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RESEARCH PAPER

Analysis of Water Quality Trends Using the Mann-Kendall Test and Sen's Estimator of Slope in a Tropical River Basin

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ABSTRACT
Trends in water quality, either increasing or decreasing over the long term, are becoming an essential guide to understanding water quality. This study aims to analyse the trends in water quality in the upstream part of the Bernam River Basin, Malaysia from 1998 to 2018. This study involved the collection of data on water quality from the Department of Environment, Malaysia. Six main parameters of the water quality index (WQI) were chosen, including the dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), total suspended solids (TSS) and pH. The analysis methods applied are the Mann-Kendall test and Sen's estimator of slope. The results of the WQI value trend analysis revealed that most stations have decreasing trends. A trend analysis of the parameters found that most stations had increasing trends for the DO, BOD, NH_3-N and pH parameters, while decreasing trends for the COD and TSS parameters were observed. An increasing trend indicated that the water quality parameters were getting better, and a decreasing trend indicated the opposite. This study will benefit the parties responsible for planning and monitoring developments to reduce water pollution around the upstream Bernam River Basin. In the upstream of Bernam River Basin, land use changes have occurred rapidly, especially forest areas have been explored for human settlements, agricultural and industrial activities. Thus, the sustainability of the river basin can be maintained and valued by the various parties in the future. The river basin is also important as a domestic water supply for the residents of Selangor and Perak.
Keywords: Trend analysis, water pollution, water quality index, Bernam river basin, physico-chemical parameters.

INTRODUCTION

Water is an indispensable resource for human beings, especially from sources of surface water, like rivers. To date, people still rely on river resources for a variety of uses, such as for domestic, industrial and agricultural purposes. Therefore, the river is often the subject of discussion among the community, especially the increasingly polluted aspects of river water quality. Today, the deterioration of river water quality is a crucial issue in the world and may pose a severe threat to the nation (Izyan Munirah et al., 2017; Ismail et al., 2013; Mohamad Adam et al., 2018). For Malaysia, from 672 rivers monitored, 59 rivers (9%) in the category polluted and 205 rivers (30%) were in the category slightly polluted (Department of

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Environment, 2020). The river pollution scenario in Malaysia is not new. River pollution is an issue that has long been experienced by the country since the 1970s, when the opening up of forest areas to agricultural areas as well as rapid urban effects began to take place. River pollution occurs not only in the estuary and central parts of a large river but also in the upstream parts of the river (Abdul Rahim et al., 2014; Ismail & Hashim, 2014; Nurain & Ang, 2015).

Trend analysis examines the occurrence of changes over the specified period based on existing data. Furthermore, trend analysis is an important tool for prediction and projection of future water quality (Camara et al. 2019; Mahmoodi et al., 2021; Ratnaningsih et al., 2019). In the context of water quality, this analysis will assess whether the value of the measured water quality variable increases or decreases over some monitored time period (Antonopoulos et al., 2001; Naddafi et al., 2007; Salam et al., 2019; Tabari et al., 2011). As a result, the use of long-term data in the conduct of research to identify the effects and factors that arise in turn from physical changes may lead to solutions to the occurrence of the phenomenon. Taheri Tizro et al. (2014) emphasised that trend analysis is critical in forecasting future values based on past events. It is also essential for decision-making in many hydrological processes and water resources management operating systems (Ismail & Hashim, 2014; Nasir et al., 2019).

Based on the analysis of water quality trends in the Selangor River, Selangor, Camara et al. (2019) provided beneficial information about relationships between land use and water quality indicators for decision-makers to manage the process of water pollution. Additionally, a study conducted by Luo et al. (2019) in Jakarta presented valuable information that resource managers could use to create a more sustainable water environment in the city. Research aimed at understanding the trends and forecasting future conditions is critical, especially in hydrology applications such as river water quality. This matter is due to the trend analysis of water quality, which plays a vital role in providing information on the variations or diversity of water quality through time-series data (Che Ngah et al., 2012; Ismail & Hashim, 2014). Water quality trend data is important to support management team in making decision on sustaining water environment. With this information, river water quality affected by deterioration could be identified. Also, conservation and preservation measures could be implemented immediately to improve river water quality and the management of more integrated drainage basins.

