Jurnal Kejuruteraan 34(4) 2022: 575-583
https://doi.org/10.17576/jkukm-2022-34(4)-05

A Review on Factors to be Incorporated in Water Quality Study

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Received 23 July 2021, Received in revised form 8 November 2021
Accepted 8 December 2021, Available online 30 July 2022

ABSTRACT

Water quality issues had been the main concern in worldwide as water resource keeps being polluted. River acts as the main source of drinking water, habitat for aquatic life, agriculture and industry. Poor in water quality led to the increase n water treatment expenses, water scarcity and affect health. River pollution is caused by industrial discharge, sewage and wastewater, chemical fertilizers and pesticides and mining activities. This paper aims to review and comments on factors to be incorporated in water quality study. Water quality index and pollutants are found to be the critical factors. USA, Canada, Iraq, Thailand, Vietnam and Malaysia used different parameters in calculating WQI. The parameters being considered in the WQI are then classified the river according to their classes and usage. Department of Environment (DOE) Malaysia has highlighted three main pollutants in water quality study which are Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (NH_3N) and Suspended Solid (SS) due to their great influence on WQI calculation. However, standard treated water quality in Malaysia is still based on Environmental Quality Act, 1974 which is nearly 50 years ago. Emerging pollutants which are mainly organic compounds present as pharmaceuticals and personal care products are found in water resources nowadays and the treatment should be improvised along time. Some modification of class on usage of water as irrigation should be considered and the relevant of considering two oxygen demands in calculating WQI (BOD and COD).

Keywords: Water quality; water resources; water quality index; Malaysia

INTRODUCTION

Water covers the earth's surface by 70%, but only 0.5% is a freshwater resource such as lakes, rivers, rainfall, and groundwater readily used by humans (Baker et al. 2016). Humans, animals, plants and microorganisms rely on freshwater to live. Most of the clean water is taken from the river and supplied to household, industry, agriculture and domestic (Petter and Clark 2013). As time goes by, urbanization occurs which caused a land-use change.

River pollution is caused by industrial discharge, sewage and wastewater, chemical fertilizers and pesticides and mining activities (Shi et al. 2019; Tao et al. 2019; Tsaboula et al. 2019; Y. Yang, Meng, and Jiao 2018; Zhao et al. 2020; Zheng et al. 2020). Pollutants come from husbandry (Huynh et al. 2019) and agriculture activities (X. Sun et al. 2019), urban stormwater (Perera et al. 2019; Tuomela, Sillanpää, and Koivusalo 2019) as well as effluent discharges (Azuma et al. 2019; Bharathiraja et al. 2019) into the river. Based on Abu et al. (2020) and Azouzi et al. (2017), polluted water cause diseases to spread to humans, dead aquatic life and disturb natural food chain.

The water quality of a river is tested to establish a record that may eventually help to improve the quality in the future. The factors need to be incorporated in water quality modelling are Water Quality Index (WQI) and pollutants. Water quality study will led us to the water quality index (WQI) (Tian et al. 2019) as it is considered as the most effective method is measuring water quality, and pollutants (Hernandez-Ramirez et al. 2019) which are the main factor to be incorporated. WQI of a river is evaluated based on parameters and classes. Some parameters which give a high impact on water quality are highlighted and studied in this paper. WQI is based on formulation proposed by the Department of Environment (DOE).

The formula consists of six parameters which are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3N), Total Suspended Solid (TSS) and pH. DOE had developed a Water Quality Index Classification to classify a river into Class I, II, III, IV and V according to the value of each parameter. This will indicate the level of pollutants had been contaminated a river. DOE also had introduced Water Classes and Uses to explain the possible usage of a river-based on their class (Class I, IIA, IIB, III, IV and V). The status of a river (clean; slightly polluted; polluted) can be known by referring to DOE Water Quality Classification based on Water Quality Index. This table consists of three parameters (BOD, NH_3N, TSS) and WQI which the range of values comes from the calculation of WQI formula. These three parameters are highlighted as the most polluted water in Malaysia contained a high level of BOD, NH_3N and TSS which had been mentioned by Huang et al. (2015).

WATER QUALITY INDEX

Water quality index can be evaluated by introducing data to accentuate the significance of water quality parameters for drinking purposes (Prasad et al. 2019). According to Tian et al. (2019), a clear understanding of the water quality in the streams can be provided by applying a comprehensive water quality index.

Water quality status can be reflected as WQI methods combined multiple environmental parameters and converted them into a single value. The water quality index method provides integrated information regarding the overall quantity and is an effective approach to water quality assessment and management (Wu et al. 2018).

WQI represents the quality of water resources and this concept is accepted among policymakers as it gives a clear and comprehensive picture of the pollution status of a water body (Tripathi and Singal, 2019).

The water Quality of Al-Gharraf River, the main branch of the Tigris River in the south of Iraq has been evaluated by mathematically developed Water Quality Index (Abed et al. 2019). Based on 25 physicochemical water quality parameters such as Temperature (T), Potential of Hydrogen (pH), Turbidity (Tur), Total Alkaline (TA), Full rigidity (TH), Calcium (Ca^{+2}), Chloride (Cl^{-1}), Magnesium (Mg^{+2}), Electrical Conductivity (EC), Sulfate (SO_4^{-2}), Total Solids (TS), Suspended Solids (SS), Iron (Fe^{+2}), Flouride (F^{-1}), Aluminium (Al^{+3}), Nitrite (NO_2^{-1}), Nitrate (NO_3^{-1}), Silica (SiO_2), Phosphate (PO_4^{-3}), Ammonia (NH3), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Sodium (Na^{+1}) and Total Dissolved Solids (TDS), proper management of water resources and gauge information can be built up by local people which will help in future water administration and protection arrangements.

Gupta et al. (2017) used three methods (Weighted Arithmetic WQI, National Sanitation Foundation WQI and Canadian Council of Ministers of the Environment WQI) to study the quality of the Narmada River. The WQI was developed based on eight parameters pH, Temperature, Total Dissolved Solids (TDS), Turbidity, Nitrate-Nitrogen ($NO^{3-}N$), Phosphate (PO_4^{3-}), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO). The idea about the overall quality of water to the policymakers can be shown by using the WQI method. Different physical, chemical and biological parameters were used to determine the water quality indices by using various mathematical equations.

