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Eco-Heart Index as a tool for community-based water quality monitoring and assessment

Nobumitsu Sakai[a,b,*], Zeeda Fatimah Mohamad[c], Affan Nasaruddin[c], Siti Norasiah Abd Kadir[c], Mohammad Shahrul Amin Mohd Salleh[c], Abdul Halim Sulaiman[d]

[a] Division of Environmental Engineering, Graduate School of Engineering, Kyoto University, Kyoto 6158540, Japan
[b] Shimadzu-UMMC Centre of Xenobiotic Studies, Department of Pharmacology, Faculty of Medicine, University of Malaya, Kuala Lumpur 50603, Malaysia
[c] Department of Science & Technology Studies, Faculty of Science, University of Malaya, Kuala Lumpur 50603, Malaysia
[d] Academic Development Centre, University of Malaya, Kuala Lumpur 50603, Malaysia

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ABSTRACT

This study aimed to develop an economical, user-friendly, policy-relevant and impactful community-based water quality monitoring and assessment tool called Eco-Heart Index. Simple and economical water quality monitoring tools, such as Pact Test and LAQUAtwin, were used for Eco-Heart Index. The data was validated by comparing with those obtained using standard methods. Eco-Heart Index is a novel water quality indicator that draws a heart shape based on a result of 6 water quality parameters (pH, heavy metals, chemical oxygen demand, transparency, ammonia nitrogen and dissolved oxygen), which then indicates the water quality (*i.e.,* a full heart stands for clean water, while a broken heart stands for polluted water). This simplified tool was applied to the Langat River basin in Malaysia to generate a water quality map and to categorize the pollution trend based on the drawn figures. The water quality map showing the results of Eco-Heart Index clearly visualized the occurrence and distribution of the water pollution in the whole river basin. Specifically, a full heart shape appeared in upstream areas, whereas various broken heart shapes appeared in mid-stream and downstream areas, particularly in populated and land development areas. Eco-Heart Index was strongly correlated with the National Water Quality Index for Malaysia, suggesting that it could also be utilized as an alternative tool for water quality categorization. In conclusion, Eco-Heart Index has the great potential to be a community-based water quality indicator that could be understood through the universal symbol of peace and love.

1. Introduction

Many watersheds in the world have poor surface water quality that often negatively affects instream and near-stream ecologic integrity as well as water supply (Lee and Chung, 2007). Malaysia is no exception and water pollution is one of the most serious water resource management issues in the country. Water treatment plants have been frequently shut down in the capital region (*i.e.,* Klang Valley) due to high levels of ammonia, turbidity, phenolic compounds and smell (Santhi et al., 2012). High levels of *Escherichia coli* (*E. coli*) were detected in the surface water, particularly around populated areas in the capital region (Kondo et al., 2015). The main sources of the organic pollutants were suggested to be from domestic and industrial sewage as well as effluents from palm oil mills, rubber factories and animal husbandry (Juahir et al., 2011; Qadir et al., 2008). The surface water in the capital region is usually turbid and the turbidity exceeds 100 mg/L in most urban areas (Sakai et al., 2016). Mining operations, housing and road development, and logging and forest clearing were the major sources of suspended solids (Mohamed et al., 2015). According to the Department of Environment Malaysia (DOE), 36.6% of rivers in Malaysia were classified as slightly polluted, and 5.2% of rivers were classified as polluted (DOE, 2014). These facts mean that untreated municipal wastewater and the effluents from the extensive land development areas are directly discharged into rivers. The intermittent unsatisfactory discharges from combined sewer overflows might also worsen the situation (Rathnayake and Tanyimboh, 2015). The general public is highly aware of the water pollution since the issues are frequently reported in mainstream media, but they may think that it is not their concern or responsibility, or they may have no idea how to deal with the issues.

The DOE adopts the National Water Quality Index (WQI) for assessing surface water quality. The WQI consists of 6 parameters: pH, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS) and ammonia

* Corresponding author at: Division of Environmental Engineering, Graduate School of Engineering, Kyoto University, Kyoto 6158540, Japan.
E-mail address: sakai@risk.env.kyoto-u.ac.jp (N. Sakai).

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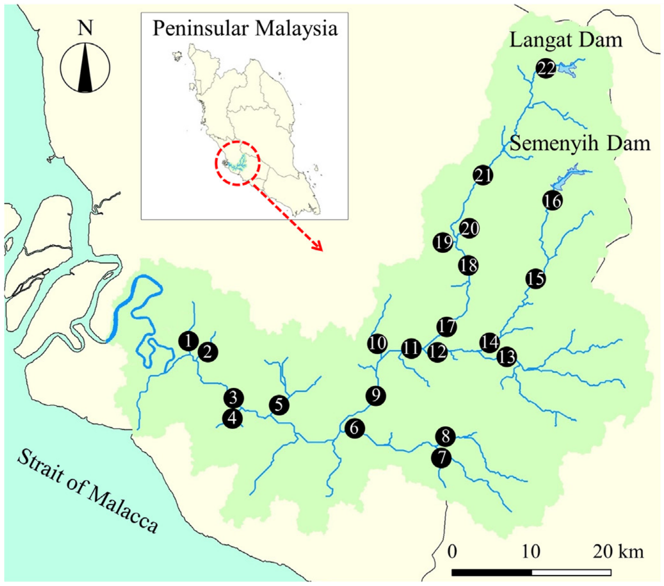