The Bernam River Basin is no exception to the changes in the quantity and quality of water, and the trends in river water quality in particular need to be studied. The Bernam River Basin is a basin shared by two states, namely Selangor and Perak. The upstream part of the basin has recently been identified as a rapid development area, especially in the state of Perak. This condition not only affects the water quality of the river but also causes flash floods when the river spills into low-lying areas due to a shallower river base. As such, the identification of the water quality index should be taken seriously as the Bernam River Basin is at high risk of contamination as a result of the development activities of both states, such as the opening up of new lands for agricultural and residential purposes and new townships. Hence, this study aims to analyse the long-term trends in water quality in the Bernam River Basin by examining data on water quality from 1998 to 2018.

MATERIAL AND METHODS

The selection of the upstream part of the Bernam River Basin as a study area is due to rapid development, mainly in the basins in Perak. The Bernam River Basin is one of the main river basins in Malaysia, a boundary between Selangor and Perak. The total length of the Bernam

River is 200 kilometres, with an average width of 50 metres, and it has an area of 3,335 km^2 (Selangor State Town & Country Planning Department, 2018). Eight stations were selected in the upstream part of the Bernam River Basin, Selangor for water quality monitoring purposes (Figure 1).

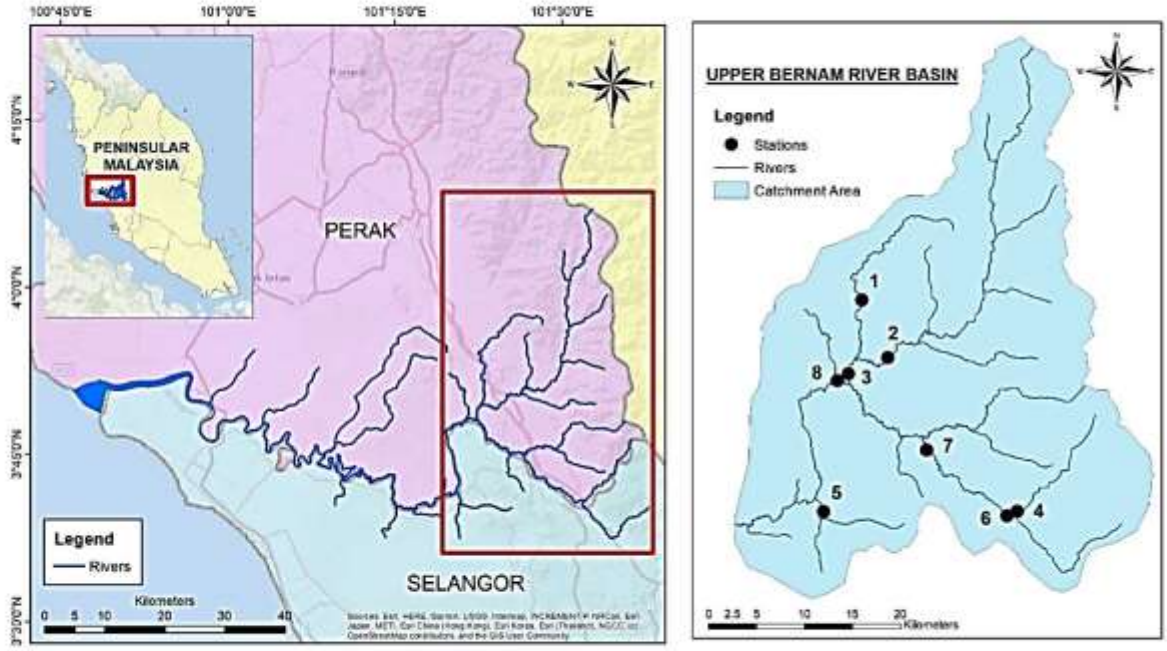

Fig. 1. Study area and water quality sampling stations

This study involved secondary data collection, i.e., data on water quality from 1998 to 2018 including dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), total suspended solids (TSS) and pH parameters. These data were obtained from the Department of Environment (DOE), Malaysia. The analytical methods used to analyse trends in water quality were the Mann-Kendall test and Sen’s estimator of slope. The MAKESENS (Mann-Kendall-Sens) software was utilised in this study to perform these tests. The MAKESENS software has been developed for detecting and estimating trends in the time series of annual values of water quality concentrations. The MAKESENS software is based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen's method for the magnitude of the trend (Salmi et al., 2002). Several researchers such as Ali et al. (2019), Ahmadi et al. (2015), Nur Hishaam et al. (2015), Mustapha (2013) and Tabari et al. (2011) adopted the software in the field of river water quality studies.

