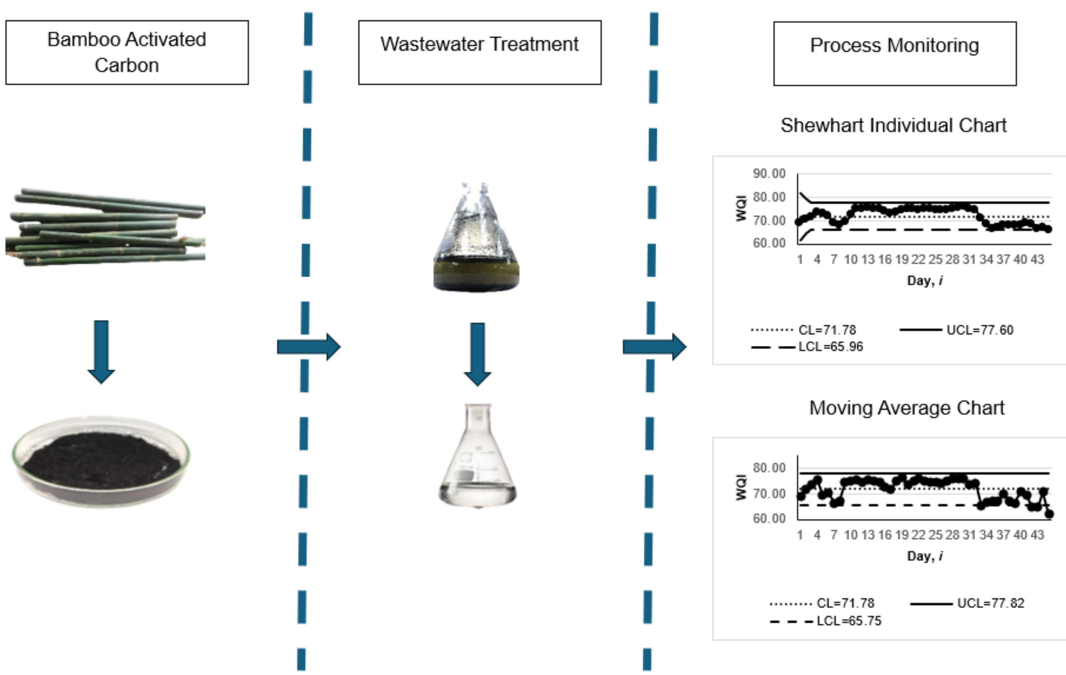
Application of a Multi-Parameter-based Water Quality Index Analysis for Monitoring Fishery Industry Wastewater Treatment using Bamboo Activated Carbon – A Control Chart Approach

Jeng Young Liew,[a,*] Danial Shamzari bin Hashim,[b] Jia Geng Boon,[b] Huck Ywih Ch'ng,[a] Kooi Huat Ng,[c] Yann Ling Goh,[c,*] and Wei Chen Lum[b]

*Corresponding author: ljyoung@umk.edu.my; gohyl@utar.edu.my

DOI: 10.15376/biores.20.1.1008-1023

GRAPHICAL ABSTRACT



Application of a Multi-Parameter-based Water Quality Index Analysis for Monitoring Fishery Industry Wastewater Treatment using Bamboo Activated Carbon – A Control Chart Approach

Jeng Young Liew,[a,*] Danial Shamzari bin Hashim,[b] Jia Geng Boon,[b] Huck Ywih Ch'ng,[a] Kooi Huat Ng,[c] Yann Ling Goh,[c,*] and Wei Chen Lum[b]

Bamboo activated carbon (BAC) was prepared and used for wastewater treatment. Its adsorption capability was investigated using control charts. The fishery industry wastewater in Jeli was sampled for 45 days. The adsorbent, *i.e.*, 45 µm BAC was prepared through the pyrolysis process with chemical-physical activations at 600 °C for 6 hours. The BAC was mixed thoroughly with the fishery industry wastewater, and the mixture was then separated by filtration. The effectiveness of wastewater treatment by BAC was determined using the water quality index (WQI), and the BAC adsorption process was monitored using the Shewhart individual and moving average (MA) charts. The charts' performance in detecting off-target processes present in the BAC wastewater treatment process was also determined. The WQI was shown to improve significantly after BAC treatment, with all values exceeding 60, surpassing the water pollution index threshold (≤ 60) set by Malaysia Department of Environment (DOE). The Shewhart individual and MA charts were able to detect the out-of-control condition(s). By comparison, the Shewhart individual chart demonstrated a preferable performance. This work paves the way for quality practitioners to properly utilize control charts to produce a more efficient wastewater treatment approach using BAC and to acquire statistical quality control.

DOI: 10.15376/biores.20.1.1008-1023

Keywords: Quality; Adsorbent; Water quality index; Control chart; Bamboo

*Contact information: a: Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Jeli Campus 17600, Jeli, Kelantan, Malaysia; b: Tropical Wood and Biomass Research Group, Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus 17600, Jeli, Kelantan, Malaysia; c: Department of Mathematical and Actuarial Sciences, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, Cheras 43000 Kajang, Selangor, Malaysia; *Corresponding author: ljyoung@umk.edu.my; gohyl@utar.edu.my*

INTRODUCTION

Water quality is a global concern (Fulazzaky *et al.* 2009). The presence of clean and safe water guarantees the survival of humans, and more aspects associated with human lives (Hamidon *et al.* 2021). Bullard (1972) expostulated that impaired surface water quality is a core vehicle for deleterious socio-economic environment. The prevalence of wastewater pollution is apparently up-surging and therefore it deserves urgent measures (Breabăn *et al.* 2012). Wastewater has detrimental substances that are known to jeopardize human health and environmental quality. Securing a proper wastewater treatment is essential to help control the wastewater problem and stop it from worsening.

Wastewater treatment can be viewed as a combination of processes applied in steps to eliminate pollutants, impurities, disease-causing organisms, *etc*., in the wastewater. Activated carbon (AC) is a commonly used inert adsorbent for adsorbing harmful components from the contaminated water. The AC is diversely adopted for practical applications in foreign material adsorption and water purification (Hamad *et al.* 2010), air purification (Zhang *et al.* 2016), sewage treatment, and air filtration (Yan *et al.* 2016). A study by Wong *et al.* (2018) has further evidenced the high adsorption capacity of AC against chemicals and other foreign materials in water or air. Growing interest among researchers to explore the new potential of AC to assist the needs of present society is a testament to the multifaceted applications of AC in many disciplines. AC is available in assorted forms derived from carbonaceous source materials. One such example of an alternative source material is bamboo, which is low-cost, sustainable, and readily available in Malaysia (Nordahlia *et al.* 2019; Narzary *et al.* 2024). Multiple studies have stressed that bamboo is a plant that can feasibly be converted to AC owing to its rich carbonaceous and fast-growing properties (Barnabas *et al.* 2020). Mahanim *et al.* (2011) generated bamboo AC (BAC) from industrial bamboo waste and demonstrated that its surface and adsorption properties were comparable to the commercial ones. As reported by Nyika and Dinka (2022), BAC has secured significant attention in wastewater treatment because of its distinct porous structure, setting it apart from traditional wood charcoal. Lamaming *et al.* (2022) reviewed the application of BAC and its significance as a wastewater treatment adsorbent, noting that BAC exhibits a good adsorption capacity.

