Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.24790

175 (2020) 32–42
January

Water quality assessment of urban catchment after the large-scale flood event: The worst natural tragedy at Pahang River, Malaysia

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Received 6 April 2019; Accepted 14 August 2019

ABSTRACT

Floods are the most significant natural disasters, which have brought miseries to approximately 23 billion victims over the last 20 years. The 2014 flood tragedy is recognized as the "Tsunami-like disaster" in the history of Malaysia. In that disaster, more than 404,000 victims were evacuated and at least 24 of them were reported deaths. In this work, the physicochemical alterations of the Pahang River, encompassing the solution pH, water temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonical-nitrogen (AN) and total suspended solids (TSS) were evaluated, after the largest flood tragedy. The significant relationship between the changing water quality parameters was assessed using the multivariate statistical analysis. Results revealed that the pollution loads showed a great amplification after the heavy flood event, with the mean values for BOD_5, COD, DO, AN, solution pH, TSS, and overall water quality index of 17.28 mg/L, 64.5 mg/L, 3.97 mg/L, 1.52 mg/L, 5.23, 39.44 mg/L and 40.93, respectively, as compared with 4.65 mg/L, 15.3 mg/L, 6.62 mg/L, 0.26 mg/L, 7.22, 7.9 mg/L and 65.95, respectively before flooding. This complementary study highlights the pressing urgency to update the existing emergency water quality strategic plan, and establish better healthcare facilities for future emergency responses.

Keywords: Climate change; Disaster; Flood; Rainfall; River; Water quality index

1. Introduction

Flood, due to intense or prolonged rain, or climate change, rising population, and poorly adapted land uses, is by far the most cataclysmic natural disasters in the world, responsible for the total economic damages of US$ 1.891 trillion, affecting approximately 23 billion of victims, with 244,000 of reported deaths and 4 billion injuries for the past 20 years [1]. Among all, the 1931 flood event in Huang He River, China, turned out to be the deadliest natural disaster with the total death of 4 million, while the 1998 Yangtze, China flood event had devastated an area of 100,000 km^2, with the infrastructure loss exceeding US$ 30 billion. Meteorological prediction has forecasted that the economic loss driven by the flood events could increase five-folds during the period from 2000 to 2045, amounting from US$ 5 billion to US$ 26 billion for the next 45 years [2].

Similarly, Malaysia has experienced a series of flood episodes since 1800s, that has affected approximately 29,720 km^2 or 9% of the total land areas, 4.9 million victims, and inflicted the economic damages of exceeding US$ 227.9 million per year [3]. The lengthy time scale of the catastrophic rainfall during the cyclical Southwest and Northeast monsoons from May to September and November to March, respectively, is the most forceful factor to trigger the rising ominous flood events in Malaysia. Pahang River, the longest river in the Peninsular Malaysia with the total catchment area of 29,300 km^2, has received the deepest annual rainfall rate, exceeding 40% of the total precipitation in Malaysia.

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The recent 2014 flood was the worst tragedy in Malaysia for the past 30 years, which had seriously inundated and devastated 18,000 km^2 of the low-lying catchments along the Pahang River out of the total flood affected area of 23,730 km^2 throughout the country [4].

During these critical moments, the seasonal variations in precipitation, surface runoff, interflow, groundwater flow and pumped in and outflows during the flood events demonstrated a strong effect on the river discharges, and subsequently on the concentration of pollutants in the water bodies. According to the Pringle et al. [5], contaminated water was one of the major problems during extreme floods, with over 70% to 100% of the backwater lakes and levees along the flooded rivers have lost their capacities, to drastically deteriorate the water supplies, watersheds, and biodiversity of the river systems. The high flowing rate of floodwater, which has spread and concentrated in the local depression, could react as the vehicle to disseminate the organic and inorganic substances, nutrients, dissolve pollutants, toxic and hazardous chemicals, faeces and infectious microorganisms from the leaking sewers, agricultural effluents, farmyard runoff, industrial wastewater discharge and slurry spreading into the nearby natural aquatic resources in a short period of time, especially in the case of heavy rainfall [6].

The large-scale contamination of floodwater was reflected directly by the rising incidences of gastrointestinal and skin disorders at the epidemic levels, and the widespread of water-borne diseases, including cholera, shigellosis, campylobacteriosis, amebiasis, giardiasis, cryptosporidiosis, norovirus, typhoid and paratyphoid fever, leptospirosis, and hepatitis A. A series of epidemic tragedies subsequent by the contamination of floodwaters have been documented: the 2004 flood incidence in Mozambique, 2004 flood incidence in Bangladesh, 2002 flood incidence in Jakarta, 2001 flood incidence in Republic of China, 2000 flood incidence in India, 1998 flood incidences in West Bengal and Argentina, 1997 flood incidence in Russian, 1996 flood incidence in Brazil and 1994 flood incidence in Indonesia [7]. To account for the water quality variability following the 2014 heavily flood event, the present work was conducted to simulate a deeper understanding on the alteration of physicochemical characteristics along the Pahang River, encompassing the solution pH, water temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonical-nitrogen (AN), total suspended solids (TSS) and overall water quality index (WQI). The unique relationship integrating these water quality parameters with the extreme weather events were statistically interpreted.

2. Materials and methods

2.1. Location of study

The location of the study area, Pahang River, situated between the longitudes of E 101° 16′ 31″ and E 103° 29′ 34″, and between the latitudes of N 2° 48′ 45″ and N 3° 40′ 24″, is the largest river in the Peninsular Malaysia. It is the main artery of Pahang River Basin (Fig. 1), with a maximum length and breadth catchment of 459 and 236 km, respectively, where it drains an area of 29,300 km^2, from the upstream of Cameron Highlands to the South China Sea. This area has a humid equatorial climate, and characterized by a bimodal pattern of Southwest and Northeast monsoons, with the mean temperature of 25°C–27°C, average humidity of 85%, and an annual rainfall rate of 1,600 mm/year. These extreme rainfalls have led to the inundation of the nearby lowland areas. From the impact of the historical global climate change, multiple problems have arisen in the evolution of the meander process along the Pahang River, with the largest flood incidences being recorded in 1926 and 2014. The flood began at the late November 2014 was the most severe tragedy in Malaysia for the past 30 years, which had submerged and devastated approximately 18,000 km^2 of lowland areas lying along Pahang River for 1 month, signifying 75.9% of the flood prone areas throughout the country [4].