The Mann-Kendall test is a non-parametric test to examine trends in time-series data (Tabari et al., 2011; Ahmadi et al., 2015). The test used a *Z*-test statistic to determine trends. A positive *Z* value signifies an increasing trend, while a negative *Z* value signifies a decreasing trend. The formula for the *Z*-test statistic applied in this article is shown in Formula (1).

$$
\begin{aligned}
Z &= \frac{S-1}{\sqrt{VAR(S)}} \qquad if\ S > 0 \\
Z &= 0 \qquad\qquad\quad if\ S = 0
\end{aligned} \tag{1}
$$

$$Z = \frac{S+1}{\sqrt{VAR(S)}} \qquad if\ S < 0$$

where VAR(S) is a Variance of the Mann-Kendall. The S variance can be calculated using Formula (2).

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \tag{2}$$

Furthermore, the magnitude of the increment or decrement in the water quality trend is determined using Sen's estimator of slope (Lento et al., 2012). The formula for Sen's estimator of slope as applied in this article is shown in Formula (3) by calculating the slope of all data value pairs.

$$Q = \frac{x_j - x_k}{j - k} \tag{3}$$

where Q is the estimated value of Sen's slope, while x_j and x_k are the data values at times j and k. If there is an n x_j value in the time-series, the estimated value of Sen's slope is the median $n(n-1)/2$ pair slope. Thus, Sen's estimator of slope can be calculated using Formulae (4) and (5).

$$Q = Q_{[(N+1)/2]} \quad \text{if } N \text{ is odd,} \tag{4}$$

$$Q = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right) \quad \text{if } N \text{ is even.} \tag{5}$$

RESULTS AND DISCUSSION

DO is a measure of the amount of dissolved oxygen that is found in the water. Plants and aquatic animals living in the water are dependent on the DO. The DO indicates the rate of pollution of the water body in that the lower the DO value, the more contaminated the water source. According to Nurain and Ang (2015), the presence of DO in water could be affected by factors such as air pressure, dissolved salt content, water depth and waterbody type, such as lakes or flowing rivers. Based on the trend analysis results, the mean DO value for all stations showed decreasing trend (Table 1). However, the DO parameter value had recorded an increasing trend at most stations except Station 5 (Fig. 2a). The increase in the DO value is good for organisms and aquatic life, as the river contains much free oxygen. However, Station 5 showed a decreasing trend due to intensive and expanding agricultural activities compared to other stations. According to Mustapha (2013), the decreasing trend in the DO might be the result of nutrient distribution and pesticides from agricultural holdings and domestic waste disposal.

BOD is a measure of the DO content demanded by some micro-organisms to oxidise organic matter into more stable non-organic substances (Nurain & Ang, 2015; Mohd Harun, 2012). A BOD increase in the waterbody can be attributed to human activities, such as the emission of domestic, agricultural and food manufacturing waste. BOD indicates the pollution rate in reverse compared with the DO; the higher the BOD, the lower the DO in the waterbody (Ang, 2015; Nayan et al., 2019). As a result, high BOD rates mean there is more organic matter that can be decomposed by micro-organisms, and more oxygen is utilised in the process of decomposition. Based on the trend analysis results for the BOD parameter, all stations recorded an increasing trend (Table 1). Figure 2b showed an increasing trend for all stations. This phenomenon is in line with the report by Mustapha (2013), who discovered an increasing trend in the BOD value of river sources due to pollution consisting of organic matter and domestic waste. Likewise, the study conducted by Luo et al. (2011) explained that there had been an increase in the BOD value in the river as a result of domestic waste and waste management activities in developing areas. Irena et al. (2016) stressed that aquatic life species will die if the BOD increases in the future. However, one of the possible reason BOD and DO showing increasing trend due to the fluctuation in amount of rainfall throughout the year especially in the tropical region, whereas the agricultural activities remain active throughout the year (Susilowati, 2018).