Site	Longitude	Latitude
S1	101’28”31E	2’53”34N
S2	101’29”22E	2’53”15N
S3	101’30”39E	2’48”56N
S4	101’30”29E	2’48”40N
S5	101’33”46E	2’49”34N
S6	101’41”27E	2’48”18N
S7	101’44”57E	2’46”49N
S8	101’45”05E	2’47”14N
S9	101’40”52E	2’51”20N
S10	101’41”03E	2’53”40N
S11	101’43”35E	2’53”49N
S12	101’44”57E	2’53”30N
S13	101’49”44E	2’53”17N
S14	101’48”32E	2’54”13N
S15	101’50”57E	2’57”31N
S16	101’52”17E	3’02”47N
S17	101’45”31E	2’55”06N
S18	101’47”05E	2’59”36N
S19	101’46”03E	3’00”54N
S20	101’46”28E	3’01”25N
S21	101’47”57E	3’05”41N
S22	101’53”01E	3’12”55N

Fig. 1. Watershed boundary of the Langat River basin and sampling sites. *2-column fitting image.

nitrogen (NH_3-N), and its value ($0 \leq WQI \leq 100$) is calculated by a single formula based on the subindex values of each parameter (DOE, 2014). The water quality in more than 470 rivers all over the country is regularly monitored by the DOE, and the results of WQI are annually published in the Malaysian Environment Quality Report (DOE, 2014).

The WQI provides the simplified results for local authorities and communities to acknowledge the overall river health of their interest, but this indicator has some disadvantages from the viewpoint of community engagement and participation. Firstly, the water quality monitoring is conducted by standard methods (Sidek et al., 2016), so only limited facilities and people can analyze all the parameters. Secondly, the 6 parameters are integrated into the WQI value (0–100) based on a specific formula and the annual reports only show the integrated value with a categorized pollution level (clean, slightly polluted or polluted) (DOE, 2014), which means that the water quality cannot be inferred from the WQI value because each parameter is masked by the integrated results. Thirdly, the numerical results of the WQI appears to not be attractive to local communities, particularly those who are not familiar with the index as well as those who are not interested in environmental conservation. Therefore, it is necessary to develop a community-based water quality monitoring and assessment tool that can be easily handled, can complement the comprehension of the WQI and can attract and inspire the heart of community so that local authorities and/or communities will be able to spontaneously monitor and assess the water quality at a local scale.

This study developed a novel community-based water quality monitoring and assessment tool called Eco-Heart Index that can depict the water quality by drawing a heart shape, which is a universally recognized symbol of peace and love (Hoystad, 2009). For instance, a full heart shape stands for clean water, while a broken heart shape stands for polluted water. The idea of using the heart shape was motivated by our theoretical and empirical work on the ‘Heartware’ approach in integrated watershed management (IWM) in Malaysia. The heartware is defined as the subjective, nebulous and humanistic dimension of the IWM that taps into the collective willingness of different stakeholders to continuously collaborate in solving complex problems for the attainment of a more sustainable IWM (Mohamad et al., 2015). The purpose of the heartware is to foster a foundation for continuous social learning and collaboration through the inclusion and acknowledgement of stakeholders’ values and perceptions, to promote meaningful dialogue and constructive exchanges, and to develop a mutually-accepted and well-informed course of action. It will lead to reducing conflicts as well as to increasing trust among stakeholders as they move to the next cycle of decision making. A good heartware foundation will begin an upwardly spiraling process toward effective and mutually acceptable solutions that are more politically sustainable in the long run (Mohamad et al., 2015).

In the present study, Eco-Heart Index was used to monitor and assess the surface water collected in the Langat River basin, which is located at the southern part of the capital region in Malaysia. The water quality results from using community-based monitoring kits were validated by those obtained using standard methods. A numerical evaluation of Eco-Heart Index was compared with the WQI in order to see whether the results were comparable. A water quality map in the Langat River basin was generated using the results of Eco-Heart Index, and the pollution trend in the whole river basin was spatially assessed accordingly. The drawn figures of Eco-Heart Index were categorized by the similarity of their appearances, and each category was associated with potential pollution sources based on land use in the catchment areas. Thus, this study aimed to develop Eco-Heart Index as a community-based water quality indicator to achieve a breakthrough in community engagement.

2. Materials and methods

2.1. Field experiment

2.1.1. Sampling sites and surface water collection

The locations of 22 sampling sites in the Langat River basin are shown in Fig. 1. A geographic information system (ArcGIS version 10.0, ESRI Inc., USA) was used to visualize the watershed boundary of the Langat River basin based on the digital elevation data (3sec GRID: Conditioned DEM in HydroSHEDS) that was downloaded from the United States Digital Service[1]. This data source is derived from the elevation data of the Shuttle Radar Topography Mission (SRTM) at a 3 arc-second resolution, and the original SRTM data have been hydrologically conditioned using a sequence of automated procedures. The selection of the sampling sites was based on the main stream (*i.e.,* the Langat River) and major tributaries visualized by GIS which substantially cover the entire river basin (Fig. 1). The sampling was conducted on 13th March, 2014, when the study area was in the inter

[1] Accessible at http://hydrosheds.cr.usgs.gov/dataavail.php1.