2.2. Water sampling scheme

The water sampling scheme was designed to cover a wide range of determinates of key sites, which reasonably represent the physicochemical qualities of the Pahang River Basin. In the study, the triplicate water samples were collected from 26 accessible areas in industrial, aquaculture, agricultural and residential areas that were heavily destroyed, and the total sampling stations, including the upstream and downstream points of the river were ascertained using the global positioning system (GPS) (Table 1), meanwhile the total rainfall pattern was acquired from the Meteorological Department, Malaysia. The sampling results recorded between July 2014 to October 2014 was rated as pre-flooding data, while the post-flooding sampling activity was scheduled from January to March 2015.

Water samples were collected in sterilized high-density polyethylene (HDPE) bottles, previously cleaned by soaking in 10% of concentrated nitric acid (HNO_3), and rinsed in ultrapure water, by dipping each bottle at 15 cm below the water surface, projecting the mouth of the container against the direction of flow. These bottles were rinsed with the source water at least three times before they could be used. These water samples were stored in an insulated ice box, and transported to the laboratory for immediate analysis.

2.3. Physicochemical analysis

The physicochemical parameters were assessed according to the laboratory standard procedures. Physicochemical parameters, including the solution pH, water temperature, dissolved oxygen (DO), total dissolved solids (TDS), and turbidity were measured using a portable multimeter (YSI 556 MPS multi-probe system), turbidity meter (2100Q Portable Turbidimeter) and a pH meter with temperature probe (XL600 accumet®, Thermo Fisher Scientific Inc., Waltham, MA, USA). The analytical determination of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonical-nitrogen (AN) and total suspended solids (TSS) were determined according to the luminescence measurement, closed reflux colorimetric, salicylate, and gravimetric digestion methods [8], using a spectrophotometer (HACH DR3900, HACH Company, Loveland, CO, USA). Each water quality and procedural blank measurements were undertaken in triplicates, and the field meters and instruments were well-calibrated according to the manufactures' specification before field samplings. The analytical precision for the

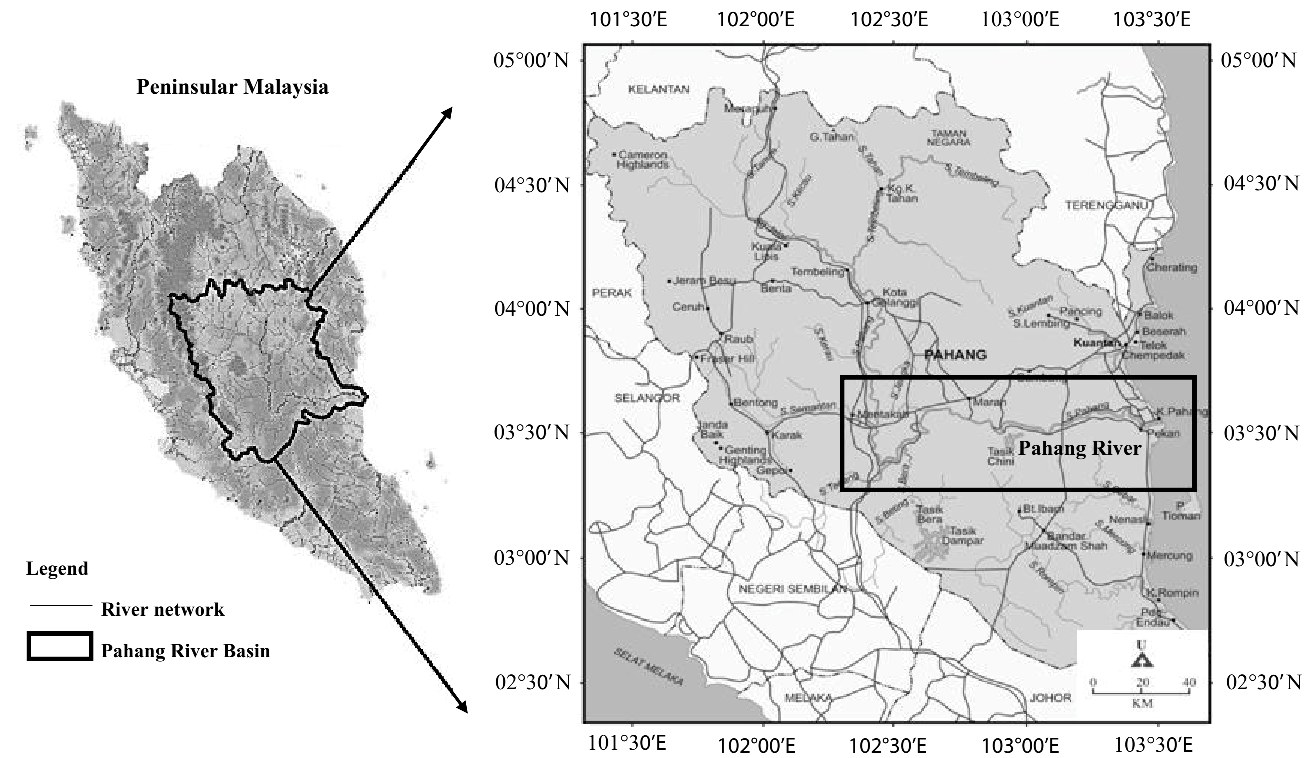

Fig. 1. Geographical location and sampling sites of Pahang River.

triplicate samples was within ±10%, and the measurement errors between the determined and certified values were less than 5%.