The importance of AC as a solution for wastewater treatment has necessitated new approaches that focus on the AC process adsorption patterns while recognizing meaningful enhancement signals if unnatural variations, *i.e.*, assignable causes are present in the wastewater treatment process. Monitoring and visualizing the variations in AC adsorption performance and early detection of process deviation signals could reduce the risks of non-conformity. To realize this aim, the use of statistical process control (SPC) technique is deemed indispensable. Implementing a systematic monitoring system with SPC is the most efficient approach available for detecting abnormality in the operational process by comparing what is happening today with what happened previously (Amin and Venkatesan 2019). That is, one can take a snapshot of a process's typical performance to predict future performance and establish control limits for expected measurements of the process's output.

Out of the seven tools in SPC, the control chart is the most technically advanced (Montgomery 2020). A control chart is a process behaviour plot with a center line (CL) denoting the mean values of the data being graphed and two control limits computed from the data. The two control limits are the upper control limit (UCL), and lower control limit (LCL), both depicting the process variations as upper and lower expectations.

It is well known that the 3-sigma limit has been the common benchmark for variable and attribute control charts in the literature of control charting method (Klein 2004). This is attributed to economic merit, since the false alarm rate on a control chart with 3-sigma limit is minimal. The control chart issues an out-of-control alarm when one single plotted point violates any of the control limits. In this context, quality practitioners could launch a timely adjustment action to extirpate the undesirable conditions, so as to guard against recurrence. The control chart has received its share of practical applications over a few decades, especially in the industrial sectors (Duarte and Saraiva 2008; Bouslah *et al.* 2018).

As evidence, the control chart is used as a crucial devise in inspecting the total losses for industrial tomato crop (Cunha *et al*. 2014).

The attractiveness of the Shewhart chart as a quality tool lies in its simplicity to the typical shop floor works (Klein 2004). Typical shop floor work primarily comprises manual labour, technical skills following the procedures, and teamwork to ensure that production goals are fulfilled efficiently and without harm to the workers. The Shewhart chart has been broadly applied in numerous essential sectors, including education, healthcare, industrial production, *etc.* (Mohammed *et al.* 2001). In practice, there exist numerous conditions where the individual sample size is used for process monitoring, and under this scenario, the control chart for individual measurement is applied. Of note, the Shewhart chart for individual measurements is particularly important for inspecting the chemical processes in which the laboratory or analysis error is the only key reason leading to the discrepancy on the repeated measurements on the process (Montgomery 2020). The Shewhart individual chart may also be desirable when one wishes to investigate every individual observation promptly from a process that is too slow in generating results (Nelson 1982). In recent years, Biswas *et al.* (2016) has used the Shewhart individual chart to deduce the optimal parameters for the weaving mill in the textile industry to achieve statistical quality control. Kisić *et al.* (2013), who explored fault detection in the boiler furnace electric power systems using the Shewhart individual chart, is another recent remarkable contribution.

A time-weighted chart, namely the moving average (MA) chart, is an alternative to the Shewhart chart that is typically used for the situation where the rate of production of manufacturing is slow and rational subgrouping is impractical, for example, one unit per day, *etc.* (Maghsoodloo and Barnes 2021). Implementing the MA chart helps the quality practitioners monitor the process stability over time as they can rapidly detect and rectify instabilities in a process. The MA chart is constructed based on the property of a familiar basic and unweighted MA, where it exerts the mean of the present data and a handful of historical data to compute each MA. The MA chart has been popularized in the financial sector, particularly in smoothing stock and index trend since its inception (Wong *et al.* 2004).

To the best of the authors' knowledge, the use of control charts to track the performance of the BAC during the wastewater adsorption process has not been explored. Therefore, this paper aimed to (i) use a multi-parameter-based Malaysia Department of Environment (DOE) water quality index (WQI) to monitor the fishery industry wastewater treatment with BAC by leveraging the control chart approach consisting of the Shewhart individual and MA charts. This approach pioneered an SPC integrated scheme in wastewater treatment. The next step was to (ii) compare the performance of the Shewhart individual and MA charts in monitoring the BAC fishery industry wastewater treatment process. It is important to note that the WQI is a straightforward practice, allowing for adequate water quality classification (Lachhab *et al.* 2014). Specifically, WQI provides a single value to convey multiple measurable parameters that reflect distinct features of water quality, offering a comprehensive evaluation of water quality rather than focusing solely on organic pollutants such as chemical oxygen demand (COD) or biochemical oxygen demand (BOD) removal efficiency alone. In contrast, the BOD test only allows one to have a rough idea of the biodegradable waste amount in the water (WSDE 2002), while the COD test only evaluates the quantity of organic and inorganic oxidizable compounds in water (Davis and McCuen, 2005). Lachhab *et al.* (2014) further highlighted that WQI is an ideal water quality indicator if the corresponding values for each parameter are well identified.

EXPERIMENTAL

Preparation of Raw Material

In this study, the bamboo species employed for producing AC was *Schizostachyum brachycladum,* or alternatively known as the Sacred Bali bamboo. Approximately 5 kg of bamboo samples were harvested from Jeli, Kelantan. The bamboo samples were chipped, cleaned, and air-dried for 24 h (Hung *et al.* 2019). After that, the bamboo samples were further oven-dried at 105 °C until a moisture content of 15% was attained before they were ground and sieved to pass through a 4-mm sieve (Vibratory Shaker, RETSCH) for the production of BAC.

Production and Characterization of Bamboo Activated Carbon

For the production of BAC, 10 g of bamboo powder was weighed into the crucible and subjected to pyrolysis at 600 °C for 6 h inside an electrical furnace (Choy *et al.* 2005). The BAC were then allowed to cool down at room temperature prior to storage in a container for subsequent experiment. The characterization of the produced BAC was conducted using Fourier Transform Infrared (FTIR) analysis and the Brunaeur-Emmet-Teller (BET) surface area and Langmuir surface area of BAC were checked by the Quantachrome Instruments (Hashim *et al.* 2022).

Fishery Industry Wastewater Treatment with Bamboo Activated Carbon

The sampling of fishery industry wastewater was carried out once daily in the morning from May 2022 to June 2022 (45 days) in a fishpond near the fishery industry area in Jeli, Kelantan. As Ismail *et al.* (2021) asserted, a fishpond is a reservoir for aquaculture consisting of wastewater. The wastewater was collected using 500 mL polypropylene water sampling bottles. There were two operations in treating the wastewater sample. In the first stage, purification was carried out, in which 50 g of BAC was mixed thoroughly with 300 mL fishery industry wastewater inside a beaker, and the mixture was shaken for 10 min using a mechanical shaker, allowing the solid to settle. Following the purification process, filtration was performed to remove the BAC from the wastewater sample. Simple filtration using filter paper was employed to separate the solid BAC from the liquid wastewater. The mixture was poured through a filter paper placed in a simple filtration setup, which retained the BAC on the paper while allowing the liquid to pass through. The contaminants adsorbed by the BAC remained on the filter. The treated wastewater, separated from the BAC, was collected in a clean container for subsequent water quality analysis and all the experimental data was recorded. These two stages of experiments were repeated for consecutively 45 days to complete the entire data collection process.