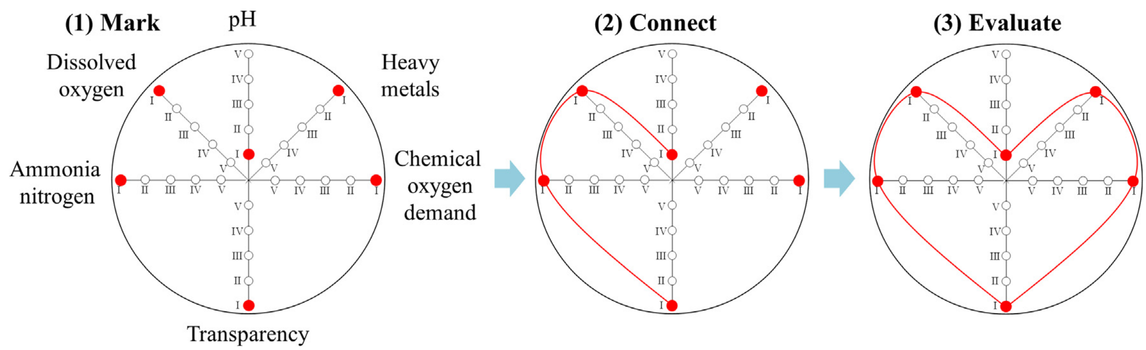

Fig. 2. Overall concept of Eco-Heart Index. *2-column fitting image.

monsoon period and affected by an extreme dry spell (Deni et al., 2010; Anuar and Abdullah, 2016). The surface water in all sampling sites was collected within a day to reduce variability of the water quality in the river basin. In each sampling site, the surface water was collected using a stainless steel container and was poured into a polypropylene bottle and stored on ice until it was returned to laboratory.

2.1.2. Community-based water quality monitoring tools

This study selected Pact Test (Kyoritsu Chemical-Check Lab, Japan) and LAQUAtwin (Horiba, Japan) for the analysis of pH, COD, NH_3-N and heavy metals. Pack Test is designed for community-based water quality monitoring and works by colorizing a specific parameter by dipping a plastic tube containing a coloring agent into a sample to quantify its concentration by comparison with a color indicator (Kikuchi et al., 2010). LAQUAtwin is a handheld meter that can check a water quality parameter within a minute by simply dipping its sensor into a sample.

A transparency tube was used for the analysis of turbidity. It can be easily prepared with a transparent tubing and a secchi disk attached to its bottom. The transparency is recorded by a maximum height of a water sample poured into the tubing where the secchi disk is visible from the top. Although the result is more or less affected by observers, and the measurement range is generally narrower than a turbidity meter, this method is much simpler and more economical than those used in turbidity and TSS (Anderson and Davie, 2004).

A portable DO meter was used for the DO measurement. Although it incurs a high initial cost, proper usage and maintenance allows for accurate and long-lasting measurements with minimal maintenance cost. Incidentally, if the initial cost or the maintenance becomes an obstruction, the DO meter can be replaced with an economical DO test kit as long as the monitoring results are accurate and fit Eco-Heart Index with an appropriate classification.

2.1.3. Water quality analysis

The on-site water quality monitoring was taken for pH, electrical conductivity (EC), DO and water temperature. The pH and EC were measured by LAQUAtwin (Horiba, Japan), and the DO and water temperature were measured by Accumet AP84 (Fisher Scientific, Malaysia). The measurements were recorded after the continuous readings were completely stabilized. On the other hand, the NH_3-N, PO_4-P, COD and heavy metals (*i.e.,* the sum of Mn, Ni, Cu, Zn and Cd concentrations) were analyzed by Pact Test (Kyoritsu Chemical-Check Lab, Japan) in laboratory within one week from the sampling date. After the water samples were reacted with the Pact Test and left for a reaction time following by the respective instruction manuals, an absorbance of the colorized samples was measured by a digital pack test apparatus (Digital Pack Test Multi, Kyoritsu Chemical-Check Lab. Corp., Japan) for NH_3-N and PO_4-P. A color indicator attached to Pack Test was used to quantify COD and heavy metals because they were not measureable by the apparatus. The turbidity was measured by a portable turbidity meter (2020wi, LaMotte Company, USA), while the transparency was measured with a 250 mL glass graduated cylinder (30 cm tall and 3.6 cm in diameter) where the outer wall was covered by aluminum foils to protect against interference by the light condition outside. A white disk marking a double perpendicular line (0.5 mm thickness and 1 mm width) was attached to the bottom of the graduated cylinder. A collected sample was poured into the graduated cylinder and a maximum height where the double perpendicular line could be observed from the top of the graduated cylinder was checked to measure the transparency.

2.1.4. Validation of water quality data

A validation of the observed water quality data of NH_3-N, PO_4-P, COD, turbidity, transparency and heavy metals measured by the simple monitoring kits was carried out by regression analysis and/or correlation analysis with those analyzed by standard methods in order to ensure the accuracy of the data. The NH_3-N, PO_4-P and COD were analyzed by indophenol method, molybdenum blue ascorbic acid method and alkaline potassium permanganate method, respectively. The suspended solids (SS) were analyzed by filtering through a GF/B glass microfiber filter (GE Healthcare UK Ltd., UK) and by weighing the filters before and after the filtration that were dried in an oven at 105 °C for 2 h. The concentration of heavy metals was analyzed by an inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 8300, PerkinElmer, USA). Twenty milliliter of the collected sample was mixed with 0.4 mL of nitric acid (1 + 1) and was digested at 80 °C for 2 h. The aliquot was filtered through a 0.2 μm regenerated cellulose syringe filter (Phenex, Phenomenex Inc., USA), and the 5 heavy metals (Mn, Ni, Cu, Zn and Cd) were analyzed by ICP-OES. The pH, EC and DO data were not validated by a correlation analysis with those analyzed by standard methods, but a calibration of the respective monitoring kits was made before the sampling to ensure the accurate measurement on-site.