Effendi et al. (2015) said USA, Canada and Malaysia have developed several water quality indices to aid water quality divisions. US National Sanitation Foundation (NSF) developed WQI based on indices. NSFWQI provided a standardized method for comparing the relative quality of various water bodies. It functioned to summarize large amounts of water quality data into simple terms for reporting to management and the public consistently.

The status of pollution load in River Yamuna, Delhi was investigated by Yadav and Khandegar (2019) by determining physicochemical parameters such as pH, temperature, DO, TDS, salinity and conductivity.

Malaysian WQI was derived from measurements of six water physicochemical parameters (pH, BOD, COD, NH_3N, DO and TSS) and compared with the Biomonitoring Working Party (BMWP), $BMWP^{Thai}$, $BMWP^{Viet}$, Average Score Per Taxon (ASTP), $ASTP^{Thai}$, $BMWP^{Viet}$, Family Biotic Index (FBI) and Singapore Biotic Index (SingScore) (Ghani et al. 2018). They found that $BMWP^{Viet}$ were the most reliable as it has strong relationship with Dissolved Oxygen content and could be adopted along with the WQI to assess water quality in urban rivers.

The Stream Quality Index (SQI) is based on a stressor-response empirical model. Beck et al. (2019) developed the unified index that compares the biological response to physical and chemical sensors using a scientifically rigorous, easy-to-understand tool intended to facilitate stream management.

WQI for every country is derived differently in terms of parameters measurement because it is based on demographic pattern and environment. WQI is formulated based on water quality as well as a pollution problem. Thus, WQI is vital in water quality study related to pollution problems and gives solutions.

PARAMETER

In order to identify the quality status of a river, six water quality parameters are used to calculate the value of WQI. Those six water quality parameters are Ammoniacal Nitrogen (NH_3-N), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), pH and Total Suspended Solids (TSS). Department of Environment (DOE) Malaysia had developed a formulation of WQI related to these six water quality parameters as in Equation 1 (Boah et al. 2015; Dhany et al. 2016; Naubi et al. 2016). Table 1 shows the water quality index classification proposed by DOE.

$$\begin{aligned} \text{WQI} = \; & (0.22*\text{SIDO}) + (0.19*\text{SIBOD}) + \\ & (0.16*\text{SICOD}) + (0.16*\text{SISS}) + \\ & (0.15*\text{SIAN}) + (0.12*\text{SIpH}) \end{aligned} \qquad \text{(Eq 1)}$$

where;
SIDO = Sub-index DO (% saturation)
SIBOD = Sub-index BOD
SICOD = Sub-index COD

SISS = Sub-index SS
SIAN = Sub-index NH_3-N
SIpH = Sub-index pH

Only six water quality parameters are considered in WQI formulation is because of their significant on water quality (Naubi et al. 2016).

TABLE 1. DOE Water Quality Index Classification

Parameter	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/L	<0.1	0.1- 0.3	0.3-0.9	0.9-2.7	>2.7
Biochemical Oxygen Demand	mg/L	<1	1-3	3-6	6-12	>12
Chemical Oxygen Demand	mg/L	<10	10- 25	10- 25	50-100	>100
Dissolved Oxygen	mg/L	>7	5-7	3-5	1-3	<1
pH	-	>7	6-7	5-6	<5	>5
Suspended Solid	mg/L	<25	25-50	50-150	150-300	>300
Water Quality Index	-	<92.7	76.5-92.7	51.9-76.5	31.0-51.9	>31

Based on DID (2009) and Prabakaran and Poorna (2012) DO's sub-index is multiplied with the highest percentage which is 22% (0.22) as DO plays the critical parameter in assessing water quality. This is because it dramatically influences the living organisms in the water body (Li et al. 2019). DO measures the amount of gaseous oxygen (O_2) dissolved in water which is available to fish, invertebrates and other aquatic life (Bahadori and Vuthaluru 2010; Wilson 2010). According to Larsen et al. (2019) and Middelburg and Levin (2009), dissolved oxygen enters the water through the air and is a byproduct from plants photosynthesis. Therefore, clear water surface and existence of aquatic plants indicates a high amount of oxygen dissolved in water (Frighetto et al. 2019; Raine 2018; Smith 2019). Table 1 shows the DO value of 7 mg/L shows a good water quality while the DO value is less than 1 mg/L shows a bad water quality.

Biochemical Oxygen Demand (BOD) sub-index is multiplied with 0.19 (19%) which is the second-highest value in the formulation. A study by Jouanneau et al. (2019), Ordaz-Díaz et al. (2014) and Prayitno et al. (2017) states that BOD value indicates the amount of dissolved oxygen used for aerobic microorganisms to decompose organic matter found in the water. Cyprowski et al. (2018) and Tang (2017) stated that these microorganisms decompose organic waste such as dead plants, sewage and food waste biodegradable as their food. A large amount of organic waste will result in many bacteria working decomposing the waste (Abdel-Shafy and Mansour 2018; Adebayo and Obiekezie 2018). These microorganisms demand high oxygen for their respiration (Jing and Kjellerup 2019; Lashgari and Diarmand-Khalilabad 2016) and remove oxygen from the water (Ketchell 2019). This process will eventually increase the BOD level and reduce the level of dissolved oxygen (Susilowati et al. 2018). Therefore, less than 1 mg/L of BOD shows a good water quality while more than 12 mg/L shows a bad water quality.

The sub-index of Chemical Oxygen Demand (COD) is multiplied with 0.16 (16%) based on Equation 1. COD level shows the amount of oxygen that would be depleted from a water body based on bacterial action and oxidation of inorganic materials (Abdulla et al. 2012; Kolb et al. 2017). Oxygen is consumed during the decomposition of organic matter by bacteria and inorganic materials such as ammonia and nitrite existed in the water body used oxygen for the oxidation process (Lajer 2012; Luo et al. 2015). High COD level (>100 mg/L) indicates that bacteria and inorganic matters consume a lot of oxygen leaving the other aquatic life with little oxygen. Low COD level (<10 mg/L) shows that the water body is less polluted by inorganic matter and bacteria as illustrated in Table 1.