Analysis of the wastewater samples before- and after-treatment with BAC were carried out in the Universiti Malaysia Kelantan (UMK) to acquire the WQI six core parameters categorized based on the Interim National Water Quality Standard (INQWS). These six INQWS parameters were used to assess the physicochemical properties of water quality. The parameters are dissolved oxygen (DO), BOD, COD, ammonia nitrate (AN), suspended Solid (SS), and potential hydrogen (pH). The computation of WQI was conducted using a formula given by the DOE Malaysia as shown in Eq. (1) after calculating the sub-index (SI) for each of the six parameters,

$$\text{WQI} = (0.22\ \text{SIDO}) + (0.19\ \text{SIBOD}) + (0.16\ \text{SICOD}) + (0.15\ \text{SIAN}) + (0.16\ \text{SISS}) + (0.12\ \text{SIpH}) \tag{1}$$

where SIDO, SIBOD, SICOD, SIAN, SISS, and SIpH denote the predefined sub-indices of DO (% saturation), BOD, COD, AN, SS, and pH, respectively.

Methods and instruments used for determining the parameters of WQI are summarized in Table 1. As reported by Kamarudin *et al.* (2018), the WQI is a prevailing conventional benchmarking method used for water quality in most watershed management agencies.

Table 1. Methods and Instruments Used to Determine the Parameters of WQI for the Study

WQI Parameter	Method	Instrument
DO	Direct reading from instrument	YSI Multiparameter
pH	Direct reading from instrument	YSI Multiparameter
BOD	Dilution Process, (DOC316.53.01200, Method 8043)	YSI Multiparameter
COD	Dichromate Method, (DOC316.53.01099, Method 800)	DR 6000, DR 2800, DR 900
SS	Photometric Method, (DOC316.53.01139, Method 8006)	DR 6000, DR 2800, DR 900
AN	Salicylate Method, (DOC316.53.01077, Method 8155)	DR 6000, DR 2800, DR 900

The Shewhart Individual and Moving Average Charts

The Shewhart individual and MA charts with 3-sigma limit approach were set up by plotting WQI against each day, up to 45 days.

The LCL, UCL, and CL of a 3-sigma Shewhart individual chart are given by Montgomery (2020).

$$\text{LCL} = \bar{x} - 3\left(\overline{\text{MR}}/d_2\right),\ \text{UCL} = \bar{x} + 3\left(\overline{\text{MR}}/d_2\right),\quad \text{and}\ \text{CL} = \bar{x}\,. \tag{2}$$

Here, d_2 is the factor for ranges given by 1.128. $\overline{\text{MR}}$ is the average moving range of the data with $m-1$ ranges, and $\bar{x}$ is the average of m individual observation, which are computed by Eq. (3) and Eq. (4), respectively.

$$\overline{\text{MR}} = \sum_{i=2}^{m} \left| x_i - x_{i-1} \right| \Big/ \left(m-1\right) \tag{3}$$

$$\bar{x} = \sum_{i=1}^{m} x_i \Big/ m \tag{4}$$

Meanwhile, the MA chart of span *w* at time *i* is (Maghsoodloo and Barnes 2021),

$$M_i = \left(x_i + x_{i-1} + \ldots + x_{i-w+1}\right)/w,\ \text{for}\ i \ge w \tag{5}$$

where x_i represents the sample value for time interval *i*. The 3-sigma MA chart's LCL and UCL could be computed from:

$$\text{LCL} = \bar{x} - 3\sigma/\sqrt{w}\ \text{and}\ \text{UCL} = \bar{x} + 3\sigma/\sqrt{w}. \tag{6}$$

Note that $\bar{x}$ and σ shown in Eq. (6) are the target values of the mean (used as the CL) and standard deviation, respectively.

The Shewhart individual and MA charts signal an out-of-control process when a point plots outside the charts' UCL or LCL. Such a signal calls for an investigation of the process to be initiated and corrective action to be taken to remove the assignable causes.

RESULTS AND DISCUSSION

Wastewater Treatment by Bamboo Activated Carbon

In this study, some critical attributes significantly affected the wastewater WQI. According to the DOE Malaysia, water quality is divided into three classes based on the WQI index range (Table 2). The results showed that weather, chemical substances, and rubbish were drivers for causing changes in the value of WQI. Furthermore, the samples' WQI demonstrated differences regardless of a rainy or hot day (Table 3). The results revealed considerable changes in the water quality after the BAC was used to treat the wastewater (Fig. 1). Specifically, the WQI value increased, on average, by about 14 from 59 (before BAC treatment) to 73 (after BAC treatment) which is about 23.7% improvement of water quality. The increment in WQI affirmed that the BAC effectively filtered out contaminants from wastewater.

Table 2. DOE Malaysia Water Quality Classification based on WQI

WQI	**Index Range**		
	Polluted	Slightly Polluted	Clean
	0 – 59	60 – 80	81 – 100

Source: Zaki (2010)

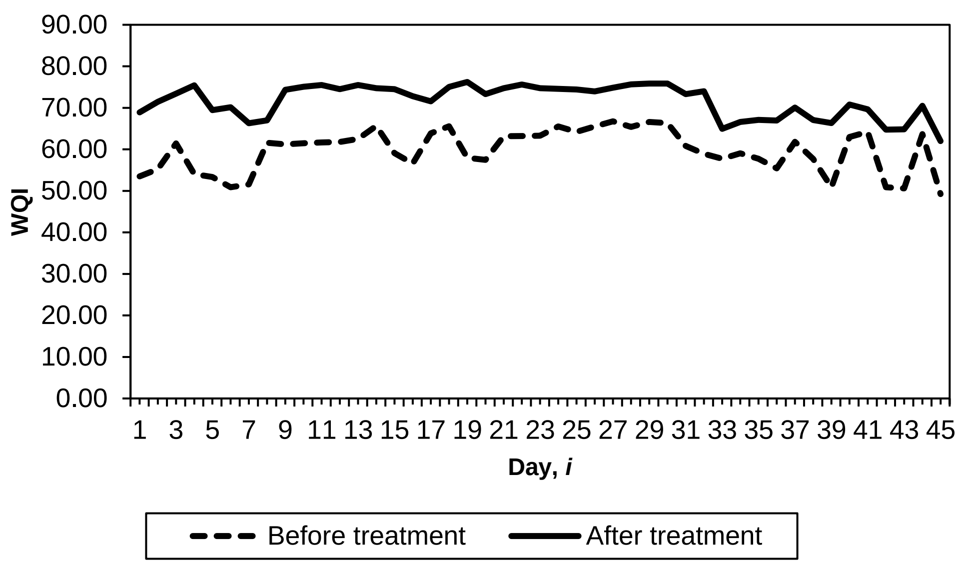


Fig. 1. WQI values (before- and after- treatments with BAC) against samples of 45 days

A close examination of the results in Table 3 enables one to infer some salient information from the study. The laboratory experiment detected some algae growth in the wastewater samples on a hot day. The chemical substances and rubbishes, such as plastic, *etc.*, were also found to float on the water's surface and thus contributed to pollution of the water. Based on Table 3, the biggest difference between the WQI occurred on day 4 of the testing period. There was a substantial 39.6% improvement of water quality when comparing the wastewater before-treatment to wastewater after-treatment with BAC. The increment of WQI in percentage was correspond to the increment of 74.5%, 48.6%, 59.5%, 27.2%, and 0.10% for sub-index of BOD, COD, AN, SS, and pH, respectively. It is worth noting that the WQI was generally higher (>60) on rainy days. The results demonstrated a similar trend on the WQI for the rainy days, irrespective of whether there was a light or heavy rainfall. This discovery concurs with the findings of Rubio-Arias *et al.* (2012) and can be attributed to the increased DO content caused by rainwater due to the added turbulence and mixing in the water currents. Besides, the lower water temperature during rainy day, also increased oxygen solubility in the water. The levels of BOD and COD exhibited some reduction, implying that both parameters were experiencing improvement. In the after-treatment results, the level of AN in the sample water was lower, indicating that the water quality had improved. The surge in SS was primarily due to soil erosion on the pond margins; however, the amount of SS declined after BAC treatment. It was found that the average value of the pH level was higher on rainy days over hot days. Overall, all data displayed improved water quality after the wastewater samples received the sewage treatment using the BAC. In other words, the rise in WQI indicated the improvement of water quality. The treated wastewater can be potentially reused for irrigation purposes (Ibrahim 2019).