2.2. Concept of Eco-Heart Index and selection of 6 water quality parameters

Fig. 2 shows an overall concept of Eco-Heart Index. Six parameters (pH, heavy metals, COD, transparency, NH_3-N and DO) are monitored and marked their levels in accordance with a classification table (Table 1). The 6 marks are connected in order by a curved line, and water quality is evaluated based on the drawn figure. If all the parameters are classified as clean (*i.e.,* level I), a full heart shape appears. In contrast, if the water is polluted and some of the parameters are not classified as clean (*i.e.,* level II, III, IV or V), a broken heart shape appears. Thus, Eco-Heart Index was designed to indicate the monitored water quality parameters visually so that it would be easily understood by people in general. The 6 water quality parameters were selected to be able to capture the overall water quality as well as to identify major pollution loads such as nutrients, suspended solids and heavy metals. The selected parameters can cover most parameters adopted in the WQI (*i.e.,* pH, DO, COD and NH_3-N and TSS), and moreover the heavy metals can cover the inorganic pollution.

Table 1
Classification of water quality by 5 levels from clean (I) to heavily polluted (V) applied to Eco-Heart Index.

Parameter	Unit	I (clean)	II (moderate)	III (slightly polluted)	IV (polluted)	V (heavily polluted)
pH	–	6.50–7.50	6.00–6.49 or 7.51–8.00	5.50–5.99 or 8.01–8.50	5.00–5.49 or 8.51–9.00	< 5.00 or > 9.00
DO	mg/L	> 6.00	5.01–6.00	3.01–5.00	1.01–3.00	0–1.00
Heavy Metals	mg/L	0–0.2	0.3–0.5	0.6–1.0	1.1–2.0	> 2.0
Transparency	cm	> 30.0	20.1–30.0	15.1–20.0	10.1–15.0	0–10.0
NH_3-N	mg/L	0–0.50	0.51–1.00	1.01–2.00	2.01–5.00	> 5.00
COD	mg/L	0–5	6–10	11–13	14–20	> 20

2.3. Classification of water quality

Each water quality parameter was classified by 5 levels from clean (I) to heavily polluted (V) (Table 1). The classification of the NH_3-N, COD and heavy metals was determined by the respective color indicators of Pact Test as well as the National Water Quality Standards for Malaysia (DOE, 2014). For instance, the indicator of NH_3-N shows 6 different colors from light blue (or light yellow) to dark blue with respective values (*i.e.,* 0.2, 0.5, 1, 2, 5 and 10 mg/L). In the National Water Quality Standards for Malaysia, the NH_3-N concentration was classified from I (*i.e.,* natural environment) at less than 0.1 mg/L to V (*i.e.,* not applicable as water source) at more than 2.7 mg/L. Accordingly, the NH_3-N concentration was classified by 0–0.50 mg/L as clean, 0.51–1.00 mg/L as moderate, 1.01–2.00 mg/L as slightly polluted, 2.01–5.00 mg/L as polluted, > 5.00 mg/L as heavily polluted (Table 1). The classification of the numerical values of pH and DO obtained using LAQUAtwin and DO meters, respectively, was determined along with the national standards (Table 1). On the other hand, the transparency was converted to TSS based on a relationship between TSS and transparency (Anderson and Davie, 2004), and its classification was determined by comparing between the converted TSS values and the national standards (Table 1).

The 5 levels of each parameter except the pH were placed in order from the edge (level I) to the center (level V) of Eco-Heart Index, while the pH was placed in the inverse order so that a full heart shape appears when all the parameters are level I (Fig. 2).

2.4. Water quality assessment with Eco-Heart Index

The observed water quality data were marked at their classified levels in Eco-Heart Index (Fig. 2), and were connected by a curved line to draw a figure. All the drawn figures (n = 22) were placed on a map of the boundary of the Langat River basin at the respective sampling points in order to make a water quality map as well as to visualize the water quality trend in the entire river basin. Furthermore, the drawn figures were categorized by the similarity of their appearances to identify potential pollution sources based on the land use in the catchment areas.

2.5. Correlation analysis between Eco-Heart Index and the WQI

Relationship between Eco-Heart Index and WQI was analyzed using a dataset in our previous study (Sakai et al., 2016) to elucidate whether Eco-Heart Index is numerically associated with the WQI. The WQI values were calculated using a single formula based on the subindex values of each parameter (DOE, 2014). To cover unavailable parameters in the dataset (*i.e.,* transparency and heavy metals) for Eco-Heart Index, suspended solids in the dataset were converted to transparency based on regression analysis obtained in the validation process. Heavy metals were referred to the monitoring results in this study (Table 2): S3, S4, S6, S9, S11, S12, S13, S14, S16, S17, S18, S19 and S22 where sampling points corresponded to the dataset. In addition, the S13 in the dataset which was not monitored in this study was complemented with a monitoring result (0 mg/L) on 7th August, 2014. Relationship between WQI values and the total count of the classified levels in Eco-Heart Index that ranges from 6 (level I in all) to 30 (level V in all) were analyzed by regression analysis with a coefficient of determination. The total count of Eco-Heart Index was also compared with the water quality categorization adopted in the WQI (*i.e.,* 81–100 as clean, 60–80 as slightly polluted and 0–59 as polluted).