Same value with COD, sub-index of Suspended Solid (SS) is multiplied with 0.16 (16%). As mentioned by Fosten (2016) and Miller (2011), Suspended Solid (SS) shows a measure of turbidity level of the water. Turbidity in the river occurred when there are floating sediments within the water body (Sahu et al. 2019). Suspended solids may originate from sedimentation, decomposing materials and inorganic materials such as bacteria and algae as mentioned by Serajuddin et al. (2019) and Zafisah et al. (2020). Stevenson and Bravo (2019) said that water with high turbidity will be likely to look milky or muddy due to the light scattering from very small particles in the water. Both Gall et al. (2019) and Huang et al. (2016) agreed that high suspended solids level causing sunlight cannot reach submerged vegetation thus reduce dissolved oxygen from photosynthesis. Decay aquatic life will decompose and increase oxygen demand used by bacteria in the water (Peterson and Risberg 2009; Tang et al. 2013). SS with a value less than 25 mg/L shows a good water quality while SS of more than 300 mg/L shows that the water is polluted.

Ammoniacal Nitrogen, NH_3N is an inorganic matter that comes from sewage, fertilizers and other industrial applications that causes direct toxic effects on aquatic life as written by Sundaram et al. (2019). Nuruzzaman et al. (2018) said that effluent discharges and runoff from agricultural lands enter the aquatic environment and cause the ammonia level to increase. Park et al. (2018) had mentioned in his writing that high ammonia levels cause the water becomes toxic for aquatic organisms which eventually led to death. The sub-index of NH_3-N is multiplied with 0.15 (15%) based on Equation 1. Based on Table 1, Class I water contain less than 0.1 mg/L NH_3-N while class V contains more than 2.7 mg/L NH_3-N.

pH value ranges from 0-6 (acid), 7 (neutral) and 8-14 (alkali). Aquatic life such as fish, weeds, amphibian etc in a river lives with a pH value of 6.5-8.5 (Kale 2016). Too high or too low pH value will cause these aquatic lives to die (Tucker and D'abramo 2008). Acidic and alkaline water cause level of DO depleted thus not enough for the respiration process. Unsuitable pH (pH of 7 for drinking water) of water cannot be used as a drinking source as it needs to be treated first which the cost will be high. pH sub-index is multiplied with 0.12 which is the lowest percentage in Equation 1.

Based on the DOE report in 2017 and 2018, WQI is still used as a reference in Malaysia. This proved that the six highlighted parameters are crucial and enough for good water quality study. Based on WQI proposed by DOE, DO, NH_3-N, BOD and SS are essential parameters that need to be considered. In most cases in Malaysia, pH value does not give too much concern in contaminating river (VishnuRadhan et al. 2017). This parameter can be substituted with other parameters such as turbidity. Turbidity level plays an important indication of the clarity of a river. The river should be sustained aesthetically in order to attract human and aquatic life. Transparent and clear water allows tourists and residence to do so much water activities in a river happily. There is two oxygen demand; BOD and COD parameters being mentioned in the WQI.

Both BOD and COD represent the biodegradable pollutants in the water body. When microorganisms increase, they need more oxygen for respiration and in order to break down organic waste In the other hand, COD level automatically increases when BOD level increase. Only BOD should be regarded as most water quality models can simulate this parameter.

CLASS

Water Classification had been used to classify all rivers in a country into their suitability and usage. A country like Thailand, Vietnam, Philippines, US, Canada etc had developed their class, Malaysia one of the countries that apply this method. The water classification and usage in Malaysia are shown in Table 2. Since 1994, The Surface Water Quality Standards were established and used as guidelines for river usage in Thailand (Yolthantham 2007). The surface water quality standards are classified into five classes; Class 1, Class 2, Class 3, Class 4 and Class 5. The Environmental Management Bureau applied Water Quality Management Areas to classify rivers in Phillippines into its class and usage (Department of Environment and Natural Resources, 2014). There are five types of class; Class AA, Class A, Class B, Class C and Class D. in Water Body Classification and Usage of Freshwater. Based on Nguyen (2018) and Pham et al. (2017), Vietnam Water Quality Index 2011 contained nine parameters and is classified into five water quality groups; A1, A2, B1, B2+ and B2-.

TABLE 2. Water Classes and Uses

Class	Uses
Class I	Conservation of natural environment
	Water Supply I – Practically no treatment necessary
	Fishery I – Very sensitive aquatic species
Class IIA	Water Supply II – Conventional treatment
	Fishery II – Sensitive aquatic species
Class IIB	Recreational use 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

Source: DOE

Based on the result of the formulation, a river is classified into five classes according to the Water Quality Index. Class I is the best while Class V is the worst and each class explains the possible uses of a river. Fishery I can be found in this river as only very sensitive aquatic species type live here. Stoneflies, mayflies, caddisflies, hellgrammites and water pennies are susceptible organisms that require high dissolved oxygen levels, clear and non-turbid water as their habitat (Hadley 2019).

Fishery II such as alderflies, dragonflies, whirligig beetles, riffle beetles, fishflies and scuds can be found in this class as wrote by (Hadley 2019). This is because these organisms can survive in fair water quality and their habitats are not as stringent as very sensitive aquatic species.

Economic value and tolerant species are type Fishery III such as black flies, midge flies and lunged snails (Hadley 2019) that are commonly found in the river.

High level of pollution in the river is not suitable for human and animal consumption. There is a low level of oxygen dissolved in Class IV river.

The last class, Class V is the most polluted and cannot be used for any purposes including irrigation and recreational activities. No living organisms can be found here as the level of dissolved oxygen is too little for any respiration or photosynthesis process. Microorganisms take place which increases the level of BOD and COD of the river. This water is strictly cannot be used as drinking water for livestock and should not have any body contact with human as this will led to serious illness such as diarrhea, Guinea worm disease, Typhoid etc (Ding et al. 2017; Haseena et al. 2017; Levy 2015).