There are several factors that influence the adsorption efficiency of BAC, including pore size, pore distribution, and the size of BAC. Smaller BAC size and its pore size resulted in a larger adsorption surface area, enhancing the BAC's ability to adsorb contaminants (Hashim *et al.* 2022). The porous structure of BAC allows liquids to penetrate deeply, increasing contact between contaminants and the BAC. Once in contact, contaminants are adsorbed and chemically bound to the active sites within the BAC's structure through attractive forces such as van der Waals forces (Nyika and Dinka 2022).

Other factors such as pH and exposure duration also play an important role. As the pH drops, adsorption capability tends to rise. Moreover, the contaminants can be filtered more efficiently when the wastewater is exposed to the BAC for extended periods.

Table 3. WQI Values for the Samples Used (Before- and After-Treatments) with BAC for 45 Days

Weather	Day, *i*	SIDO	SIBOD	SICOD	SIAN	SISS	SIpH	WQI	Result
Hot	1^X	-0.20	59.23	72.71	50.90	74.77	91.98	53.48	P
	1^Y	-0.22	64.56	108.33	91.05	91.49	92.25	68.92	SP
Hot	2^X	-0.24	57.38	76.10	60.66	74.74	92.77	55.22	P
	2^Y	-0.25	62.92	117.71	99.45	91.50	92.90	71.44	SP
Rainy	3^X	-0.06	75.19	74.60	69.45	81.05	98.65	61.43	SP
	3^Y	-0.09	75.19	119.74	99.45	85.07	95.50	73.41	SP
Hot	4^X	-0.16	46.92	78.18	61.68	72.33	98.45	54.03	P
	4^Y	-0.18	81.86	116.16	98.40	92.01	98.55	75.41	SP
Hot	5^X	-0.17	46.10	75.69	57.38	75.41	98.69	53.35	P
	5^Y	-0.18	51.23	117.99	96.30	90.95	98.91	69.44	SP
Hot	6^X	-0.18	30.86	74.88	59.65	76.02	99.62	50.87	P
	6^Y	-0.20	50.93	118.93	99.45	91.45	99.33	70.13	SP
Hot	7^X	-0.19	35.82	77.27	58.67	73.38	99.09	51.56	P
	7^Y	-0.21	34.26	117.47	99.45	89.27	98.60	66.29	SP
Rainy	8^X	0.00	75.19	75.89	65.62	83.53	99.60	61.59	SP
	8^Y	-0.03	41.88	118.58	97.35	85.07	98.60	66.97	SP
Rainy	9^X	0.08	74.68	73.82	65.25	84.04	99.49	61.19	SP

	9^Y	0.06	81.86	116.54	99.45	83.43	98.95	74.35	SP
Rainy	10^X	0.05	73.08	76.66	67.13	84.10	98.12	61.46	SP
	10^Y	0.02	82.23	118.88	98.40	86.11	99.06	75.07	SP
Rainy	11^X	0.05	75.83	73.52	67.13	84.88	98.55	61.66	SP
	11^Y	0.02	80.94	121.75	99.45	86.52	98.99	75.50	SP
Rainy	12^X	-0.13	74.89	79.22	64.16	84.43	98.23	61.79	SP
	12^Y	0.04	83.49	113.26	99.45	86.11	98.23	74.48	SP
Rainy	13^X	0.09	75.40	74.28	70.25	86.52	99.12	62.51	SP
	13^Y	0.06	82.93	121.39	97.35	86.11	99.46	75.51	SP
Rainy	14^X	0.11	72.79	78.72	87.90	88.20	99.02	65.63	SP
	14^Y	0.08	82.09	115.88	99.45	86.10	99.06	74.74	SP
Hot	15^X	-0.12	60.61	80.48	69.45	77.57	99.06	59.08	P
	15^Y	-0.14	79.71	113.86	99.45	90.45	97.99	74.48	SP
Hot	16^X	-0.14	54.78	74.85	68.28	75.40	99.30	56.58	P
	16^Y	-0.16	66.82	119.75	96.30	91.56	99.06	72.80	SP
Rainy	17^X	0.10	75.53	76.96	77.40	85.44	99.09	63.86	SP
	17^Y	0.07	59.74	118.72	98.40	90.94	99.28	71.58	SP
Rainy	18^X	0.13	76.43	77.41	85.80	86.51	99.33	65.57	SP
	18^Y	0.10	82.23	117.20	99.45	86.24	99.30	75.03	SP
Hot	19^X	-0.01	57.11	72.95	73.20	78.36	99.37	57.96	P
	19^Y	-0.04	83.21	122.72	97.35	89.22	99.30	76.23	SP
Hot	20^X	-0.01	56.39	73.40	78.45	76.11	92.11	57.46	P
	20^Y	-0.04	63.72	122.80	99.45	92.41	98.95	73.32	SP
Rainy	21^X	0.04	71.92	77.53	80.55	84.54	95.50	63.15	SP
	21^Y	0.01	80.57	116.28	98.40	90.49	96.43	74.73	SP
Rainy	22^X	0.16	71.52	74.73	80.55	85.65	98.55	63.19	SP
	22^Y	0.13	82.88	117.88	99.45	88.73	98.99	75.63	SP
Rainy	23^X	0.14	72.87	77.54	80.55	85.98	92.90	63.27	SP
	23^Y	0.11	82.09	117.73	97.35	89.27	94.78	74.72	SP
Rainy	24^X	0.22	74.85	78.26	85.80	87.59	98.65	65.51	SP
	24^Y	0.19	81.49	116.88	99.45	84.97	98.50	74.56	SP
Rainy	25^X	0.18	74.00	74.89	84.75	87.36	95.40	64.22	SP
	25^Y	0.14	81.95	115.46	98.40	85.63	98.99	74.41	SP
Rainy	26^X	0.34	77.35	76.04	84.75	87.54	98.69	65.50	SP
	26^Y	0.30	85.16	112.72	99.45	80.51	98.83	73.94	SP
Rainy	27^X	0.34	76.52	80.16	86.85	90.37	98.50	66.75	SP
	27^Y	0.30	85.21	108.28	98.40	91.39	98.87	74.83	SP
Rainy	28^X	0.35	75.27	76.17	85.80	90.93	95.30	65.42	SP
	28^Y	0.31	82.88	117.91	97.35	92.58	96.25	75.65	SP
Rainy	29^X	0.77	78.14	78.84	85.80	90.72	96.43	66.59	SP
	29^Y	0.39	85.69	112.31	99.45	93.79	96.69	75.86	SP
Rainy	30^X	0.92	78.68	75.61	84.75	90.60	98.91	66.33	SP
	30^Y	0.41	86.32	112.08	99.45	93.15	96.69	75.85	SP
Hot	31^X	0.61	63.79	72.99	76.35	85.05	98.40	60.80	SP
	31^Y	0.12	69.62	122.15	95.25	90.38	97.99	73.31	SP
Hot	32^X	0.48	62.74	65.12	77.40	81.54	98.50	58.92	P
	32^Y	0.03	69.15	123.72	97.35	91.50	98.60	74.01	SP
Hot	33^X	0.41	63.28	60.94	78.45	76.12	99.28	57.72	P
	33^Y	-0.04	68.17	74.46	98.40	86.72	95.50	64.95	SP
Hot	34^X	0.17	62.20	69.93	80.55	74.91	99.43	59.04	P
	34^Y	-0.13	70.14	74.91	99.45	91.50	97.99	66.60	SP
Hot	35^X	0.04	61.88	71.49	72.15	73.69	99.33	57.74	P
	35^Y	-0.22	70.58	75.75	99.45	92.59	99.06	67.10	SP
Hot	36^X	-0.01	62.59	59.69	76.35	67.41	97.87	55.42	P
	36^Y	-0.26	68.99	74.53	98.40	96.11	98.50	66.93	SP