3. Results and discussion

3.1. Validation of water quality data

The concentrations of NH_3-N, PO_4-P, COD and heavy metals analyzed by the simple monitoring kits were strongly correlated with those analyzed by standard methods as their coefficients of determination showed over 0.86 ($P < 0.01$) (Fig. 3). Likewise, the turbidity showed a positive linear correlation ($r = 0.992$, $R^2 = 0.983$, $P < 0.001$) with suspended solids (Fig. 4a). In contrast, the transparency showed a negative logarithmic correlation ($r = -0.930$, $R^2 = 0.864$, $P < 0.001$) with suspended solids (Fig. 4b), as reported previously (Anderson and Davie, 2004).

3.2. Relationship between Eco-Heart Index and the WQI

The correlation analysis between Eco-Heart Index and the WQI is shown in Fig. 5. The total count of Eco-Heart Index was associated with the WQI values as there was a strong negative correlation between the indices ($R^2 = 0.853$, $P < 0.001$). The negative correlation was expected because water quality consistently deteriorates as the total count of Eco-Heart Index increases. When the total count of Eco-Heart Index is categorized by clean (81–100), slightly polluted (60–80) and polluted (0–59) based on the linear regression (Fig. 5), the most appropriate categorization is 6–11 as clean, 12–16 as slightly polluted, and 17–30 as polluted because the total counts of Eco-Heart Index at the border of the 3 categories (*i.e.,* WQI = 60 and 80) were 16.7 and 11.0, respectively. Therefore, Eco-Heart Index could be numerically used as an alternative tool for the water quality categorization, although further validation is necessary to evaluate the relationship between the two indices, particularly because heavy metals are substituted for BOD in Eco-Heart Index which could result in large variability. Nevertheless, because BOD is a time-consuming test and heavy metals analysis can monitor inorganic pollution, Eco-Heart Index has great potential to complement the WQI in terms of applicability for the community as well as for inorganic contaminant monitoring.

3.3. Water quality monitoring in the Langat River basin

Table 2 shows the water quality monitoring results of 22 sampling sites in the Langat River basin. The pH was almost neutral in most of the sampling sites ranging from 6.86 to 7.87, except S2 at 4.42 where the color of the collected sample was dark brown. The dark brown water was observed in some downstream areas because peat swamp forests exist (Nourqolipour et al., 2015). The peat soils produce humic acids that are dark brown to black in color (Wallage et al., 2006), and acid sulphate soils that contain pyrite in a reduced condition are covered below the peat soils (Wöstena et al., 1997). A severe acidification arises when the acid sulphate soils surface and the pyrite is oxydized

Table 2
On-site water quality monitoring (DO, pH and EC) and laboratory analysis (COD, NH_3-N, PO_4-P, heavy metals and transparency).

Site	DO (mg/L)	pH (–)	EC (mS/cm)	COD (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Transparency (cm)	Heavy Metals (mg/L)
S1	0.00	7.72	1.29	50.0	7.92	2.21	10.7	0.2
S2	4.54	4.42	1.01	30.0	6.60	0.46	8.2	1
S3	1.97	6.88	0.35	16.5	< 0.2	0.03	5.2	0
S4	0.13	7.28	0.57	20.0	7.68	0.64	10.8	0
S5	6.10	6.86	0.22	16.5	0.60	< 0.03	15.3	0
S6	5.69	7.81	0.88	10.0	12.24	0.26	11.6	0.5
S7	5.10	7.51	0.18	11.5	0.53	0.07	> 30.0	0
S8	4.41	7.57	0.45	13.0	11.24	0.92	16.5	0
S9	3.09	7.24	0.34	10.0	5.92	0.14	> 30.0	0
S10	7.11	7.86	0.10	6.0	< 0.2	< 0.03	> 30.0	0
S11	3.72	7.39	0.36	13.0	7.40	0.41	> 30.0	0
S12	4.52	6.92	0.11	6.0	0.49	0.26	9.9	0
S13	4.96	7.31	0.29	13.0	0.68	0.13	2.2	0
S14	6.46	7.11	0.06	4.0	0.23	0.21	> 30.0	0
S15	6.39	7.21	0.05	5.0	0.30	< 0.03	30.0	0
S16	6.27	7.06	0.04	4.0	0.46	< 0.03	> 30.0	0
S17	1.23	7.27	0.36	13.0	7.12	0.52	25.8	0
S18	0.00	7.17	0.37	16.5	6.64	0.45	6.8	0
S19	6.83	7.87	0.39	20.0	10.28	1.54	> 30.0	1
S20	4.39	7.42	0.33	10.0	8.96	1.21	3.8	0.2
S21	6.92	7.76	0.05	5.0	< 0.2	< 0.03	> 30.0	0
S22	7.04	7.28	0.04	6.0	0.29	< 0.03	> 30.0	0

(Wöstena et al., 1997). Therefore, the low pH at S2 was probably because of the oxidized pyrite and could be worsen by the land development.

The water quality at a tributary from Putrajaya Lake (S10), upstream sites of the Semenyih River (S14-S16) as well as the Langat River (S21 and S22) was almost pristine condition. The water quality in Putrajaya Lake is well managed by wetlands that were created in 1997–1998 to absorb nutrients as a natural water treatment (Sim et al.,