Irrigation act as an alternative to water cropland for agriculture production. Irrigation system had helped to increase the crop production. However, Class IV of the river is allowed to be used as irrigation purposes. This type of water has a high level of pollution. If this class of water used to water cropland, the salt contained in the water will accumulate at the root cause loss of permeability (Warrence et al. 2002). The quality of agriculture may degrade compared to less polluted water. Thus, a suitable class for irrigation should be changed to Class III.

POLLUTANTS

Several pollutants exist in water and can be found by testing the water quality (Yu et al. 2019). However, there are some pollutants which have high impact on water quality thus they are highlighted and studied. Table 3 shows the Water Quality Classification used in Malaysia.

DOE developed a Water Quality Classification based on Water Quality Index to classify all rivers in Malaysia into three categories; clean, slightly polluted and polluted in Environmental Quality Report (EQR). There are four main indicators of the water quality classification; Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (NH_3N), Total Suspended Solid (SS) and Water Quality Index (WQI). These indicators are ranged differently according to their categories. Why only BOD, NH_3-N and SS sub-index are being considered in Table 3. This is because these three parameters are the major contributor to river pollution thus, they are highlighted by DOE.

TABLE 3. DOE Water Quality Classification Based on Water Quality Index

Sub Index & Water Quality Index	Index Range		
	Clean	Slightly Polluted	Polluted
Biochemical Oxygen Demand (BOD)	91-100	80-90	0-79
Ammoniacal Nitrogen (NH_3N)	92-100	71-91	0-70
Suspended Solids (SS)	76-100	70-75	0-69
Water Quality Index (WQI)	81-100	60-80	0-59

Haseena et al. (2017) defined that water pollutants are unwanted chemicals and materials that contaminated water in a river that cause the water quality degraded. Usually, pollutants originate from agricultural, sewage or treatment plant and commercial activities. This fact also supported by Sasakova et al. (2018) said that pollutions on ground surface flow into the river through surface runoff and effluent discharges from factories increasing pollution.

Agricultural pollution comes from agriculture and husbandry activities which produce biotic and abiotic byproducts that result in contamination of ecosystems (Ogbuewu et al. 2012). Koslow (2013) mentioned that fertilizers, pesticides and animal waste used from agricultural activities are washed away in waterways during rainfall events. Surface runoff brings along the contaminations such as nutrients and pathogens; bacteria and viruses into the river. The contamination contains excess nitrogen and phosphorus which will cause an increase of NH_3N, SS and BOD level in a river. Livestock breeder often released excess water from animal waste into the nearest drain which eventually flows into the mainstream. It is quite disappointing that no actions taken from authorities toward these people as the activities usually takes place in rural area where people usually focus more in urban area.

Sewage is wastewater that usually contained faeces, urine and laundry waste. This wastewater comes from a residential area or housing area. Residential area with sewage system is less worried compared to an area with no sewage system, especially in a rural area. The wastewater flows through sewage pipes into treatment plants to be treated (Huler 2010). However, people lived in a rural area tend to flush the wastewater directly into a river. As written by Va et al. (2018), restaurants and other commercial buildings also tend to flush wastewater from sinks into a drain that will eventually flow into the river. Wastewater is known as water-borne disease. During flooding, untreated sewage flows into the river and contaminate the water sources. The contamination can cause diseases (Pandey et al. 2014) to spread such as cholera, diarrhea and hepatitis A, which indicates increasing of microorganisms in water body.

The treated sewage will be disposed into the sea. In some cases, water disposal may still contain pollution. This is because the treatment used in the treatment plant is still based on the Environmental Quality Act, 1974. We are now in the 20th century, 2021to be specific. A lot of new pollution and diseases brought by viruses and bacteria can be found in the wastewater due to rapid development of molecular tools and wide application of next generation sequencing technologies. Previous treatment still does not include disinfection processes of inactivation of new pathogens to treat the wastewater. Thus, the treatment of sewage should be improvised to adapt environment nowadays.

Effluent discharges from factories and premises always need to be monitored before release it into the river. There are standards that need to be followed by manufacturers and public as stated in guidelines provided by DOE. However, some irresponsible manufacturer released the wastewater without making sure it met the standard highlighted by authorities. Pollutants from industrial sources are asbestos, lead, mercury, nitrates, phosphates, sulphur, oils and petrochemicals. Usually manufacturing factories released the effluent into nearby drain which will eventually carried away by streamflow. These pollutants will increase the Ammoniacal Nitrogen level and thus the level of dissolved oxygen depleted. Expose to this pollution not only give harm to animals, but it also causes illness to a human who had unknowingly consumed this in their drinking water.

After WQI is calculated by using Equation 1, the river is classified as either clean, slightly polluted or polluted. For clean river, this means that the six parameters; DO, BOD, COD, NH_3-N, SS and pH had met the requirements. When a river is classified as either slightly polluted or polluted river, we need to look into level of BOD, NH_3-N and SS. Thus, we can focus more into the main pollutants contribute to the decrease of water quality.

The amount of oxygen consumed by microorganisms such as viruses and bacteria during the respiration process caused depletion of dissolved oxygen and increase of Biochemical Oxygen Demand (BOD) level. These microorganisms resulted from wastewater which is untreated or partially treated that enters the water body.

Ammoniacal Nitrogen comes from fertilizers and other industrial applications. Decomposition of organic waste matter by microorganisms also contributed to a high level of NH3-N in a river. High level of NH_3-N means that BOD level also increases thus, less amount of oxygen dissolved in the river.

Total Suspended Solids (TSS) are larger than 2 microns, smaller size than that is considered dissolved solid. Land clearing, debris brought by surface runoff, microorganisms existed in sewage and decomposition of organic materials contributed to the increase of SS. The high amount of SS present in the water will cause the clarity of river decrease.

These three parameters and WQI are sufficient to show the status of a river and classify it into clean, slightly polluted and polluted.