Rainy	37^X	0.05	75.66	73.50	78.45	76.35	97.39	61.82	SP
	37^Y	-0.21	82.37	81.88	97.35	94.32	97.32	70.08	SP
Hot	38^X	-0.06	63.28	72.99	71.10	72.37	98.06	57.70	P
	38^Y	-0.28	68.95	75.65	98.40	96.11	98.12	67.06	SP
Hot	39^X	-0.11	62.59	31.72	69.45	73.22	98.45	50.89	P
	39^Y	-0.32	68.87	73.68	97.35	94.26	98.55	66.32	SP
Rainy	40^X	0.04	76.56	78.86	70.05	84.54	98.06	62.97	P
	40^Y	-0.26	84.44	82.05	97.35	95.54	98.12	70.78	SP
Rainy	41^X	0.11	76.83	78.33	75.30	87.15	98.45	64.21	P
	41^Y	-0.17	85.54	81.65	97.35	87.12	98.60	69.65	SP
Hot	42^X	-0.05	60.47	24.88	76.35	76.55	97.74	50.89	P
	42^Y	-0.30	66.78	71.55	99.45	87.43	97.99	64.74	SP
Hot	43^X	-0.10	58.99	29.30	72.15	75.11	99.02	50.60	P
	43^Y	-0.34	65.42	74.35	99.45	86.01	99.06	64.82	SP
Rainy	44^X	-0.09	73.29	73.43	86.85	82.04	98.91	63.68	SP
	44^Y	-0.33	81.63	85.14	99.45	91.50	98.99	70.49	SP
Hot	45^X	-0.17	60.54	8.54	85.80	73.10	98.60	49.23	P
	45^Y	-0.34	65.98	59.03	98.40	84.22	98.69	61.99	SP

*Letter P denotes the water is polluted as per the DOE Malaysia water quality classification
*Letter SP denotes the water is slightly polluted as per the DOE Malaysia water quality classification
*Superscript letter X denotes the fishery industry wastewater before-treatment with BAC
*Superscript letter Y denotes the fishery industry wastewater after-treatment with BAC

Monitoring the Performance of Shewhart Individual and Moving Average Charts in Wastewater Treatment with Bamboo Activated Carbon

The Shewhart chart for individual measurements and the MA chart were adopted to monitor the wastewater treatment process with BAC. The charts were constructed using the WQI data (after-treatment). The control limits set for monitoring the wastewater treatment process, aligning with the environmental regulations, have yet to be presented in the literature, and this scenario necessitates the estimation of the chart's parameters from the preliminary samples. A sizeable preliminary sample is recommended to estimate the parameters for a typical control chart (Montgomery 2020). Provost and Murray (2011) stressed that for an effective C-chart, at least eight observations are required in estimating the CL, UCL, and LCL. Considering these recommendations, this study used the first 12 individual WQI observations as a preliminary sample to estimate the CL and control limits for both charts. The average of the moving ranges of two observations was computed using Eq. (3). Other parameters and plotting statistics for the Shewhart individual and MA charts were illustrated in Table 4. In any event, the MA chart with a shorter span has a more optimistic view of the larger changes in the process and vice versa (Montgomery 2020). As Maghsoodloo and Barnes (2021) illuminated, the span $w = 5$ is amongst the most common. For a meaningful performance comparison, the MA chart with different spans, *i.e.*, $w \in \{3,5,7\}$ were considered in this study.

The results in Table 4 showed that the MA charts could detect the possible out-of-control situations in the BAC wastewater treatment process. To enable a more accessible performance visualization, the MA charts plotted using data in Table 4 were illustrated in Figs. 2 to 4, respectively. The assignable causes of variation, which are intermittent and unpredictable, were the culprits responsible for these process deviations. There is an urgency to detect and remove these undesirable assignable causes to re-enter the process back into a statistically in-control state. Assignable causes of variations can be dismissed by modifying the parts, operations, or processes. To successfully remove the assignable causes, operator, management, and engineering action are of utmost importance. In this configuration, the operational staff is instructed to check process parameters, including calibration, when the MA chart prompts an out-of-control signal, aiming at reverting the off-target process into statistical in-control. If these modifications are futile, the process engineer or quality practitioners should be notified.

Pertaining to the statistical performance evaluation in the control charting method, a control chart is declared to be deemed sensitive to the departures from the desired process target if it can alert an out-of-control alarm at the quickest speed. The number of points plotted beyond the control limits for the MA chart by means of the conventional spans w = 3, w = 5, and w = 7 were 1, 3, 6, respectively (Figs. 2 to 4). Specifically, the MA chart of span w = 5 issued the first out-of-control condition at point 37, while the MA chart of span w = 3 signaled for the first time at the 45th observation, *i.e.*, the last observation. The performance of the MA chart of span w = 7 was sandwiched between the MA chart with $w \in \{1,5\}$, even though it recorded the highest number of out-of-control signals. In this case, the MA chart of span w = 5 outperformed all other spans under comparisons.

The Shewhart individual chart has shown a relatively favourable performance in this study. It can be seen that four points were plotted outside the control limits of the Shewhart individual chart (Fig. 5). To explain, the chart detected the first off-target situation at point 33, followed by the points 42, 43, and 45, respectively.

Notably, the Shewhart individual chart's performance was more effective than the MA chart in this study. This claim is testified by the fact that the Shewhart individual chart could respond to an out-of-control process much quicker than the MA chart. The performance gap between both charts was large as the MA chart (w = 5) signaled shortly at point 37, precisely 4 observations behind the Shewhart individual chart whose first signal was at point 33. Even though one chart may be superb in the context of other properties, one should consider the non-statistical criteria when deciding which chart to use in a given condition. It is advisable to use a similar control chart if the chart is being adopted in the majority of applications (Lucas and Saccucci 1990).