COD refers to the measurement of the amount of organic and non-organic toxic compounds in the surface water (Ang, 2015). COD and BOD are closely related to the decomposition of organic elements in the waterbody. However, COD involves the decomposition of organic and non-organic matters chemically. In contrast, BOD involves the decomposition of organic matter biologically. Usually, COD concentration rates are higher than BOD because an oxidising agent can break down organic matter more quickly, whereas the BOD is related to the process of the decomposition of organic matter naturally (Ang, 2015; Mohd. Suhaimi et al., 2016). Based on the trend analysis results, the mean COD value for all stations showed decreasing trend (Table 1). The COD parameter had recorded decreasing trends at most stations (Fig. 2c). This condition showed that the river water quality was good and was consistent with previous studies conducted by Zhai et al. (2014), which also found a decreasing trend for the COD parameter in the upstream part of the river. However, the findings contrasted with the Mustapha (2013) study, which showed an increasing trend of the COD parameter for the river as a result of human activities around the river, including organic waste pollution from domestic waste.

NH_3-N refers to the measurement of the amount of ammonia and a toxic pollutant frequently found in landfill leachate and waste products such as sewage, animal husbandry, liquid manure and other organic waste liquid products (Ang, 2015). Ammonia is a compound that comprises the process of degradation of nitrogenous organic matter. If ammonia compounds are not ionised, the water will cause aquatic life toxicity (Nurain & Ang, 2015). Based on the trend analysis results, the mean NH_3-N value for all stations showed increasing trend (Table 1). Moreover, the NH_3-N parameter had recorded increasing trend for 5 stations and decreasing trend for 2 stations (Fig. 2d). The increasing trend of NH_3-N is due to sewage treatment plant and agriculture-based (livestock). Attention should be paid to the growing presence of NH_3-N at these six stations, as they may have a toxic impact on aquatic life and clean water supply for future domestic needs. Thus, Ang (2015) highlighted that NH_3-N is one of the most widely used measurements of water health, particularly involving natural water bodies, such as rivers or lakes. These findings are similar to those of the previous study conducted by Mustapha (2013): the value of NH_3-N presented an increasing trend in river sources due to human activities such as pollution consisting of organic matter from domestic waste.

TSS refers to the measurement of the presence of underwater particles that are larger than 0.45 µm (Ang, 2015). According to Irena et al. (2016) and Mahvi and Razazi (2005), TSS is also a natural pollutant that can cause turbidity in the river. This pollution can be detected by the physical condition of the waterbody, which appears murky and yellow. The high presence of TSS in water will prevent the penetration of sunlight entering the water and negatively affect the habitat and aquatic lives (Ismail & Hashim, 2014). Based on the trend analysis results, the mean TSS value for all stations showed decreasing trend (Table 1). Moreover, the TSS parameter had recorded decreasing trend for 5 stations and increasing trend for 2 stations (Fig. 2e). This situation was consistent with the results of the Mustapha (2013) study of river samples showing a decreasing trend for the TSS parameter. Suhaimi et al. (2006) emphasised that rainwater played an important role in the transport of solid material from the land into the river. Control of development activities in the vicinity of the Bernam River Basin, in particular at Station 2 and Station 3, should be carried out. Attention should also be paid to lessening the amount of land opening and lowering the value of TSS in the future.