CONCLUSION

Water Quality Index (WQI) act as a reference for water quality researchers to understand more about the status of a river. Every country has developed its own WQI developed and differs according to demographic status and environment. Although Malaysia has adapted the NWQI calculation and standards for almost 25 years, some adjustment should be considered. BOD only is sufficient to represent oxygen demand in NWQI out of two oxygen demand; BOD and COD. Besides, improvement of treatment process of newly found pathogens in our wastewater due to rapid development of technologies in recent decades need to be highlighted. Last but not least, usage of water as irrigation should be modified to suit it class in NWQI.

ACKNOWLEDGEMENT

A special thanks to Fundamental Research Grant Scheme (FRGS) (Grant number: 203. PREDAC. 6071432) and Universiti Sains Malaysia for giving the opportunities and funding this paper.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Abdel-Shafy, H. I., & Mansour, M. S. M. 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum* 27(4): 1275–1290). https://doi.org/10.1016/j.ejpe.2018.07.003

Abdulla, H. J., Al-Quraeshi, N. K. B., & Al-Awadi, F. N. J. 2012. Study of Chemical Oxygen Demand (COD) in Relation to Biochemical Oxygen Demand (BOD) BOD نيجسكولال ةيويحلاو COD ةسارد ةقلاعلا نيب تابلطتملا ةيئايميكلا. *Journal of Kerbala University 10*(3): 8–11.

Abu H. H., Muhammad, M. H., & Ismail, N. I. (2020). A review of biological drinking water treatment technologies for contaminants removal from polluted water resources. In *Journal of Water Process Engineering* 33. https://doi.org/10.1016/j.jwpe.2019.101035

Abed. S. A., Hussein Ewaid, S., & Al-Ansari, N. 2019. Evaluation of Water quality in the Tigris River within Baghdad, Iraq using Multivariate Statistical Techniques. *Journal of Physics: Conference Series 1294*(7). https://doi.org/10.1088/1742-6596/1294/7/072025

Adebayo, F. O., & Obiekezie, S. O. 2018. Microorganisms in waste management. *Research Journal of Science and Technology 10*(1): 28. https://doi.org/10.5958/2349-2988.2018.00005.0

Azouzi, R., Charef, A., Ayed, L., & Khadhar, S. 2017. Effect of water quality on heavy metal redistribution-mobility in agricultural polluted soils in semi-arid region. *Pedosphere*. https://doi.org/10.1016/s1002-0160(17)60367-9

Azuma, T., Otomo, K., Kunitou, M., Shimizu, M., Hosomaru, K., Mikata, S., Ishida, M., Hisamatsu, K., Yunoki, A., Mino, Y., & Hayashi, T. 2019. Environmental fate of pharmaceutical compounds and antimicrobial-resistant bacteria in hospital effluents, and contributions to pollutant loads in the surface waters in Japan. *Science of the Total Environment 657*: 476–484. https://doi.org/10.1016/j.scitotenv.2018.11.433

Bahadori, A., & Vuthaluru, H. B. 2010. Simple Arrhenius-type function accurately predicts dissolved oxygen saturation concentrations in aquatic systems. *Process Safety and Environmental Protection 88*(5): 335–340. https://doi.org/10.1016/j.psep.2010.05.002

Baker, B. H., Omer, A., & Aldridge, C. A. 2016. *Water: Availability and use*. Mississippi State University Extension Service. https://www.researchgate.net/publication/324226678_Water_Availability_and_use

Beck, M. W., Mazor, R. D., Theroux, S., & Schiff, K. C. 2019. The Stream Quality Index: A multi-indicator tool for enhancing environmental management. *Environmental and Sustainability Indicators 1–2*, 100004. https://doi.org/10.1016/j.indic.2019.100004

Bharathiraja, B., Ebenezer Selvakumari, I. A., Iyyappan, J., & Varjani, S. 2019. Itaconic acid: an effective sorbent for removal of pollutants from dye industry effluents. *Current Opinion in Environmental Science & Health*, *12*: 6–17. https://doi.org/10.1016/j.coesh.2019.07.004

Boah, D. K., Twum, S. B., & Pelig-Ba, K. B. 2015. Mathematical computation of water quality index of vea dam in upper east region of Ghana. *Environmental Sciences 3*(1): 11–16. https://doi.org/10.12988/es.2015.4116

Cyprowski, M., Stobnicka-Kupiec, A., Ławniczek-Wałczyk, A., Bakal-Kijek, A., Gołofit-Szymczak, M., & Górny, R. L. 2018. Anaerobic bacteria in wastewater treatment plant. *International Archives of Occupational and Environmental Health 91*(5): 571–579. https://doi.org/10.1007/s00420-018-1307-6

Department of Environment and Natural Resources. 2014. *Water Quality Management Area | Water Quality Management Section*. http://water.emb.gov.ph/?page_id=12

DID. 2009. *Study on the River Water Quality Trends and Indexes in Peninsular Malaysia 2009 Water Resources Management and Hydrology Division Department of Irrigation and Drainage Ministry of Natural Resources and Environment Malaysia*.

Ding, Z., Zhai, Y., Wu, C., Wu, H., Lu, Q., Lin, J., & He, F. 2017. Infectious diarrheal disease caused by contaminated well water in Chinese schools: A systematic review and meta-analysis. *Journal of Epidemiology 27*(6): 274–281. https://doi.org/10.1016/j.je.2016.07.006

Effendi, H., Romanto, & Wardiatno, Y. 2015. Water quality status of Ciambulawung River, Banten Province, based on pollution index and NSF-WQI. *Procedia Environmental Sciences 24*: 228–237. https://doi.org/10.1016/j.proenv.2015.03.030

Fosten, A. 2016. *How & Why We Measure Suspended Solids*. Partech. https://www.partech.co.uk/how-why-we-measure-suspended-solids/

Frighetto, D. F., Souza, G. M., & Molter, A. 2019. Spatio-temporal population control applied to management of aquatic plants. *Ecological Modelling 398*: 77–84. https://doi.org/10.1016/j.ecolmodel.2018.09.027