Table 4. The Shewhart Individual and MA Charts' Plotting Statistics Based on The WQI of the Samples After-Treatment with BAC for 45 Days

Shewhart Individual Chart			MA Chart				
Days, i	WQI (After BAC treatment)	UCL = 77.82 CL = 71.78 LCL = 65.75	Day, i	WQI (After BAC treatment)	UCL = 77.60 CL =71.78 LCL = 65.96	UCL = 76.29 CL = 71.78 LCL = 67.28	UCL = 75.59 CL = 71.78 LCL = 67.97
		MR			M_i (w =3)	M_i (w =5)	M_i (w =7)
1	68.92		1	68.92	68.92	68.92	68.92
2	71.44	2.52	2	71.44	70.18	70.18	70.18
3	73.41	1.98	3	73.41	71.25	71.25	71.25
4	75.41	1.99	4	75.41	73.42	72.29	72.29
5	69.44	5.97	5	69.44	72.75	71.72	71.72
6	70.13	0.69	6	70.13	71.66	71.97	71.46
7	66.29	3.84	7	66.29	68.62	70.94	70.72
8	66.97	0.68	8	66.97	67.80	69.65	70.44
9	74.35	7.38	9	74.35	69.20	69.44	70.86

10	75.07	0.72	10	75.07	72.13	70.56	71.09
11	75.50	0.43	11	75.50	74.98	71.64	71.11
12	74.48	1.03	12	74.48	75.02	73.28	71.83
13	75.51	1.03	13	75.51	75.16	74.98	72.60
14	74.74	0.77	14	74.74	74.91	75.06	73.80
15	74.48	0.26	15	74.48	74.91	74.94	74.88
16	72.80	1.68	16	72.80	74.01	74.40	74.65
17	71.58	1.22	17	71.58	72.96	73.82	74.16
18	75.03	3.44	18	75.03	73.14	73.73	74.09
19	76.23	1.20	19	76.23	74.28	74.03	74.34
20	73.32	2.91	20	73.32	74.86	73.79	74.03
21	74.73	1.41	21	74.73	74.76	74.18	74.03
22	75.63	0.90	22	75.63	74.56	74.99	74.19
23	74.72	0.91	23	74.72	75.02	74.93	74.46
24	74.56	0.16	24	74.56	74.97	74.59	74.89
25	74.41	0.15	25	74.41	74.56	74.81	74.80
26	73.94	0.47	26	73.94	74.30	74.65	74.47
27	74.83	0.89	27	74.83	74.39	74.49	74.69
28	75.65	0.82	28	75.65	74.80	74.68	74.82
29	75.86	0.22	29	75.86	75.44	74.94	74.85
30	75.85	0.01	30	75.85	75.79	75.22	75.01
31	73.31	2.54	31	73.31	75.01	75.10	74.83
32	74.01	0.71	32	74.01	74.39	74.94	74.78
33	64.95	9.06	33	64.95	70.76	72.80	73.49
34	66.60	1.65	34	66.60	68.52	70.94	72.32
35	67.10	0.50	35	67.10	66.22	69.20	71.10
36	66.93	0.17	36	66.93	66.88	67.92	69.82
37	70.08	3.14	37	70.08	68.04	67.13	69.00
38	67.06	3.02	38	67.06	68.02	67.55	68.10
39	66.32	0.74	39	66.32	67.82	67.50	67.01
40	70.78	4.46	40	70.78	68.05	68.23	67.84
41	69.65	1.12	41	69.65	68.92	68.78	68.27
42	64.74	4.92	42	64.74	68.39	67.71	67.94
43	64.82	0.08	43	64.82	66.40	67.26	67.63
44	70.49	5.68	44	70.49	66.68	68.10	67.69
45	61.99	8.51	45	61.99	65.77	66.34	66.97