2.3.1. Water quality index

The water quality was classified into different classes, according to the WQI system adopted by the Department of Environment, Malaysia [9]. Six water quality parameters, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonical-nitrogen (AN), and solution pH are the pre-dominant parameters quantified by Eq. (1):

$$\text{WQI} = 0.22\text{SIDO} + 0.19\text{SIBOD}_5 + 0.16\text{SICOD} + 0.16\text{SITSS} + 0.15\text{SIAN} + 0.12\text{SIpH} \quad (1)$$

where SI refers to the sub-index function for each of the given parameters, and the coefficients are the weighing factors derived from the opinion poll, with SIDO, $SIBOD_5$, SICOD, SIAN, SITSS and SIpH are the sub-indexes of DO, BOD_5, COD, AN, TSS, and pH, respectively derived as:

Sub-index for DO (in % saturation):

$$\text{SIDO} = 0 \quad \text{for DO} \leq 8 \quad (2)$$

$$= 100 \quad \text{for DO} \geq 92 \quad (3)$$

$$= -0.395 + 0.030\text{DO}^2 - 0.00020\text{DO}^3 \quad \text{for } 8 < \text{DO} < 92 \quad (4)$$

Sub-index for BOD_5:

$$\text{SIBOD}_5 = 100.4 - 4.23\text{BOD}_5 \quad \text{for BOD}_5 \leq 5 \quad (5)$$

$$= 108e^{-0.055\text{BOD}_5} - 0.1\text{BOD}_5 \quad \text{for BOD}_5 > 5 \quad (6)$$

Sub-index for COD:

$$\text{SICOD} = -1.33\text{COD} + 99.1 \quad \text{for COD} \leq 20 \quad (7)$$

$$= 103e^{-0.0157\text{COD}} - 0.04\text{COD} \quad \text{for COD} > 20 \quad (8)$$

Sub-index for AN:

$$\text{SIAN} = 100.5 - 105\text{AN} \quad \text{for AN} \leq 0.3 \quad (9)$$

$$= 94e^{-0.573\text{AN}} - 5\,|\text{AN} - 2| \quad \text{for } 0.3 < \text{AN} < 4 \quad (10)$$

$$= 0 \quad \text{for AN} \geq 4 \quad (11)$$

Sub-index for TSS:

$$\text{SITSS} = 97.5e^{-0.00676\text{TSS}} + 0.05\text{TSS} \quad \text{for TSS} \leq 100 \quad (12)$$

$$= 71e^{-0.0016\text{TSS}} - 0.015\text{TSS} \quad \text{for } 100 < \text{TSS} < 1000 \quad (13)$$

$$= 0 \quad \text{for TSS} \geq 1000 \quad (14)$$

Table 1
Description of sampling locations along Pahang River

Coordinates of sampling sites			Sampling stations	District	Major economic activities
Samples	North	East			
1	03°30.544′	103°23.685′	Kuala Pahang	Pekan	Sand dredging
2	03°30.586′	103°23.584′	Kampung Pulau Maulana		Fishery
3	03°30.869′	103°23.579′	Kampung Permatang Arang		Aquaculture
4	03°30.796′	103°23.226′	Kampung Pasir Panjang		Jetty port
5	03°30.874′	103°23.226′	Kamgpung Pulau Tambun		Aquaculture
6	03°31.486′	103°23.225′	Kampung Ketapang		Forest
7	03°31.388′	103°22.592′	Kampung Pekan Seberang		Swamp
8	03°32.332′	103°20.577′	Kampung Pulau Keladi		Recreational
9	03°33.230′	103°21.056′	Kampung Langgar		Aquaculture
10	03°32.137′	103°17.436′	Ganchong		Water treatment plant
11	03°29.546′	103°06.546′	Temai		Jetty port
12	03°29.510′	103°06.480′	Lepar		Oil palm plantation
13	03°29.346′	103°05.889′	Kampung Paloh Hinai		Flood gate
14	03°27.499′	103°03.973′	Penyor		Sand mining
15	03°30.119′	103°45.574′	Lubuk Paku	Maran	Recreational
16	03°30.076′	103°45.512′	Luit		Lockgate to Chini Lake
17	03°30.041′	103°45.476′	Tajau		Oil palm plantation
18	03°30.670′	103°43.877′	Kampung Pesagi		Swamp
19	03°30.157′	103°36.099′	Chenor		Agriculture
20	03°28.763′	103°35.774′	Kertau		Forest
21	03°28.736′	103°35.723′	Mentakab	Temerloh	Industrial park
22	03°28.741′	103°35.679′	Bandar Bera		Jetty port
23	03°27.140′	103°25.643′	Lebak		Aquaculture
24	03°27.167′	103°25.590′	Kampung Teluk		Oil palm plantation
25	03°27.264′	103°25.576′	Perak		Residential area
26	03°26.583′	103°25.730′	Kuala Semantan		Fishery and recreational

Sub-index for pH:

$$SIpH = 17.2 - 17.2pH + 5.02pH^2 \quad \text{for } pH < 5.5 \quad (15)$$

$$= -242 + 95.5pH - 6.67pH^2 \quad \text{for } 5.5 \le pH < 7 \quad (16)$$

$$= -181 + 82.4pH - 6.05pH^2 \quad \text{for } 7 \le pH < 8.75 \quad (17)$$

$$= 536 - 77.0pH + 2.76pH^2 \quad \text{for } pH \ge 8.75 \quad (18)$$

2.4. Statistical analysis

Water quality parameters were analysed statistically using the Box–Whisker plots, a powerful statistical tool that demonstrates the median, range and shape of the data distributions. The box plots were generated for the solution pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonical-nitrogen (AN) and water quality index (WQI) before and soon after the flood event. Box plot defines the minimum and maximum values at the end of the vertical lines, with the central line in the box to indicate the median value, while the 25th percentile and 75th percentile of the data set was depicted as the lower and upper edges of the box plots, respectively. The significant inter-relationship between the pair variables were conducted by using Pearson's correlation coefficient, while the mean difference between each water quality variables was detected using the One-Way analysis of variance (ANOVA) and Duncan post hoc test. A probability value of $p < 0.05$ was considered as significant.

3. Results and discussions

3.1. Physicochemical characteristics of Pahang River

3.1.1. Rainfall pattern and water temperature

3.1.1.1. Rainfall pattern

Climate change is a major initiating factor affecting the critical state changes of extreme rainfall event, in term of distribution, duration, intensity and local rainfall frequency. With reference to the climate change prediction suggested by the General Circulation Model (GCMa), a 1.5°C–4.5°C rise in the global mean air temperature would increase the global mean precipitation at approximately 3%–15% [10]. The projected changes in air temperature and rainfall patterns are highly and positively associated with the incidence and magnitude of the flood hazards in major cities of the world, including Malaysia. The specific features of the monthly rainfall at Pahang River throughout 2014 have been plotted in Fig. 2a, according to the analysis at three gauging stations, namely Pekan, Rumah Pam Paya Kangsar and Temerloh rainfall stations.