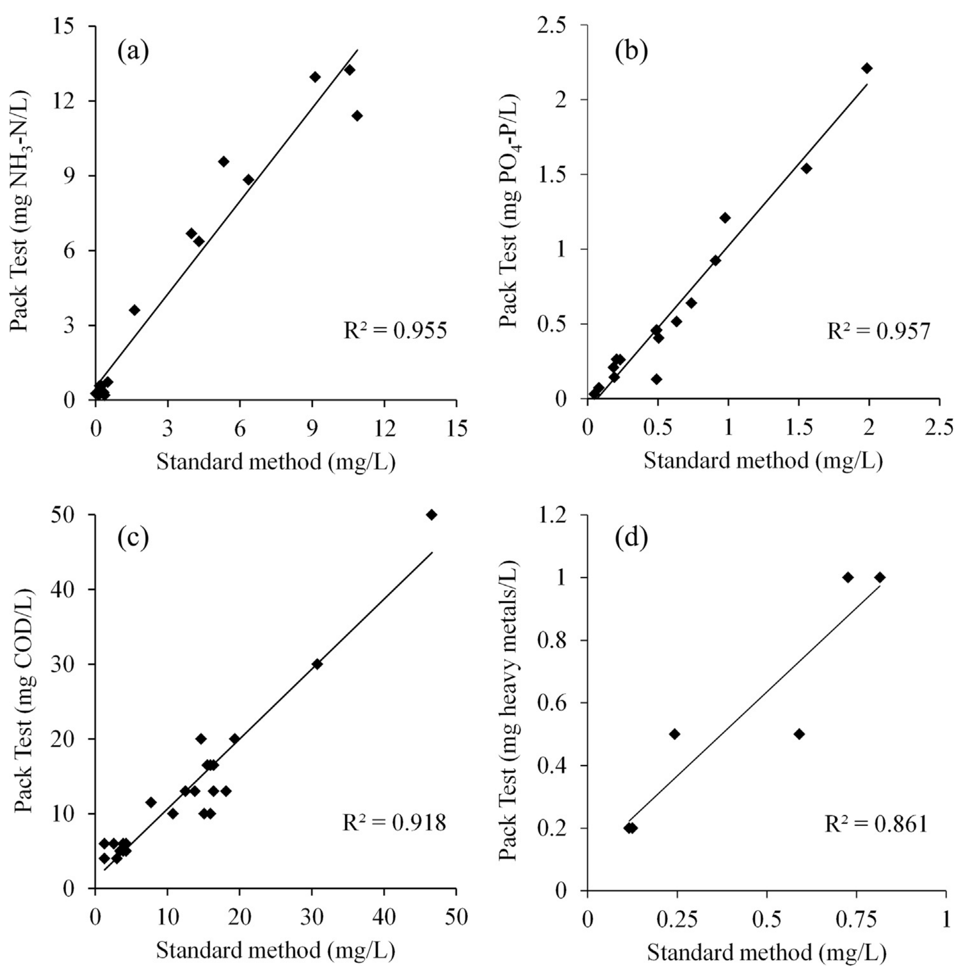

Fig. 3. Correlation analysis between the observed data of Pact Test and standard methods: (a) NH_3-N ($R^2 = 0.955$, $P < 0.001$); (b) PO_4-P ($R^2 = 0.957$, $P < 0.001$); (c) COD ($R^2 = 0.918$, $P < 0.001$); (d) heavy metals (*i.e.*, the sum of Mn, Ni, Cu, Zn and Cd) ($R^2 = 0.861$, $P = 0.008$). *2-column fitting image.

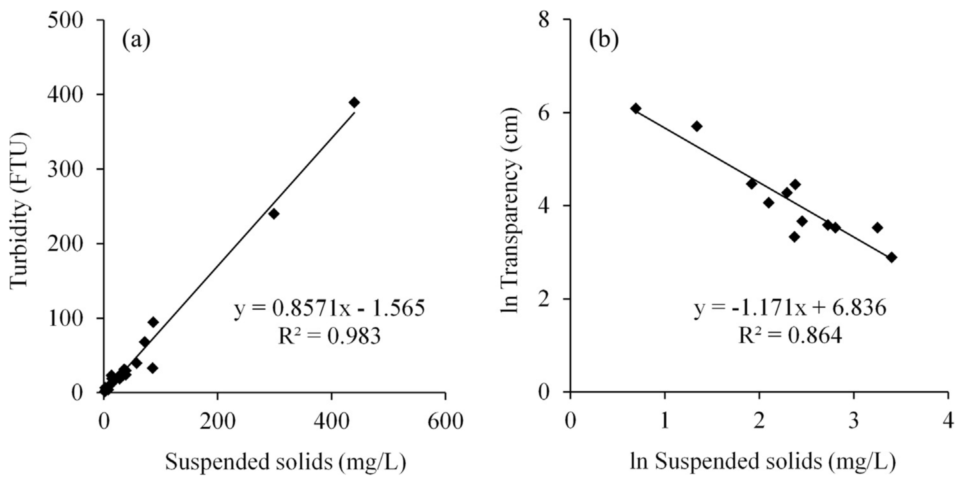

Fig. 4. Regression analysis between (a) turbidity and suspended solids (R^2 = 0.983, P < 0.001) and (b) logarithmic values of transparency and suspended solids (R^2 = 0.864, P < 0.001). *2-column fitting image.

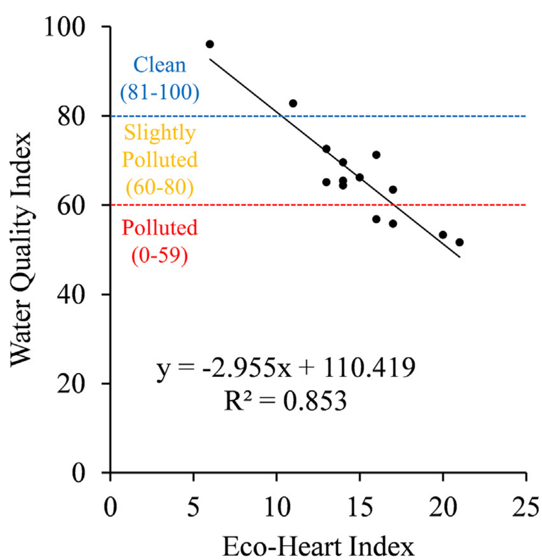

Fig. 5. Regression analysis between the total count of Eco-Heart Index and the WQI values with the water quality categorization (WQI = 81–100: clean; WQI = 60–80: slightly polluted; WQI = 0–59: polluted) (R^2 = 0.853, P < 0.001). *1-column fitting image.