Gall, M., Swales, A., Davies-Colley, R., & Bremner, D. 2019. Predicting visual clarity and light penetration from water quality measures in New Zealand estuaries. *Estuarine, Coastal and Shelf Science 219*: 429–443. https://doi.org/10.1016/j.ecss.2019.01.003

Gupta, N., Pandey, P., & Hussain, J. 2017. Effect of physicochemical and biological parameters on the quality of river water of Narmada, Madhya Pradesh, India. *Water Science* 31(1): 11–23. https://doi.org/10.1016/j.wsj.2017.03.002

Hadley, D. 2019. *What Aquatic Insects Tell Us About Water Quality*. ThoughtCo. https://www.thoughtco.com/water-monitoring-and-aquatic-macroinvertebrates-1968647

Haseena, M., Malik, M. F., Javed, A., Arshad, S., Asif, N., Sharon, Z., & Hanif, J. 2017. Water pollution and human health. *Environmental Risk Assessment and Remediation 1*(3). https://doi.org/10.4066/2529-8046.100020

Haseena, M., Malik, M. F., Javed, A., Arshad, S., Asif, N., Zulfiqar, S., & Hanif, J. 2017. Water pollution and human health. *Environmental Risk Assessment and Remediation 1*(3): 16–19. https://doi.org/10.1007/BF00158344

Huang, Y. F., Ang, S. Y., Lee, K. M., & Lee, T. S. 2015. Quality of Water Resources in Malaysia. In *Research and Practices in Water Quality*. InTech. https://doi.org/10.5772/58969

Huang, Y., Xiong, W., Liao, Q., Fu, Q., Xia, A., Zhu, X., & Sun, Y. 2016. Comparison of Chlorella vulgaris biomass productivity cultivated in biofilm and suspension from the aspect of light transmission and microalgae affinity to carbon dioxide. *Bioresource Technology 222*: 367–373. https://doi.org/10.1016/j.biortech.2016.09.099

Huler, S. 2010. *How Does Sewage Treatment Work?* Scientific American. https://www.scientificamerican.com/article/treating-sewage/

Huynh, T. V., Nguyen, P. D., Phan, T. N., Luong, D. H., Truong, T. T. Van, Huynh, K. A., & Furukawa, K. 2019. Application of CANON process for nitrogen removal from anaerobically pretreated husbandry wastewater. *International Biodeterioration and Biodegradation 136*: 15–23. https://doi.org/10.1016/j.ibiod.2018.09.010

Jing, R., & Kjellerup, B. V. 2019. Predicting the potential for organohalide respiration in wastewater: Comparison of intestinal and wastewater microbiomes. *Science of The Total Environment* 135833. https://doi.org/10.1016/j.scitotenv.2019.135833

Jouanneau, S., Grangé, E., Durand, M. J., & Thouand, G. 2019. Rapid BOD assessment with a microbial array coupled to a neural machine learning system. *Water Research 166*. https://doi.org/10.1016/j.watres.2019.115079

Kale, V. S. 2016. Consequence of Temperature, pH, Turbidity and Dissolved Oxygen Water Quality Parameters. *International Advanced Research Journal in Science, Engineering and Technology ISO*, *3297*. https://doi.org/10.17148/IARJSET.2016.3834

Ketchell, M. 2019. *How is oxygen "sucked out" of our waterways?* The Conversation. http://theconversation.com/how-is-oxygen-sucked-out-of-our-waterways-109795

Kolb, M., Bahadir, M., & Teichgräber, B. 2017. Determination of chemical oxygen demand (COD) using an alternative wet chemical method free of mercury and dichromate. *Water Research 122*: 645–654. https://doi.org/10.1016/j.watres.2017.06.034

Koslow, M. 2013. *National Wildlife Federation Report: Taken By Storm*. The National Wildlife Federation. https://www.nwf.org/Educational-Resources/Reports/2013/04-29-2013-Taken-By-Storm

Lajer, K. 2012. Ammonium removal by nitrification in drinking water treatment. *Kvalitet Voda 10*: 47–53. https://www.researchgate.net/publication/282765937_Ammonium_removal_by_nitrification_in_drinking_water_treatment

Larsen, S. J., Kilminster, K. L., Mantovanelli, A., Goss, Z. J., Evans, G. C., Bryant, L. D., & McGinnis, D. F. 2019. Artificially oxygenating the Swan River estuary increases dissolved oxygen concentrations in the water and at the sediment interface. *Ecological Engineering 128*: 112–121. https://doi.org/10.1016/j.ecoleng.2018.12.032

Lashgari, M., & Diarmand-Khalilabad, H. 2016. Electrochemical insights into bacterial respiration upon polarized substrates: A proposal for tricking bacteria and compelling them to exhibit desired activities. *Journal of Electroanalytical Chemistry 783*: 125–131. https://doi.org/10.1016/j.jelechem.2016.11.035

Levy, K. 2015. Does poor water quality cause diarrheal disease? In *American Journal of Tropical Medicine and Hygiene* 93(5): 899–900. https://doi.org/10.4269/ajtmh.15-0689

Li, F., Sun, Z., Qi, H., Zhou, X., Xu, C., Wu, D., Fang, F., Feng, J., & Zhang, N. 2019. Effects of rice-fish co-culture on oxygen consumption in intensive aquaculture pond. *Rice Science 26*(1): 50–59. https://doi.org/10.1016/j.rsci.2018.12.004

Luo, X., Yan, Q., Wang, C., Luo, C., Zhou, N., & Jian, C. 2015. Treatment of ammonia nitrogen wastewater in low concentration by two-stage ozonization. *International Journal of Environmental Research and Public Health*, *12*(9): 11975–11987. https://doi.org/10.3390/ijerph120911975

Middelburg, J. J., & Levin, L. A. 2009. Coastal hypoxia and sediment biogeochemistry. *Biogeosciences 6*(7): 1273–1293. https://doi.org/10.5194/bg-6-1273-2009

Miller, D. 2011. *What is Suspended Solids? – The Laboratory People*. Camlab. https://camblab.info/wp/index.php/what-is-suspended-solids/