The analyzed results in Fig. 2a showed that the rainfall along Pahang River in 2014 ranged from 222.33 mm to 2,868.33 mm, with an average rainfall of 1,545.33 mm. The highest rainfall was recorded in December, while the lowest rainfall fell in June, with the mean value of 2,868.33 mm and 222.33 mm, respectively. From the findings, the rainfall stations along Pahang River received the maximum rainfall during the regime of Northeast monsoon period in 2014, amounting to almost 40% of total rainfall annually in Malaysia. The sequence of the continuous rainfall caused by the seasonal wind flow pattern and local topographic features, has resulted in higher river flow and water level of the Pahang River, contributing to the overflow phenomena or serious flood events along the river basin, especially at the lowland areas and floodplains [11].

3.1.1.2. Water temperature

Water temperature is a description of the thermal condition of the river systems, and the predominant parameters affecting the river water temperature are heat exchange between the earth surface under controlled radiation, groundwater movement, and chemical and thermonuclear process in the aquifer system. The water temperature along Pahang River varied from 23.8°C to 27.8°C throughout 2014, as indicated by in-situ readings demonstrated in Fig. 2b. The water temperature range is very much dependent on the weather condition, sampling time, and sampling locations. The alteration of water temperature would further affect the chemical reaction kinetics, and deterioration of the temperature-dependent water quality parameters, including dissolved oxygen (DO), water pH and microbial activity [12].

During the dry season from June to September, the water temperature ranged within 25.2°C–27.8°C, mainly ascribed to the low precipitation rate, and the rising temperature of surface water driven by the penetration of sunlight to the bottom of the river water. Additionally, the release of the heated industrial effluents from boilers and turbines, may promote thermal pollution in the watercourse, to significantly affect the aquatic flora and fauna. During the flooding month, the lowest mean water temperature of 23.8°C was recorded along Pahang River. The phenomenon was attributed to the large volume of water inputs and higher flow rate during the heavy rainfall, with a sharp drop in the evaporation rate, that were responsible to cool down the temperature of the surface water. In this work, the lowest temperature range was recorded at some sampling points in the vicinity of the forest at Kampung Ketapang, Pekan and Kertau, Maran, with low human anthropogenic activity, and associated with the presence of riparian vegetation, channeled points and tributary receivers at the sampling stations.

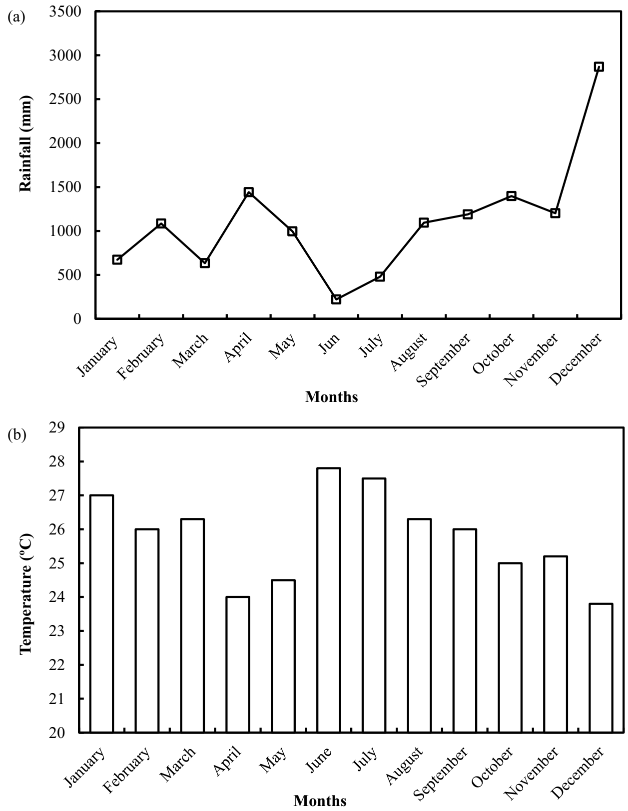

Fig. 2. The monthly rainfall depth (a) and water temperature (b) along Pahang River in 2014.

The changing temperature regime after a series of continuous extreme rainfall could play a key role in the regulation of freshwater ecological status, particularly the life cycle of phytoplankton, macrophytes and epiphytes, which show high sensitivity to the rising temperatures as they are cold-blooded, and with a limited thermal tolerance range [13]. This observation was in agreement with the finding reported by Hussain et al. [14], where the water temperatures of River Ravi, Pakistan, started to rise in February, peaked at 33.89°C during the summer (July–September), and it dropped drastically to 14°C–15°C in December, mainly ascribed to the excessive rainfall and mixing of incoming cold river water with the floodwater.

3.1.2. pH and turbidity

3.1.2.1. pH

The acidity and alkalinity of surface water could be varied according to the degree of decomposition of the biotic activities, and the changing abiotic factors at the location of study. pH value is a function of the concentration of hydrogen ions [H+] in the aqueous phase, with the pH lower than 7 implies an acidic behavior, and pH greater than 7 is denoted to the basic medium. The changing water pH before and after the 2014 flood incident along the Pahang River is illustrated in Fig. 3a. Before the flood incident, the pH of the floodwater ranged between 6.84 and 7.62, with the mean value of 7.22, that is within the limit permitted by the Department