2008). The upstream areas of the Semenyih and Langat Rivers have less population as well as less anthropogenic influence, hence a minimal amount of pollutants would be discharged into rivers (Sakai et al., 2017a).

In contrast, the surface water was polluted at the mid-stream sites of the Langat River and its tributaries (S17-20), at the Semenyih River and its tributary (S12 and S13), at the Labu River and its tributaries (S6-S8), and at all of the downstream sites (S1-S5). The NH_3-N concentrations of most of these sites were higher than 5 mg NH_3-N/L that was categorized as heavily polluted (Table 1). During the end of January and mid-March 2014, there was an extreme dry spell in Malaysia and the precipitation in Kuala Lumpur during this period was only 21.83 mm, according to Tutiempo.net[2]. Therefore, the water level in the Langat River basin became extremely low and organic pollutants in the surface water would be concentrated. Furthermore, some of these sites were considerably turbid as the transparency showed less than 10 cm (*i.e.,* suspended solids were higher than 50 mg/L). As a consequence, the mid-stream and downstream of the Langat River (*i.e.,* S3, S9, S11, S17 and S18) received all these pollutant loads, and the water quality was deteriorated accordingly.

3.4. Water quality map with Eco-Heart Index and categorization of pollution trend

The occurrence and distribution of the water pollution in the Langat River basin were clearly visualized by Eco-Heart Index (Fig. 6). Upstream sites (S14-S16, S21 and S22) and a tributary from Putrajaya Lake (S10) showed almost a full heart shape (Fig. 7a), whereas most of the mid-stream and downstream sites showed various broken heart shapes. Interestingly, the broken heart shapes could be categorized by 4 types. The S9, S11, S17 and S19 showed high concentrations of NH_3-N and COD as well as a low DO concentration (*i.e.,* nutrient-rich water). Accordingly, the heart shape became thinner and sharpened (Fig. 7b). Because built-up areas had significantly expanded and the population had dramatically increased around these areas, particularly around S17, S18 and S19 during 2005 and 2014 (Muhamad et al., 2015), the thin heart shape indicating the nutrient-rich water could be related to municipal wastewater.

The S3, S12, S13 and S20 showed an extremely low transparency and low concentrations of NH_3-N and COD (*i.e.,* turbid water). Accordingly, Eco-Heart Index showed a rabbit-ear shape or a flattened shape (Fig. 7c). The high turbidity in S13 and S20 could be due to extensive land developments such as housing and quarry operations. A huge area around S13 was being developed for housing and extensive bare lands were observed on the sampling date. The land cover along the Semenyih River from 2004 to 2016 was predicted that the forest area would significantly decrease, whereas the cultivated land and the oil palm plantation as well as the urban area would increase, hence the Semenyih River would be consequently prone to soil erosion by 2016 (Mojaddadi Rizeei et al., 2015). On the other hand, there were many quarry operations as well as extensive mining areas around S20 (Memarian et al., 2013), and moreover illegal quarry operations had been disclosed by a local newspaper (The Star Online, 2015). Consequently, the siltation became a serious problem due to the quarry operations, particularly during the early stage such as land clearing and site preparation (Pereira and Ng, 2004). Thus, the rabbit-ear shape indicating the turbid water could be related to quarry operations as well as the land development.

The S1, S4 and S18 showed not only polluted by nutrients but also turbid by suspended solids (*i.e.,* nutrient-rich and turbid water). Accordingly, Eco-Heart Index showed a finger shape (Fig. 7d). The land

[2] provides climate information for every country in the world with historical data in some cases date back to 1929. Website: http://en.tutiempo.net/climate/01-2014/ws-486470.html.

