribution of the data. From both box plots that have been constructed, the data for water pH value and TDS level are normally distributed, with no outliers found. Next, the scatter plots are also being constructed to achieve the first objective. The finding shows a positive correlation between parameter, which is water pH value and TDS level. Furthermore, the correlation value of 0.4063 indicates that there is a weak positive relationship between water pH and TDS level as well. In such a way, the TDS level often continues to increase as the water pH increases.

The control chart was constructed to reduce variability as much as possible. In this analysis, $\overline{x}$ and *R* charts were used to monitor the process average as the mean and variability as the range because the sample size, *n* less than 10, where *n* equal to 3. From the $\overline{x}$ chart analysis for water pH, the pH values in the river water were found to be varied from 5.6335 to 9.4332. The average pH value is 7.5, which indicate the pH is neutral. Moreover, in the *R* chart analysis for water pH, the water pH range is 1.6499 to 4.7803. Besides, there are no special causes of variability in the process for both charts; thus, a process is said to be in-control. Next, in the $\overline{x}$ chart analysis for TDS level, on average, the TDS value of the river water at Dungun River Basin is around 656.8. The TDS value must not go beyond 2353.9 or below -1040.3 to ensure that the river water is in control of the physical dimension of water quality. From the *R* chart analysis for TDS level, the average TDS level range is 1658.9, while the range of TDS level for each station at Dungun River Basin must not go beyond 4270.1 from time to time. From both the $\overline{x}$ chart and *R* chart, it can be observed that there is no point fall beyond the control limits and the TDS level in river water is said to be in-control. The TDS level range is still in the situation where the water requires conventional treatment, and if the TDS level is close to the upper control limit, the water can still be used for irrigation. Lastly, in the case of Dungun River Basin, Terengganu, Malaysia, although the river water is found to be stable in the context of water pH and TDS level, the chemical dimension and microbiological dimensions of river water quality remain questionable.

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School of Quantitative Sciences
College of Arts and Sciences
Universiti Utara Malaysia
06010 Sintok
Kedah DA, MALAYSIA
E-mail: tengkuaimi98@gmail.com, aishah@uum.edu.my*

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*Corresponding author

Appendix. Table of Control Chart Constants (Joglekar A.M. 2003)

				$\bar{X}$ and R Charts			$\bar{X}$ and S Charts		
n	d_2	d_3	C_4	A_2	D_3	D_4	A_3	B_3	B_4
2	1.128	0.8525	0.7979	1.880	—	3.267	2.659	—	3.267
3	1.693	0.8884	0.8862	1.023	—	2.574	1.954	—	2.568
4	2.059	0.8798	0.9213	0.729	—	2.282	1.628	—	2.266
5	2.326	0.8798	0.9400	0.577	—	2.114	1.427	—	2.089
6	2.534	0.8480	0.9515	0.483	—	2.004	1.287	0.030	1.970
7	2.704	0.8332	0.9594	0.419	0.076	1.924	1.182	0.118	1.882
8	2.847	0.8198	0.9650	0.373	0.136	1.864	1.099	0.185	1.815
9	2.970	0.8078	0.9693	0.337	0.184	1.816	1.032	0.239	1.761
10	3.078	0.7971	0.9727	0.308	0.223	1.777	0.975	0.284	1.716
11	3.173	0.7873	0.9754	0.285	0.256	1.744	0.927	0.321	1.679
12	3.258	0.7785	0.9776	0.266	0.283	1.717	0.886	0.354	1.646
13	3.336	0.7704	0.9794	0.249	0.307	1.693	0.850	0.382	1.618
14	3.407	0.7630	0.9810	0.235	0.328	1.672	0.817	0.406	1.594
15	3.472	0.7562	0.9823	0.223	0.347	1.653	0.789	0.428	1.572
16	3.532	0.7499	0.9835	0.212	0.363	1.637	0.763	0.448	1.552
17	3.588	0.7441	0.9845	0.203	0.378	1.662	0.739	0.466	1.534
18	3.640	0.7386	0.9854	0.194	0.391	1.607	0.718	0.482	1.518
19	3.689	0.7335	0.9862	0.187	0.403	1.597	0.698	0.497	1.503
20	3.735	0.7287	0.9869	0.180	0.415	1.585	0.680	0.510	1.490
21	3.778	0.7272	0.9876	0.173	0.425	1.575	0.663	0.523	1.477
22	3.819	0.7199	0.9882	0.167	0.434	1.566	0.647	0.534	1.466
23	3.858	0.1759	0.9887	0.162	0.443	1.557	0.633	0.545	1.455
24	3.895	0.7121	0.9892	0.157	0.451	1.548	0.619	0.555	1.445
25	3.931	0.7084	0.9896	0.153	0.459	1.541	0.606	0.565	1.435