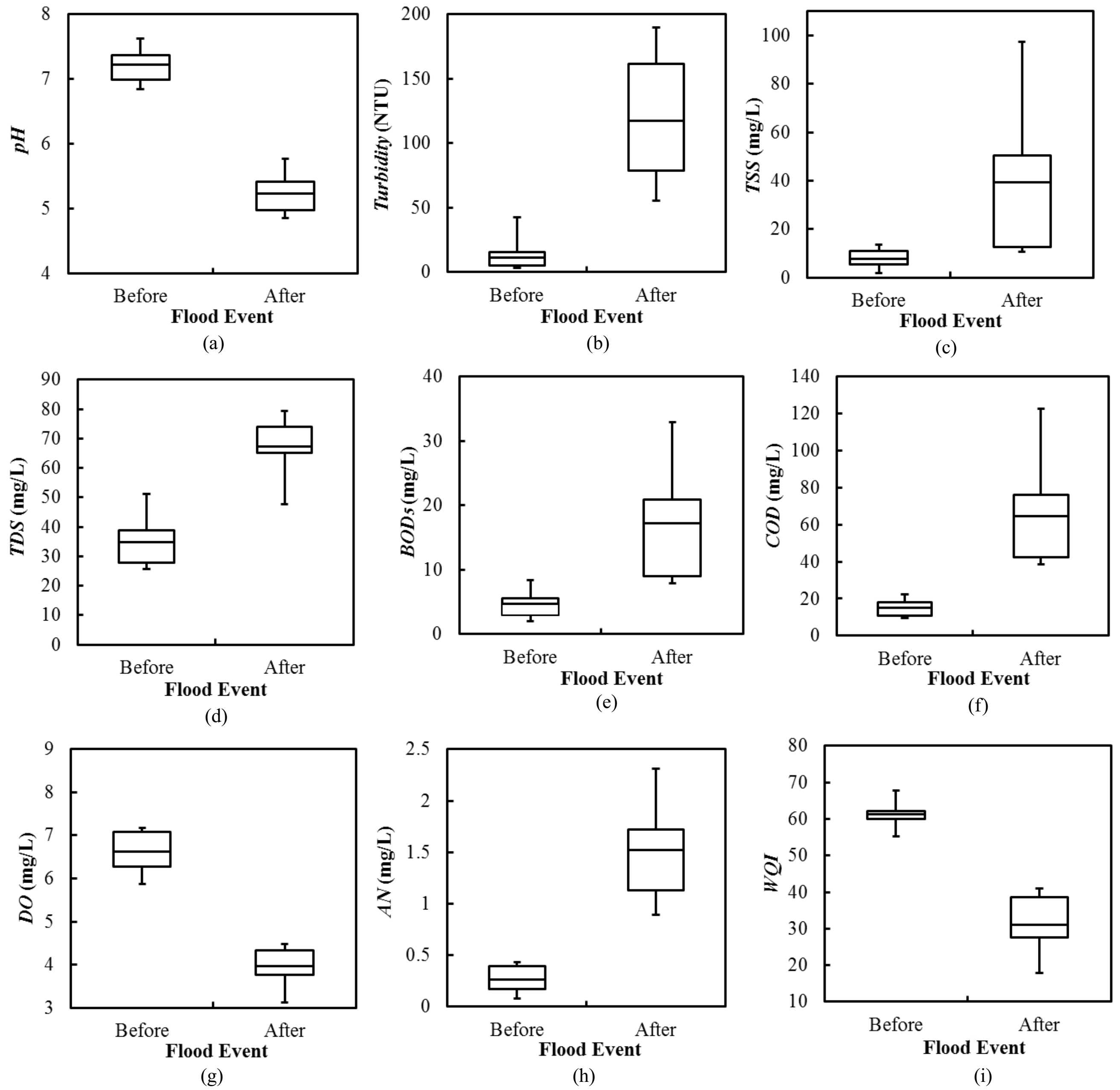

Fig. 3. Changing water pH (a), turbidity (b), TSS (c), TDS (d), BOD_5 (e), COD (f), DO (g), AN (h) and WQI (i) before and after the 2014 flood incident along Pahang River.

of Environment, Malaysia and World Health Organization [15], that lies from 6.0 to 9.0, and from 6.5 to 8.5, respectively. Meanwhile, it dropped drastically to 4.85–5.77, with the average value of 5.23, which is slightly acidic soon after the prolonged raining season. According to the Interim National Water Quality Standard (INWQS) [9], the pH of the river water before flooding fell under Class I, and it degraded to Class III soon after the flood event ($F = 85.347$, $p < 0.05$) (Table 2).

The fluctuation of the water pH may be mainly governed by the mixing of river water with the anthropogenic chemicals, hazardous pollutants, agricultural discharges, industrial effluents or sewage waste emitted from the commercial, domestic and industrial zones. The rising decomposition activities and acid precipitation rate, driven by the heavy rainfall, have concurrently affected the chemical compositions of the river water. The lowest pH condition was recorded at the sampling stations near to the agricultural sites at Lepar, Pekan; Tajau, Maran; and Kampung Teluk, Temerloh, with the mean pH of less than 4.85.

This research findings could be attributed to the wide-scale application of pesticides, fertilizers and acid-forming substances, including sulphates, phosphates and nitrates, that were brought by the rain water into the river basin, to severely alter the acid-base equilibria, resulting in the lower acid-neutralizing capacity, microbial oxidation and fermentation process [16]. Additionally, the changing water pH

Table 2
Classification of water quality index according to the Department of Environment (DOE), Malaysia

Parameter	Unit	Class				
		I	II	III	IV	V
Ammonical-nitrogen (AN)	mg/L	<0.1	0.1–0.3	0.3–0.9	0.9–2.7	>2.7
Biochemical oxygen demand (BOD_5)		<1	1–3	3–6	6–12	>12
Chemical oxygen demand (COD)		<10	10–25	25–50	50–100	>100
Dissolved oxygen (DO)		>7	5–7	3–5	1–3	<1
Total suspended solids (TSS)		<25	25–50	50–150	150–300	>300
pH	–	>7.0	6.0–7.0	5.0–6.0	<5.0	>5.0
Water quality index (WQI)	–	>92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0
Status	–	Very good	Good	Average	Polluted	Very polluted

could affect the solubility of the heavy metals and nutritive chemicals, and particularly highly sensitive to the sustainability of aquatic communities, leading to the deterioration of the ecosystems once the maximum tolerance level has been exceeded.