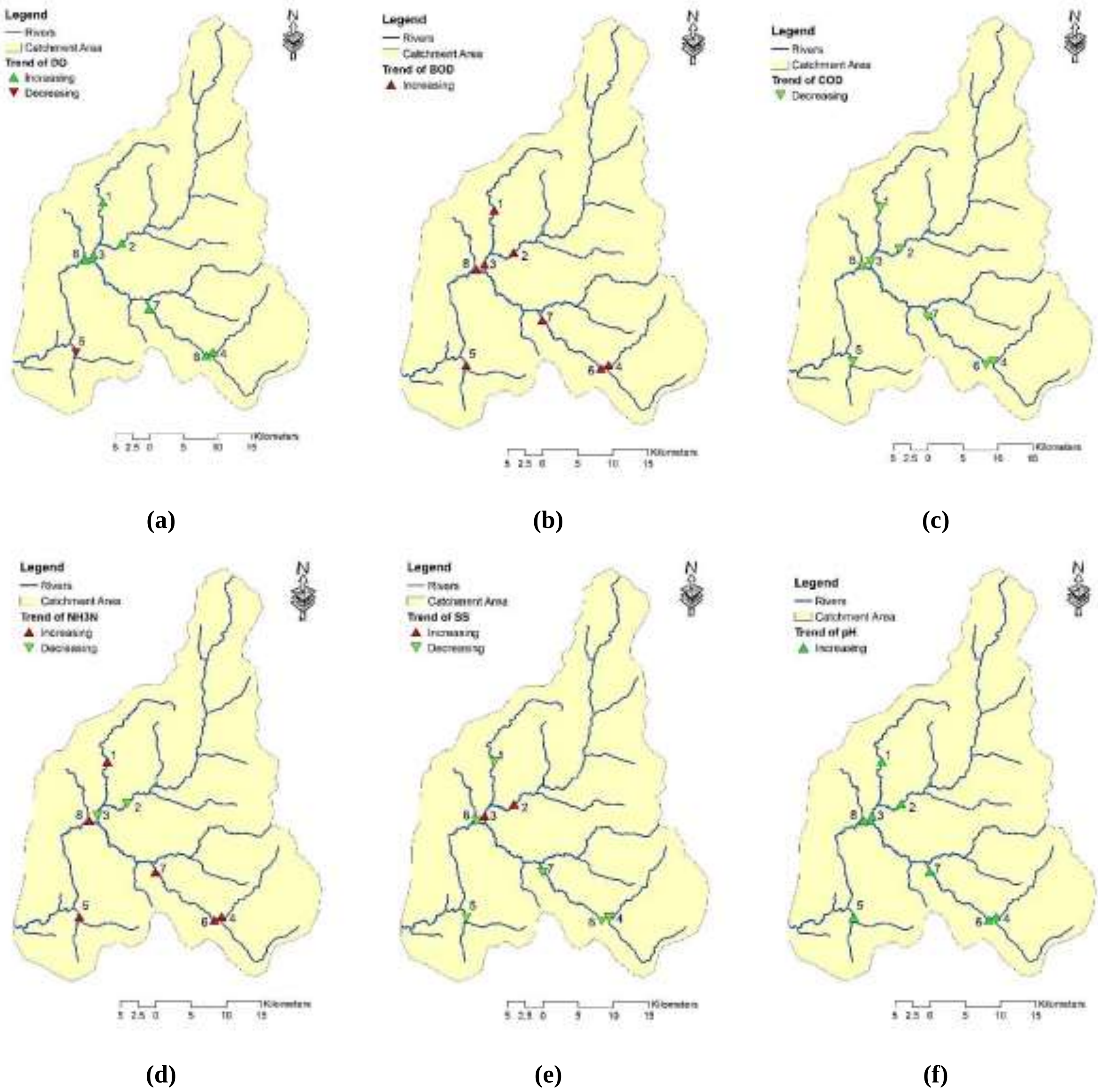

Fig. 2. Parameter trends for (a) DO, (b) BOD, (c) COD, (d) NH_3-N, (e) SS and (f) pH

A pH value refers to the level measurement of the acidity or alkalinity of the water content (Cech, 2005). The range of pH values is between 0 and 14, where 7 indicate a neutral pH. A pH value of less than 7 is categorised as acidic, while a pH value greater than 7 is categorised as alkaline. According to Nurain and Ang (2015), the pH value of the river is important for determining the survival of organisms and bacteria in the water. This is because a pH value which is too high or too low is not suitable for the life of organisms and bacteria (Nurain & Ang, 2015) and prevents the growth of micro-organisms in the water (Spellman, 2008). Based on the trend analysis results, the mean pH value for all stations showed increasing trend (Table 1). Furthermore, the pH parameter had recorded increasing trend for all stations (Fig. 2f). The trend of increasing pH values will cause the river source to be alkaline in the future if it is not properly managed. Saeed and Attaullah (2014) pointed out that highly alkaline water (10 to 12.5) can cause hair problems, skin problems and stomach disorders in humans.