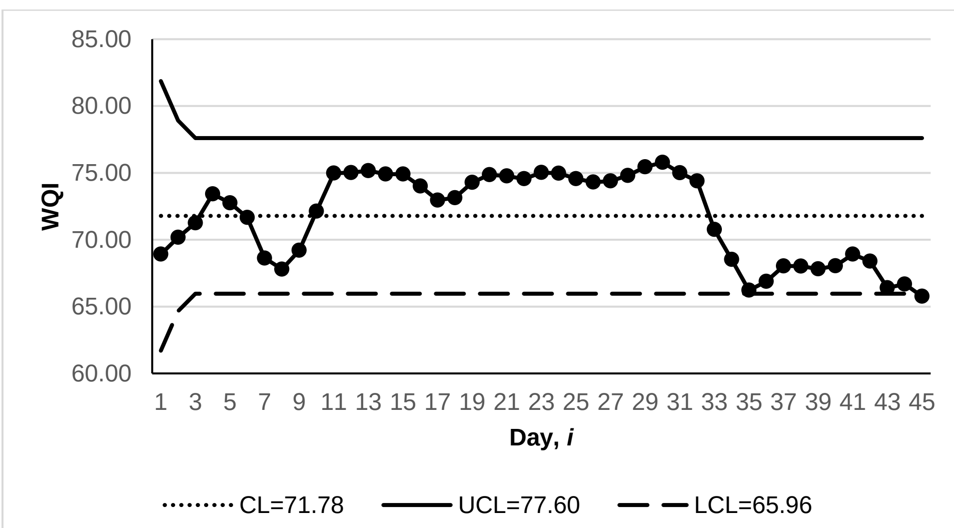


Fig. 2. MA chart for wastewater WQI after-treatment with BAC at the span $w = 3$

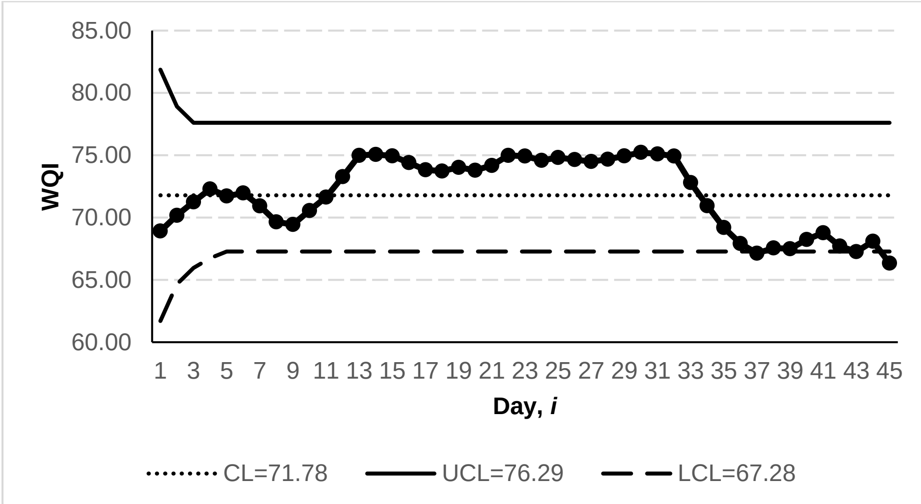


Fig. 3. MA chart for wastewater WQI after-treatment with BAC at the span *w* = 5

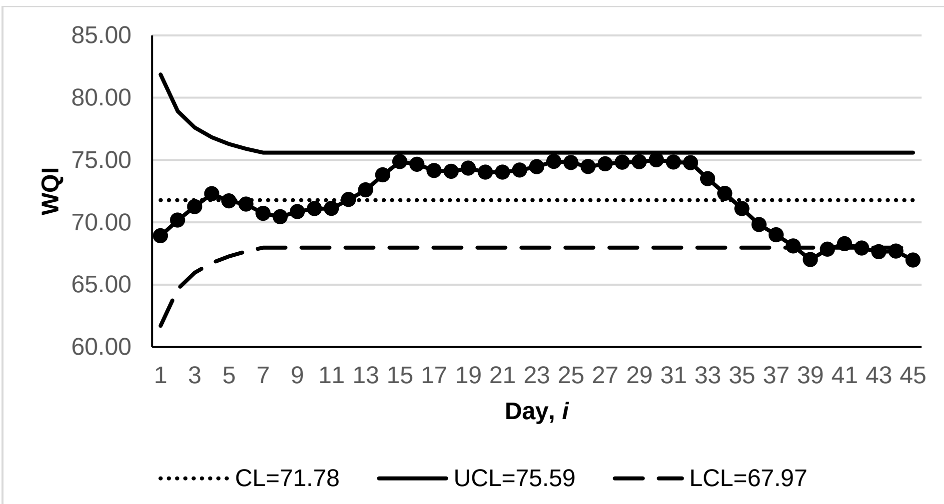


Fig. 4. MA chart for wastewater WQI after-treatment with BAC at the span *w* = 7

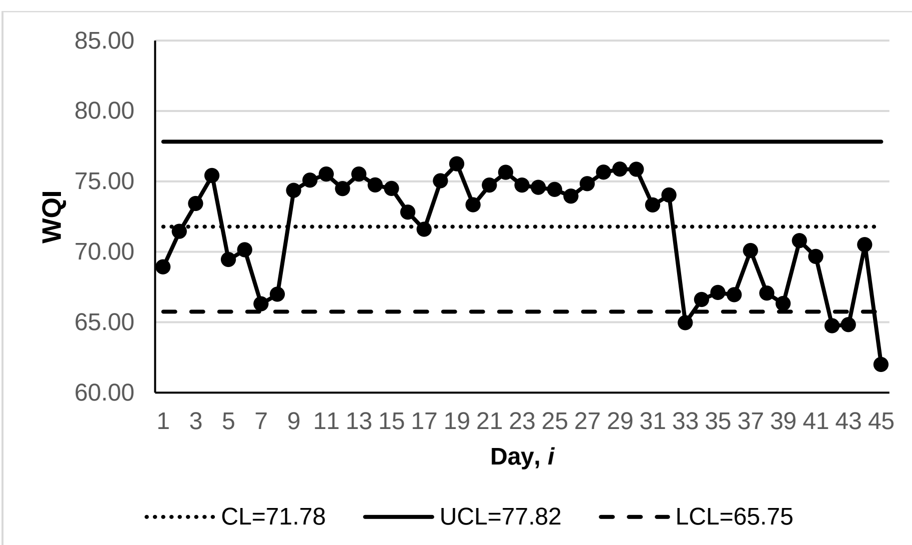


Fig. 5. Shewhart individual chart for wastewater WQI after-treatment with BAC

CONCLUSIONS

Based on the DOE Malaysia water quality classification, the WQI with index ranges of 0 to 59, 60 to 80, and 81 to 100 are classified as polluted, slightly polluted, and clean, respectively. After BAC treatment, the quality of the fishery industry wastewater showed a promising improvement in WQI, ranging from 61.99 to 76.23 compared to 49.23 to 66.75 before-treatment. Specifically, the water quality had been successfully upgraded from initially polluted to nearly clean levels using the BAC treatment. This finding has affirmed that the BAC offers a sound and sustainable advantage in wastewater treatment. This study has also successfully used the Shewhart individual and MA charts to monitor the BAC wastewater treatment process by signaling alarm when an out-of-control situation occurs. Notably, the Shewhart individual and MA charts were found to be a valuable tool in scrutinizing the water quality parameter, namely the WQI in the wastewater treatment process. The Shewhart individual chart, however, was superior to the MA chart as the former chart detected the out-of-control process quicker than the latter. The performance comparisons revealed that the MA chart at $w = 5$ generated a more favourable outcome than other spans under consideration. This pioneering integration of control charts furnishes an effective and economical way for quality practitioners in the wastewater treatment industry to monitor process output and identify when changes in process inputs are necessary to revert the off-target process into a statistically in-control state again.

ACKNOWLEDGMENTS

This research was supported by the Fundamental Research Grant Scheme (FRGS) with grant no: FRGS/1/2022/SS10/UMK/02/3 of Ministry of Higher Education (MoHE), Malaysia.

REFERENCES CITED

Amin, S. A. and Venkatesan, D. (2019). "Recent developments in control charts technique," *Journal of Applied Research Review* 8, 746-756.

Barnabas, N. N., Kaam, R., Tchamba, M., Zapfack, L., Chimi, C., and Tanougong, A. (2020). "Assessing the spatial distribution of bamboo species using remote sensing in Cameroon," *Journal of Ecology and the Natural Environment* 12(4), 172-183. DOI: 10.5897/JENE2020.0839

Biswas, R.K., Masud, M. S., and Kabir, E. (2016). "Shewhart control chart for individual measurement: An application in a weaving mil," *Australian Journal of Business, Social Science and Information Technology* 2(2), 89-100.

Bouslah, B, Gharbi, A., and Pellerin, R. (2018). "Joint production, quality and maintenance control of a two-machine line subject to operation-dependent and quality-dependent failures," *International Journal of Production Economics* 195, 210-226. DOI: 10.1016/j.ijpe.2017.10.016

Breabăn, I. G., Gheţeu, D., and Paiu, M. (2012) "Determination of water quality index of Jijia and Miletin ponds," *Bulletin UASVM Agriculture* 69(2), 2012.

Bullard, W. E. (1972). *Effects of Land Use on Water Resources in the Ecology of Man: An Ecosystem Approach*, Smith, R. L. (ed.), Harper and Row Publisher, New York.

Choy, K. K. H., Keith, C., Barford, J. P., and McKay, G. (2005). "Production of activated carbon from bamboo scaffolding waste-process design, evaluation and sensitivity analysis," *Chemical Engineering Journal* 109(1-3), 147-165. DOI: 10.1016/j.cej.2005.02.030

Cunha, J. P. B., de Machado, T. A., Santos, F. L., and Coelho, L. M. (2014). "Perdas na colheita de tomate industrial em função da regulagem da colhedora," *Pesq Agropec Trop Goiânia* 44(4), 363-369. DOI: 10.1590/S1983-40632014000400006

Davis, A. P., and McCuen, R. H. (2005). *Stormwater Management for Smart Growth*, Springer Science & Business Media, New York.