3.1.2.2. Turbidity

Turbidity is a measurement of cloudiness of water, resulting from the presence of different suspended particles within the surface water, including silt, plankton, solid particles (clay and mud) and organic matters, generated by the dissolution and weathering of rocks and soils. Water turbidity could be related to the expression of optical property, and it reflects the intensity of light scattered by the colloidal particles in the water [17]. Accordingly, Hammer and MacKichan [18] have suggested that the turbidity value of 10 NTU or less would indicate a very clear water, whereas a value greater than 25 NTU shows an impaired water quality for domestic uses, while a value higher than 50 NTU is defined as the cloudy condition.

The changing water turbidity before and after the flood incident is illustrated in Fig. 3b. From the figure, the turbidity reading, that ranged within 3.09–34.72 NTU, with the mean value of 11.31 NTU, was substantially lower during normal condition. Meanwhile, an extremely higher water turbidity value, between 55.31 and 189.93 NTU, with the mean reading of 117.55 NTU, was detected at the Pahang River soon after the heavily flooding under 10 m in depth ($F = 16.743$, $p < 0.05$). The alteration of the water turbidity at the flooding month is attributed to the water wave and surface turbulence induced by the tides and winds during the flooding season, which have facilitated the mixing of sediments, silt, clay and different suspended particles with the overlying water volume, surface-runoff, stream flow, and overland flowing natural waters [19]. Moreover, the changing turbidity of the river water may be driven by the effluent discharges originated from the livestock farms, agricultural fields, soil erosions or urban runoffs. A similar abrasive effect has been reported at Bonny River, Nigeria [20] and Weija water system, Ghana [21], that have reported an extremely high water turbidity, induced by the soil erosion at the high flow of the floodwater, resulting in the transportation of nutrient detritus, silt and industrial effluents into the water body. This rising water turbidity would eventually affect the natural environment via several major mechanisms, including smothering of benthic organisms, reduction of visual clarity, irritation of fish gills, and reduction of available light in supporting the photosynthetic process.

3.1.3. TSS and TDS

3.1.3.1. TSS

Total suspended solids (TSS), in both forms of organic and inorganic loadings, usually with the particle size greater than 0.45 μm, are the colloidal suspensions in the water body. The excessive presence of TSS would affect the turbidity reading of the surface water, to turn the water into milky or muddy looking. The TSS readings before and after the 2014 flood event are shown in Fig. 3c. Generally, the TSS concentrations of the river water ranged between 1.85 and 13.46 mg/L, with the mean value of 7.90 mg/L before flooding, and it increased significantly soon after the flood incident, that vary from 10.75 to 97.28 mg/L, with the average value of 39.44 mg/L ($F = 3.854$, $p < 0.05$). The rising concentration in the water column was likely due to the heavy rainfalls, which was approximately three times higher than the same month at the flooding season in 2013. During this period, the TSS pollutants were carried from the nearby terrestrial environment by the huge flow of floodwater, and deposited as bottom sediments in the water body, and churned up or re-suspended by the precipitation process, to affect the turbidity level and TSS content along the Pahang River.

Specifically, the sampling stations that are vicinity to the agricultural and industrial sites at Mentakab, Temerloh, and Kuala Pahang and Penyor, Pekan were heavily exposed to the particle pollutants, with the highest suspended solids readings at 80 mg/L, indicating a huge accumulation of water sediments after the flood event. Similar observation had been found at the Guadalquivir River, Spain, which exhibited a new peak of TSS value of up to 250 mg/L, at the area near the agricultural fields and mining zones after a series of heavy rainstorm [22]. These heavy rainfalls had enhanced the river flow, and directed by the severe input of urban pollutants, to contribute towards the high concentration of TSS and dissolved metals in the river system.

This deposition could prevent sufficient oxygen transfer, and hamper the water quality by increasing the water density, the solubility of oxygen and water clarity, to stimulate the osmoregulation of the freshwater organisms. According to the INWQS, the maximum threshold limit for TSS in the river systems is less than 25 mg/L [9]. An average TSS concentration of 25 mg/L is known to be an indication of unimpaired water quality, and surface water with the TSS value higher than 50 mg/L shows a potential impairment to the water body, that is unpalatable and significantly unhealthy to the freshwater ecosystem [23].

3.1.3.2. TDS

Total dissolved solids (TDS) reveals the soluble organic and inorganic substances in the surface water, in both molecular, ionized or micro-granular suspended forms, consist of mainly carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron and manganese ions [24]. Fig. 3d shows the variation of TDS before and after the 2014 flood event along Pahang River. From the present study, the TDS values varied between 25.7 and 51.2 mg/L, with the mean reading of 34.83 mg/L before the flood event, and it rose dramatically to 47.6–79.33 mg/L, with the average value of 67.35 mg/L after the tragedy ($F = 19.648$, $p < 0.05$). This phenomenon could be due to the variety of water contaminants that were brought by the stormwater into the river body, specifically from the residential areas, pesticides or fertilizers from the extreme anthropogenic activities along the river course [25].

According to the World Health Organization [26], the TDS value of less than 300 mg/L is still suitable for daily activities, while the TDS measurement of greater than 500 mg/L signifies a high degree of pollution, with potential gastrointestinal irritation. The obtained result is in parallel with the research findings reported by Anyanwu [27], along the Ogba River, Nigeria, with the TDS range between 14.48 mg/L and 66.4 mg/L after the devastated flood incident in 2012, which could be ascribed to the changing water compositions, inorganic pollutants, and population density of flora and fauna. The exposure to high TDS of the floodwater could be expressed in terms of water toxicity, resulting in the nutrient enrichment status, eutrophication of aquatic ecosystem, to provide unpleasant laxative effects, and give rise to the biological and chemical oxygen demands, and eventually lead to the depletion of dissolved oxygen throughout the water system [28].

3.1.4. BOD_5 and COD

3.1.4.1. BOD_5

Biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are the measurement of organic compounds in the water, with BOD_5 is a gross estimation of the oxygen demanding potential of microorganisms to oxidize and decompose the organic materials via a series of biochemical reactions over a 5-days period at a temperature of 20°C. It serves as a useful pollution index or indicator for organic enrichment in the water body. Hence, in the condition with sufficient oxygen supply in the wastewater, the useful aerobic bacteria will flourish and carry out aerobic biological decomposition of wastewater until the oxidation process is fully completed.