Table 1. Mean value for all stations based on Mann-Kendall and Sen Slope Estimator during 1998-2018

Parameter	Unit	*S*	*Z*	*Q*	Trend
DO	mg/L	-9	-0.44	-5.23E-03	Decrease
BOD	mg/L	61	3.28	4.31E-01	Increase
COD	mg/L	-11	-0.55	-2.77E-01	Decrease
NH_3-N	mg/L	44	2.41	4.69E-03	Increase
TSS	mg/L	-15	-0.77	-1.56E+00	Decrease
pH	mg/L	21	1.09	3.86E-02	Increase
WQI	%	-41	-2.19	-2.14E-01	Decrease

The WQI is a guideline for measuring and detecting the causes of pollution occurring in a river or water source. According to Mohd. Azlan and Sarimah (2002), WQI is one of the methods applied to assess water quality using a ranking system, either good or bad, formed from a six-parameter sub-index to reflect the water quality. Based on the trend analysis results, the mean WQI value for all stations showed decreasing trend (Table 1). Furthermore, the WQI recorded decreasing trend for all stations except Station 7 (Fig. 3). In accordance

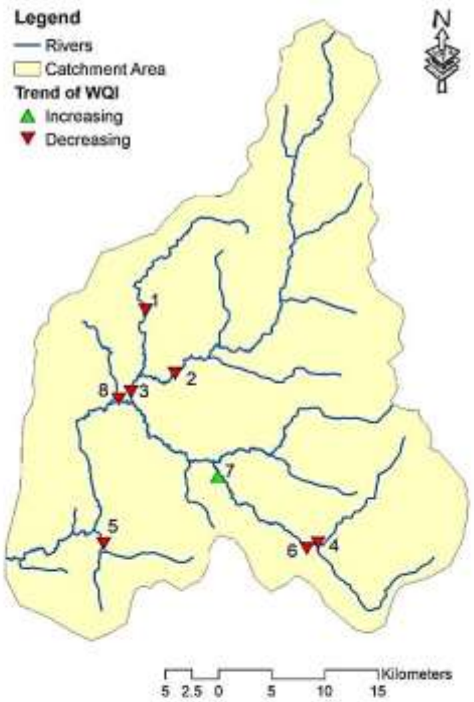

Fig. 3. WQI trend in the River Bernam Basin

with Faridah et al. (2012), the decrease in the WQI value can be attributed to factors such as the presence of large amounts of pollution, urbanisation activities and land development in the area. Hence, more efforts should be made by the authorities to improve the river water quality in the upstream part of the Bernam River Basin.

Based on research conducted in the upstream part of the Bernam River Basin, it has been observed that most stations have recorded increasing trends for the DO, BOD, NH_3-N and pH parameters, while they've recorded decreasing trends for the COD and TSS parameters. Overall, it was found that most stations experienced decreasing trends in WQI values from 1998 to 2018. Human activities that could decreased the WQI in the Bernam River Basin include, land use changes for human settlement, agricultural activities and domestic wastes. Furthermore, new residential and industrial areas are being developed in Tanjong Malim, Proton City, Slim River, Behrang 2020 and Behrang Stesen. The result of this study was in parallel with Camara et al. (2019) and Giri and Qiu (2016). This situation indicates that various conservation and preservation efforts should be made by the responsible parties to improve the water quality in the upstream areas of the basin.

Furthermore, land development planning around the Bernam River Basin should be lessened or environmental impact assessments should be carried out. As stated by Giri and Qiu (2016), solutions to water quality problems include the provision of environmental education, the use of new technologies and community environmental awareness. Indirectly, studies related to the time-series of water quality would overcome the problem of water pollution, thus maintaining the sustainability of the river basin area. If proactive action is not taken, the water quality of the Bernam River is at higher risk of serious river pollution problems in the future. Consequently, the water resources of the Bernam River will no longer be suitable and safe to be utilised by consumers as a source of the domestic water supply.

CONCLUSION

The Bernam River Basin plays a vital role in providing clean water resources to the surrounding residents, flora and fauna. However, human exploration around the river basin for developmental purposes has affected the sustainability of river basins by polluting the river. Based on the stations observed from 2008 until 2018, it was found that the water quality of the Bernam River had shown decreasing trends. Two parameters showing increasing trends, namely BOD and NH_3-N, indicated that the Bernam River Basin had decreased its water quality. Management in maintaining the sustainability of the upstream part of the Bernam River Basin is necessary, either legal or non-legislative. Based on the findings, this research can be used by the authorities to plan developments around the Bernam River Basin. Moreover, the outcomes and information from this research will help environmental management agencies to monitor and reduce water pollution in the Bernam River Basin. In some ways, sustainable development can overcome the problem of river pollution. Not only can developments be experienced by the residents, but the sustainability of the river basin could also be maintained and utilised by the residents in the future.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication, double publication and/or submission, and redundancy, has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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