Naubi, I., Zardari, N. H., Shirazi, S. M., Ibrahim, N. F. B., & Baloo, L. 2016. Effectiveness of water quality index for monitoring Malaysian river water quality. *Polish Journal of Environmental Studies 25*(1): 231–239. https://doi.org/10.15244/pjoes/60109

Nguyen, T. T. M. 2018. Integrated evaluation model for surface water quality a case study in Ho Chi Minh City, Vietnam. *Vietnam Journal of Science and Technology 54*(4B): 232. https://doi.org/10.15625/2525-2518/54/4b/12046

Nuruzzaman, M., Mamun, A. A., & Salleh, M. N. B. 2018. Determining ammonia nitrogen decay rate of Malaysian river water in a laboratory flume. *International Journal of Environmental Science and Technology 15*(6): 1249–1256. https://doi.org/10.1007/s13762-017-1482-0

Ogbuewu, I. P., Odoemenam, V. U., Omede, A. A., Durunna, C. S., Emenalom, O. O., Uchegbu, M. C., Okolo, I. C., & Iloeje, M. U. 2012. Livestock Waste and Its Impact on the Environment. *Scientific Journal of Review 1*(3): 17–32. https://doi.org/10.5325/jmedirelicult.37.1.0060

Ordaz-Díaz, L. A., Rojas-Contreras, J. A., Rutiaga-Quiñones, O. M., Moreno-Jiménez, M. R., Alatriste-Mondragón, F., & Valle-Cervantes, S. (2014). Microorganism degradation efficiency in BOD analysis formulating a specific microbial consortium in a pulp and paper mill effluent. *BioResources 9*(4): 7189–7197. https://doi.org/10.15376/biores.9.4.7189-7197

Pandey, P. K., Kass, P. H., Soupir, M. L., Biswas, S., & Singh, V. P. 2014. Contamination of water resources by pathogenic bacteria. *AMB Express*, *4*(1): 1–16. https://doi.org/10.1186/s13568-014-0051-x

Park, T. J., Lee, J. H., Lee, M. S., Park, C. H., Lee, C. H., Moon, S. D., Chung, J., Cui, R., An, Y. J., Yeom, D. H., Lee, S. H., Lee, J. K., & Zoh, K. D.2018). Development of water quality criteria of ammonia for protecting aquatic life in freshwater using species sensitivity distribution method. *Science of the Total Environment 634*: 934–940. https://doi.org/10.1016/j.scitotenv.2018.04.018

Perera, T., McGree, J., Egodawatta, P., Jinadasa, K. B. S. N., & Goonetilleke, A. 2019. Taxonomy of influential factors for predicting pollutant first flush in urban stormwater runoff. *Water Research 166*. https://doi.org/10.1016/j.watres.2019.115075

Peterson, F., & Risberg, J. 2009. *Low Dissolved Oxygen in Water - Causes, Impact on Aquatic Life - An Overview*. http://www.pca.state.mn.us/water/tmdl/index.html

Petter, J. R., & Clark, J. A. 2013. *The Water We Drink*. PennState Extension. https://extension.psu.edu/the-water-we-drink

Pham, H., Rahman, M. M., Nguyen, N. C., Vo, P. Le, Van, T. Le, & Ngo, H. 2017. Assessment of surface water quality using the water quality index and multivariate statistical techniques-a case study: The upper part of Dong Nai River Basin, Vietnam. *Journal of Water Sustainability 7*(4): 225–245. https://doi.org/10.11912/jws.2017.7.4.

Prabakaran, A., & Poorna, B. 2012. *Computaional Complexity Analysis on Water Quality Index*.

Prasad, M., Sunitha, V., Reddy, Y. S., Suvarna, B., Reddy, B. M., & Reddy, M. R. 2019. Data on water quality index development for groundwater quality assessment from Obulavaripalli Mandal, YSR district, A.P India. *Data in Brief 24*. https://doi.org/10.1016/j.dib.2019.103846

Prayitno, Rulianah, S., Saroso, H., & Meilany, D. 2017) Biodegradation of BOD and Ammonia-Free Using Bacterial Consortium in Aerated Fixed Film Bioreactor (AF2B). *Green Process, Material and Energy: A Sustainable Solution for Climate Change*, *1855*, 50001. https://doi.org/10.1063/1.4985515

Raine, R. (2018). *Aquatic Plants That Purify Water | Home Guides | SF Gate*. https://homeguides.sfgate.com/aquatic-plants-purify-water-43531.html

Sahu, R. L., Dash, R. R., Pradhan, P. K., & Das, P. 2019. Effect of hydrogeological factors on removal of turbidity during river bank filtration: Laboratory and field studies. *Groundwater for Sustainable Development 9*. https://doi.org/10.1016/j.gsd.2019.100229

Sasakova, N., Gregova, G., Takacova, D., Mojzisova, J., Papajova, I., Venglovsky, J., Szaboova, T., & Kovacova, S. 2018. Pollution of surface and ground water by sources related to agricultural activities. *Frontiers in Sustainable Food Systems 2*. https://doi.org/10.3389/fsufs.2018.00042

Serajuddin, Chowdhury, A. I., Haque, M., & Haque, E. 2019. Using Turbidity to Determine Total Suspended Solids in an Urban Stream : A Case Study. *2nd International Conference on Water and Environment Engineering (ICWEE2019)*, *March*, 148–154.