The variation of BOD_5 concentration before and soon after the flood event is given in Fig. 3e. The BOD_5 values of these sampling points, which lied between 1.98 to 8.33 mg/L, with the mean value of 4.65 mg/L ($BOD_5 \leq 5$ mg/L) before the flood disaster, indicated that the ecosystem was healthy with respect to the biodegradable organic pollution. In contrast, it had degraded to 17.28 mg/L, in the range of 7.92–32.91 mg/L soon after the flood event ($F = 6.966$, $p < 0.05$), that has exceeded the INWQS threshold level of BOD_5 according to the guidelines enacted under INWQS [9], which may be due to the huge volume of floodwater, which had transported a series of industrial discharge, and organic and inorganic chemicals from the lowland of plantation areas and septic systems into the water stream. The higher BOD_5 level in the floodwater could be ascribed to the rising decomposition activity of microorganisms on the dead aquatic plants, leaves, manure and sewage waste being flushed by the inflow floodwater.

Similar condition has been reported in the historical flood tragedy in New Orleans, Philippine, with exceeding 24 municipal treatment plants were flooded after the Hurricane Floyd, which contributed greatly to the BOD_5 content [29]. The scenario was found at the lower stretch of the Pasig River, Philippines, which functioned as the conduit for stormwater runoffs [30], and in Metro Manila, Philippines, approximately 58% of the BOD_5 loading generated by the domestic waste was transported to the aquatic system through large volume of floodwater. The same conclusive statement was found at the Kaoping River, Taiwan, after the flood event in 2009 [31]. Theoretically, the high BOD_5 concentration could be inversely related to the concentration of DO in the water surface, to induce stressful implication to the aquatic flora and fauna. The high BOD_5 level in the natural water may reduce the oxygen content available to the aquatic organisms, and stimulate anaerobic conditions, with the possible release of hydrogen sulfide and ammonia, that could severely affect the sustainability of the ecosystems.

3.1.4.2. COD

Chemical oxygen demand (COD) is an important parameter elucidating the total quantity of oxygen required to oxidize high amount of organic and inorganic constituents, in the form of proteins, carbohydrates, detergents, tannins, lignin, humic acid, fulvic acid, melanic acid and dissolved organic compounds enriched in the wastewater by using a strong chemical oxidant, to be converted into carbon dioxide (CO_2) and water [32]. The extent of oxidative degradation is characterized by the amounts of electrons transferred to the chemical oxidizing agent during chemical oxidation, and the strong oxidizing agent preferred in this test is potassium dichromate, due to its superior oxidizing ability, applicability to a variety of samples, and ease of manipulation [33]. The COD values are always greater than BOD_5 values as many organic substances in the water could be oxidized chemically but not biologically. The ratio of BOD_5/COD expresses the quantity of biodegradable matter in relation to the total organic matter. These two parameters are both lower in the rainy seasons due to the influx of fresh water, leading to the dilution in stream, sewage and industrial waste samples.

The variation of COD before and after the 2014 flood event is depicted in Fig. 3f. Generally, the COD concentration ranged between 9.70 to 22.25 mg/L with the average value of 15.3 mg/L, to be classified under Class II before the flood event, and it increased significantly to 38.4–122.5 mg/L, with the mean value of 64.5 mg/L soon after the disaster, which fall under Class IV, according to the classification defined under INWQS ($F = 9.229$, $p < 0.05$) [9]. The fluctuation of the COD concentration indicated a higher degree of pollution, with dramatic changes of the organic and inorganic matter contents deposited in the river system. The high COD values after the flooding incident could be correlated with the wide chemical contents, specifically organic fertilizers or sewage discharge being carried by the floodwater and surface runoff, pointing to a detrimental deterioration of the available water resources. Zhang et al. [34] have reported a similar finding, whereby the COD concentration along Fu River, China increased by 46.5%–50% during the flooding season between 2001 and 2015, that may be ascribed to the huge accumulation of industrial wastewater and municipal sewage from the Baoding City, which have significantly threatened the overall water pathways.

3.1.5. DO and AN

3.1.5.1. DO

Dissolved oxygen (DO) is the amount of dissolved oxygen freely available in the water sample. It is a predominant parameter required to assess the waste assimilative capacity of the river water, and vital to all forms of aquatic life. The DO level before and after the flood event is demonstrated in Fig. 3g. Generally, the DO concentrations of the river water ranged within 5.87–7.18 mg/L, with the mean value of 6.62 mg/L before the flood event, that was classified under Class II according to the INWQS classification, while the DO concentration of the water samples was degraded to Class III, with the mean concentration of 3.97 mg/L, and concentration range of 3.13–4.48 mg/L, respectively, after the flood event ($F = 58.614$, $p < 0.05$) [9].

The quantitative changes of the DO level were dependent primarily on the intensity of the biological processes, including photosynthesis, respiration, phytoplankton metabolism, and re-mineralization of organic matters, driven by the changing hydro-meteorological conditions. The oxygen consumption rate during the large-scale flooding appeared to be higher, supported by the rising heterotrophic microbial activities, and continuous input of organic matters: organic carbon, ammonium and inorganic reducing agents, including hydrogen sulphide, ammonia, nitrites, and oxidizable substances from the submerged drains in the nearby water resources. Similar research findings were recorded in Minjiang River, China and Hindon River, India, which demonstrated a heavily drop of the oxygen budget of 4.2–6.2 mg/L and 5.2–9.2 mg/L, respectively, during the flooding season [35,36]. This alteration of DO content is closely associated with the dramatic deterioration of aquatic life, that may adversely affect the functioning and survival of the overall biological communities [37].

3.1.5.2. AN

In surface water, nitrogen could exist in many chemical forms, including organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, with ammonical-nitrogen (AN) being the major form [38]. AN is formed by a series of chemical and bacterial decomposition steps, or breakdown of the principally protein-bearing materials. It serves as the most influencing water quality parameter for different water sources, as it could affect the pre-chlorination and disinfection of the wastewater treatment plants [39]. The changing AN concentration before and after the flood event is displayed in Fig. 3h.