Duarte, B. P. M. and Saraiva, P. M. (2008). "An optimization based approach for designing attribute acceptance sampling plan," *Quality and Reliability Engineering International* 25(2), 824-841. DOI: 10.1108/02656710810898630

Fulazzaky, M. A.l., Seong, T. W., and Masirin, M. I. M. (2009). "Assessing of water quality status for the Selangor river in Malaysia," *Water, Air, and Soil Pollution* 205(1-4), 63-77. DOI: 10.1007/s11270-009-0056-2

Hamad, B. K., Noor, A. M., Afida, A. R., Asri, M. N. M. (2010). "High removal of 4-chloroguaiacol by high surface area of oil palm shell-activated carbon activated with NaOH from aqueous solution," *Desalination* 257(1-3), 1-7. DOI: 10.1016/j.desal.2010.03.007

Hamidon, H. N., Mohd Najib, S. A., and Aliah, S. (2021). "Water quality of selected rivers in Behrang river catchment, Perak Malaysia," *Geografi* 9(2), 107-118. DOI: 10.37134/geografi.vol9.2.6.2021

Hashim, D. S. B., Liew, J. Y., Boon, J. G., Ng, K. H., and Shum, M. S. (2022, June). "Investigation of activated carbon made from Kelantan bamboo as an economical and effective adsorbent for wastewater treatment," in: *AIP Conference Proceedings*, Vol. 2454, No. 1, AIP Publishing.

Hung, K. C., Wu, T. L., Xu, J. W., and Wu, J. H. (2019). "Preparation of biomorphic porous SiC ceramics from bamboo by combining sol–gel impregnation and carbothermal reduction," *Polymers* 11(9), article 1442. DOI: 10.3390/polym11091442

Ibrahim, M. N. (2019). "Effluent quality assessment of selected wastewater treatment plant in jordan for irrigation purposes: Water quality index approach," *Journal of Ecological Engineering* 20(10), 206-216. DOI:10.12911/22998993/112491

Ismail, I. S., Rashidi, N.A., and Yusup, S. (2021). "Production and characterization of bamboo-based activated carbon through single-step H_3PO_4 activation for CO_2 capture," *Environmental Science and Pollution Research* 29, 12434-12440. DOI: 10.1007/s11356-021-15030-x

Kamarudin, M. K. A., Abd Wahab, N., Juahir, H., Nik Wan, N. M. F., Gasim, M. B., Toriman, M. E., Ata, F. M., Ghazali, A., Anuar, A., Abdullah, H., Hussain, N. I., Azmee, S. H., Md Saad, M. H., Saupi, M., Islam, M. S., and Elfithri, R. (2018). "The potential impacts of anthropogenic and climate changes factors on surface water ecosystem deterioration at Kenyir Lake, Malaysia," *International Journal of Engineering & Technology* 7(3.14), 67-74. DOI: 10.14419/ijet.v7i3.14.16864

Kisić, E., Petrović, V., Jakovljević, M., and Đurović, Z. (2013). "Fault detection in electric power systems based on control charts," *Serbian Journal of Electrical Engineering* 10(1), 73-90. DOI: 10.2298/SJEE1301073K

Klein, M. (2004) "Two alternatives to Shewhart $\bar{X}$ control chart," *Journal of Quality Technology* 32(4), 427-431. DOI: 10.1080/00224065.2000.11980028

Lachhab, A., Beren, M., and Zuidervliet, B. (2014). "Middle creek water assessment using water quality index (WQI)," *Journal of the Pennsylvania Academy of Science* 88(1), 4-12.

Lamaming, J., Saalah, S., Rajin, M., Ismail, N. M., and Yaser, A. Z. (2022). "A review on bamboo as an adsorbent for removal of pollutants for wastewater treatment," *International Journal of Chemical Engineering* 2022(1), 7218759.

Lucas, J. M., and Saccucci, M. S. (1990). "Exponentially weighted moving average control schemes: Properties and enhancements," *Technometrics* 32(1), 1-12. DOI: 10.2307/1269835

Maghsoodloo, S., and Barnes, D. (2021). "On moving average control charts and their conditional average run lengths," *Quality and Reliability Engineering International* 37(8), 3145-3156. DOI: 10.1002/qre.2992

Mahanim, S. M. A., Asma, I. W., Rafidah, J., Puad, E., and Shaharuddin, H. (2011). "Production of activated carbon from industrial bamboo wastes," *Journal of Tropical Forest Science* 23(3), 417-424.

Mohammed, M. A., Cheng, K. K., Rouse, A., and Marshall, T. (2001). "Bristol, Shipman, and clinical governance: Shewhart's forgotten lessons," *The Lancet* 357(9254), 463-467. DOI: 10.1016/s0140-6736(00)04019-8

Montgomery, D. C. (2020) *Introduction to Statistical Quality Control*, 8th Ed., John Wiley & Sons, Inc, New York.

Narzary, I., Mahato, R. K., Middha, S. K. Usha, T. and Goyal, A. K. (2024). "Valorization of bamboo charcoal as a low-cost adsorbent for waste water treatment: A mini review," *Advances in Bamboo Science* 7, article 100067. DOI: 10.1016/j.bamboo.2024.100067

Nelson, L.S. (1982) "Control charts for individual measurements," *Journal of Quality Technology* 14(3), 172-173. DOI: 10.1080/00224065.1982.11978811

Nordahlia, A. S., Khairun, M. U., Husain, H., Mohmod, A., and Awalludin, M. (2019). "Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species," *BioResources* 14(2), 3925-3943. DOI:10.15376/biores.14.2.3925-3943

Nyika, J., and Dinka, M. (2022). "Activated bamboo charcoal in water treatment: a mini-review," *Materials Today: Proceedings*, 56, 1904-1907. DOI: 10.1016/j.matpr.2021.11.167

Provost, L. P., and Murray, S. K. (2011). *The Health Care Data Guide: Learning from Data for Improvement*, 1st Ed., Jossey-Bass, San Francisco.

Rubio-Arias, H., Contreras-Caraveo, M., Quintana, R. M., Saucedo-Teran, R. A., and Pinales-Munguia, A. (2012). "An overall water quality index (WQI) for a man-made aquatic reservoir in Mexico," *International Journal of Environmental Research and Public Health* 9(5), 1687-1698.

Wong, H. B., Gan, F. F., and Chang, T. C. (2004). "Designs of moving average control chart," *Journal of Statistical Computation and Simulation* 74(1), 47-62. DOI:10.1080/0094965031000105890

Wong, S., Ngadi, N., Inuwa, I. M., and Hassan, O. (2018). "Recent advances in applications of activated carbon from biowaste for wastewater treatment: A short review," *Journal of Cleaner Production* 175, 361-375. DOI: 10.1016/j.jclepro.2017.12.059

WSDE (Washington State Department of Ecology) (2002). *Setting Standards for the Bacteriological Quality of Washington's Surface Water: Draft Discussion Paper and Literature Summary*, Publication No. 00-10-072. Washington DC.

Yan, X., Jia, Y., Chen, J., Zhu, Z., and Yao, X. (2016). "Defective-activated-carbon-supported Mn-Co nanoparticles as a highly efficient electrocatalyst for oxygen reduction," *Advanced Materials* 28(39), 8771-8778. DOI: 10.1002/adma.201601651

Zaki, Z. (2010). "Benchmarking river water quality in Malaysia," *Jurutera* 50, 12-15.

Zhang, B., Zeng, X., Xu, P., Chen, J., Xu, Y., Luo, G., Xu, M., and Yao, H. (2016). "Using the novel method of nonthermal plasma to add Cl active sites on activated carbon for removal of mercury from flue gas," *Environmental Science & Technology* 50, 11837-11843. DOI: org/10.1021/acs.est.6b01919

Article submitted: June 14, 2024; Peer review completed: July 14, 2024; Revised version received and accepted: August 13, 2024; Published: December 2, 2024.
DOI: 10.15376/biores.20.1.1008-1023