Shi, P., Zhang, Y., Song, J., Li, P., Wang, Y., Zhang, X., Li, Z., Bi, Z., Zhang, X., Qin, Y., & Zhu, T. 2019. Response of nitrogen pollution in surface water to land use and social-economic factors in the Weihe River watershed, northwest China. *Sustainable Cities and Society 50*. https://doi.org/10.1016/j.scs.2019.101658

Smith, S. 2019. *Live Aquarium Plants That Clean the Water DoItYourself.com*. https://www.doityourself.com/stry/live-aquarium-plants-that-clean-the-water

Stevenson, M., & Bravo, C. 2019. Advanced turbidity prediction for operational water supply planning. *Decision Support Systems*, 119: 72–84. https://doi.org/10.1016/j.dss.2019.02.009

Sun, X., Hu, Z., Li, M., Liu, L., Xie, Z., Li, S., Wang, G., & Liu, F. 2019. Optimization of pollutant reduction system for controlling agricultural non-point-source pollution based on grey relational analysis combined with analytic hierarchy process. *Journal of Environmental Management* 243: 370–380. https://doi.org/10.1016/j.jenvman.2019.04.089

Sundaram, P. K., Mani, I., & Parray, R. A. 2019. Effect of urea ammonium nitrogen fertilizer on corrosion of different metals. *International Journal of Chemical Studies* 7(5): 2256–2259.

Susilowati, S., Sutrisno, J., Masykuri, M., & Maridi, M. 2018. *Dynamics and factors that affects DO-BOD concentrations of Madiun River ARTICLES YOU MAY BE INTERESTED IN. 2049*, 20052. https://doi.org/10.1063/1.5082457

Sutadian, A. D., Muttil, N., Yilmaz, A., & Perera, C. 2016. *Development of River Water Quality Indices-A Review*.

Tang, J. Y., Cao, P. P., Xu, C., & Liu, M. S. 2013. Effects of aquatic plants during their decay and decomposition on water quality. *Chinese Journal of Applied Ecology* 24(1): 83–89.

Tang, K. 2017. *The Microorganisms Found in Sewage*. https://sciencing.com/microorganisms-found-sewage-8224693.html

Tao, K., Liu, Y., Ke, T., Zhang, Y., Xiao, L., Li, S., Wei, S., Chen, L., & Hu, T. 2019. Patterns of bacterial and archaeal communities in sediments in response to dam construction and sewage discharge in Lhasa River. *Ecotoxicology and Environmental Safety* 178: 195–201. https://doi.org/10.1016/j.ecoenv.2019.03.107

Tian, Y., Jiang, Y., Liu, Q., Dong, M., Xu, D., Liu, Y., & Xu, X. 2019. Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China. *Science of the Total Environment* 667: 142–151. https://doi.org/10.1016/j.scitotenv.2019.02.356

Tsaboula, A., Menexes, G., Papadakis, E. N., Vryzas, Z., Kotopoulou, A., Kintzikoglou, K., & Papadopoulou-Mourkidou, E. 2019. Assessment and management of pesticide pollution at a river basin level part II: Optimization of pesticide monitoring networks on surface aquatic ecosystems by data analysis methods. *Science of the Total Environment* 653: 1612–1622. https://doi.org/10.1016/j.scitotenv.2018.10.270

Tucker, C. S., & D'abramo, L. R. 2008. *Managing High pH in Freshwater Ponds*.

Tuomela, C., Sillanpää, N., & Koivusalo, H. 2019. Assessment of stormwater pollutant loads and source area contributions with storm water management model (SWMM). *Journal of Environmental Management* 233: 719–727. https://doi.org/10.1016/j.jenvman.2018.12.061

Va, V., Setiyawan, A. S., Soewondo, P., & Putri, D. W. 2018. The Characteristics of domestic wastewater from office buildings in Bandung, West Java, Indonesia. *Indonesian Journal of Urban and Environmental Technology* 1(2): 199. https://doi.org/10.25105/urbanenvirotech.v1i2.2826

Vishnu Radhan, R., Zainudin, Z., Sreekanth, G. B., Dhiman, R., Salleh, M. N., & Vethamony, P. 2017. Temporal water quality response in an urban river: a case study in peninsular Malaysia. *Applied Water Science* 7(2): 923–933. https://doi.org/10.1007/s13201-015-0303-1

Warrence, N., Bauder, J. W. & Pearson, K. E. 2002. Basics of salinity and sodicity effects on soil physical properties. *Land Resources and Environmental Sciences Department Montana State University - Bozeman.*

Wilson, P. C. 2010. *Water Quality Notes: Dissolved Oxygen 1*. http://edis.ifas.ufl.edu.

Wu, Z., Wang, X., Chen, Y., Cai, Y., & Deng, J. 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. *Science of the Total Environment* 612: 914–922. https://doi.org/10.1016/j.scitotenv.2017.08.293

Yadav, A., & Khandegar, V. 2019. Dataset on assessment of River Yamuna, Delhi, India using indexing approach. *Data in Brief* 22: 1–10. https://doi.org/10.1016/j.dib.2018.11.130

Yang, Y., Meng, Z., & Jiao, W. 2018. Hydrological and pollution processes in mining area of Fenhe River Basin in China. *Environmental Pollution* 234: 743–750. https://doi.org/10.1016/j.envpol.2017.12.018

Yolthantham, T. 2007. *Water Quality Monitoring and Water Quality Situation in Thailand*.

Yu, C., Yin, X., Li, H., & Yang, Z. 2019. A hybrid water-quality-index and grey water footprint assessment approach for comprehensively evaluating water resources utilization considering multiple pollutants. *Journal of Cleaner Production*: 119225. https://doi.org/10.1016/j.jclepro.2019.119225

Zafisah, N. S., Ang, W. L., Mohammad, A. W., Hilal, N., & Johnson, D. J. 2020. Interaction between ballasting agent and flocs in ballasted flocculation for the removal of suspended solids in water. *Journal of Water Process Engineering 33*. https://doi.org/10.1016/j.jwpe.2019.101028

Zhao, H., Liu, Y., Lindley, S., Meng, F., & Niu, M. 2020. Change, mechanism, and response of pollutant discharge pattern resulting from manufacturing industrial transfer: A case study of the Pan-Yangtze River Delta, China. *Journal of Cleaner Production* 244. https://doi.org/10.1016/j.jclepro.2019.118587

Zheng, G., Yu, B., Wang, Y., Ma, C., & Chen, T. 2020. Removal of triclosan during wastewater treatment process and sewage sludge composting—A case study in the middle reaches of the Yellow River. *Environment International* 134. https://doi.org/10.1016/j.envint.2019.105300