Typically, the AN contents of the water samples before the flood event were lower than 0.1 mg/L, that were below the maximum permissible limit permitted by the World Health Organization [26], and classified as Class II (0.08–0.43 mg/L), derived as "Clean", and it had drastically degraded into Class IV (0.89–2.31 mg/L), defined as "Polluted" after the flood event ($F = 24.542$, $p < 0.05$). Similar result was recorded at Ciliwung River, Thailand, detected a quantitatively higher concentration of 2 mg/L in the river water samples after the severe flood event in 2005 [40]. The high concentrations of AN could be an indication of the heavily eroded soil and nitrogenous inputs from the livestock farming, domestic sewage, and the presence of un-ionized compounds of nitrogen, derived from the inadequate disposal of manure from industrial effluents. The excessive presence of AN implied the rapid decomposition of nitrogen compounds, in promoting extreme eutrophication activities in the freshwater system [41].

3.1.6. Water quality index

3.1.6.1. WQI

The WQI score is a viable tool for the categorization of the water body, that could be divided into one of the six classes as provided under the Interim National Water Quality Standards for Malaysia (INWQS). The water quality index is established according to six predominant water quality parameters, including DO, BOD_5, COD, AN, TSS and water pH, with respect to the Malaysian's Water Quality Index Guidelines. The WQI value should fall within the range of $0 \leq WQI \leq 100$, which a higher index value represents the better water quality, with 100 is the highest possible score, and denotes a pristine river, and zero indicates the lowest. This rating has been widely applied to illustrate the degree of water pollution status, and designation of classes of beneficial uses [42]. The variation of WQI before and after the flood event is demonstrated in Fig. 3i. The mean WQI at the Pahang River before the flood event was 65.94, whereas the WQI had dropped to 40.93 after the flood event ($F = 29.449$, $p < 0.05$).

According to the Classification of Water Quality Index given by INWQS, the WQI score fell under Class III (51.9–92.7), derived as "Average" before the flood event, and it was categorized under Class IV (31.0–51.9), defined as "Polluted" after the flood tragedy [9]. According to the guidelines provided by INWQS (Table 2), the collected floodwater after the flood incident is not suitable for daily activities, and

Table 3
Pearson's correlation coefficient (r) of the water quality parameters and calculated water quality index (WQI) at the Pahang River

	pH	Turbidity	DO	COD	BOD_5	AN	TSS	WQI	Rainfall
pH	1								
Turbidity	–0.809	1							
DO	–0.701	0.814	1						
COD	0.775	–0.814	–0.982**	1					
BOD_5	0.841*	–0.751	–0.994**	0.966**	1				
AN	0.891*	0.771	0.633	–0.596	–0.599	1			
TSS	–0.309	0.631	0.712	–0.576	–0.730	0.707	1		
WQI	0.701	–0.202	–0.189	0.264	0.170	–0.612	0.018	1	
Rainfall	–0.643	0.425	0.212	–0.380	–0.129	0.089	0.918**	–0.339	1

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

only applicable for irrigation purposes. The current findings indicated the seasonal flood event in the regulation of DO, BOD_5, COD, AN, TSS and water pH, which has contributed to the overall contamination of the river water.

3.2. Statistical analysis

Pearson's correlation is the evaluation of the significant association between the rainfall with the changing water quality parameters. It was conducted with the primary aim to assess the major influence of rainfall distribution on the water quality status along Pahang River, as demonstrated in Table 3. From the presented results, significant correlations between pH-BOD_5 ($r = 0.841$; $p < 0.05$) and pH-AN ($r = 0.891$; $p < 0.05$) were found on the tested samples. The rising BOD_5 concentration was probably due to the natural decaying process, which has enhanced the total nutrient loads, particularly AN in the river system, that could be closely related to the discharge of fertilizers, construction effluents, animal farms and septic systems. The presence of excessive organic matters, which could promote the decomposition activities of the microorganisms, has enhanced the BOD_5 and AN contents, resulting in the lower water pH [43].

Similarly, the changing COD content was found positively associated with the BOD_5 concentration ($r = 0.966$; $p < 0.01$), but negatively correlated with the DO content ($r = –0.982$; $p < 0.01$). The results could be explained by the complete submergence of sewage system, and indiscriminate mixing of human excreta, sullage, and household effluents with the river water, contributing to the high BOD_5 and COD concentrations, and requirement of additional oxygen for the decomposition of these organic and inorganic matters [35]. The rising concentrations of BOD_5 and COD, justified the lower DO content in the river water. Meanwhile, the changing rainfall pattern was effectively associated with the TSS level ($r = 0.918$; $p < 0.01$). The result was stimulated mainly by serious erosion on the two sides of the riverbanks by the huge flow of river water. This alteration of TSS contents, driven by the heavy discharge of organic and inorganic effluents, is a serious indication of ecological imbalance, high water turbidity and sediment re-suspension process, riding towards the water quality deterioration [44].

4. Conclusion

The present work established a detailed and complete water quality data of the Pahang River after the severe 2014 flooding incident. Majority of water resources along Pahang River have been severely contaminated by the tragic flood event 2014. According to the classification of Water Quality Index given by the Interim National Water Quality Standards (INWQS) for Malaysia, the WQI of the river water ranged within 59.96–72.41, fell under Class III (51.9–92.7), derived as "Average" before the flood event, while it drastically degraded to 27.64–50.85, lied in Class IV (31.0–51.9), defined as "Polluted" after the flood incident. The changing water quality parameters during the flooded conditions were positively correlated as pH-BOD_5, pH-COD, COD-BOD_5, and rainfall-TSS, while the alteration of COD and BOD_5 was negatively associated with DO. During the incidence, the water supply was unfit for both daily sanitation and consumption, with a potential health risk to the flood victims. Keeping in view of the hazardous implications of this flood disaster, an effective emergency response procedure for the supply of safe potable water is warranted to reduce fatality rate on the affected population, and to minimize the widespread of water-borne diseases.

Acknowledgement

The authors acknowledge the financial support provided by the Ministry of Education Malaysia under the Malaysia Research University Network (MRUN) Collaborative Research Program, with the project title: Sustainable water resources management solutions to overcome national water security issues (Project No. 203/PREDAC/6720016).

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