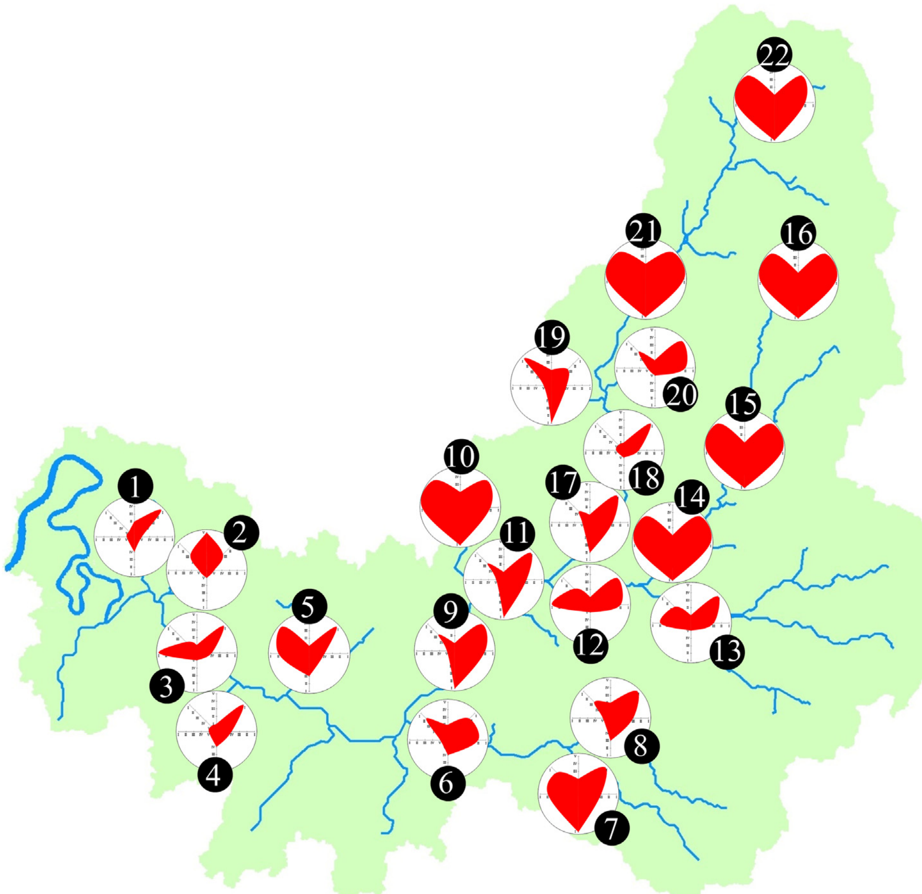

Fig. 6. Water quality map with Eco-Heart Index in the Langat River basin. *1.5-column fitting image.

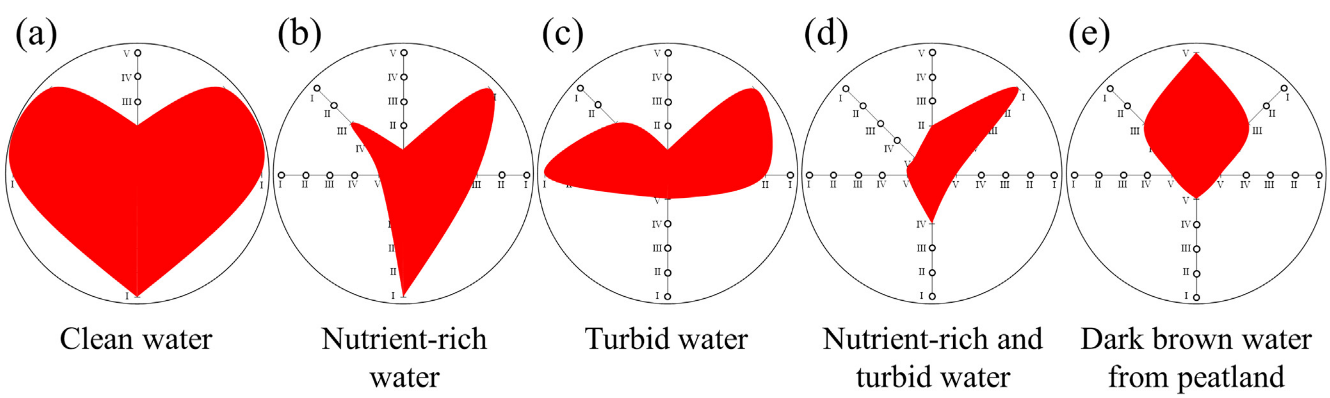

Fig. 7. Categorization of the pollution trends visualized by Eco-Heart Index: (a) clean water; (b) nutrient-rich water; (c) turbid water; (d) nutrient-rich and turbid water; (e) dark brown water from peatland. *2-column fitting image.

cover around S1 and S4 is dominated by the oil palm plantation that could aggravate the surface runoff due to the compacted soil (Firdaus et al., 2010). Furthermore, many livestock farms exist around S1 and S4 where no effective wastewater treatment system has been installed (Sakai et al., 2016). Therefore, the water quality in S1 and S4 could be significantly affected by the surface runoff as well as the effluents from livestock farms. On the other hand, S18 is located downstream of S19 and S20 where the nutrient-rich water and the turbid water were flowing. Therefore, the finger shape indicating the nutrient-rich and turbid water could be related to combined water pollution from various pollution sources. If heavy metals were also contaminated at S1, S4 and S18, the shape would become a small dot at the center of Eco-Heart Index that represents a worst water quality.

The dark brown water at S2 showed a unique shape in Eco-Heart Index. Eco-Heart Index showed a diamond shape (Fig. 7e) because of an extremely low pH, high concentrations of NH_3-N and COD, and moderate concentrations of DO and heavy metals (Table 1). Because peat soils are generally deficient in micronutrients, particularly iron, copper and zinc, and heavy metals that are supplied to the peatland change into non-available forms due to the soil property (Ambak and Takano, 1991; Yonebayashi et al., 1994), the contamination of the heavy metals could be attributed to the excess application of fertilizers such as pruned fronds, empty fruit bunches, treated palm oil mill effluent and solid sludge (Sakai et al., 2017b; Ludin et al., 2014).

Nevertheless, the type of heart shapes (Fig. 7a-e) as well as the association with pollution sources could need recategorization in other watersheds because water quality should vary with water resources, pollutants, land use, geological condition *etc*. The developed categorization for the Langat River basin also may need modification in the future because the land use, anthropogenic influence or water resource would change along with the local needs and the economic transition. Seasonal water quality changes also need to be clarified as the concentrations of pollutants in streams could vary with weather conditions. Therefore, the categorization needs to be checked prior to use, and recategorization/modification may be necessary in a timely manner. If the parameters need to be changed in the recategorization/modification process, the number of parameters must be fixed at 6 because heart shape only works with 6 parameters, otherwise it would need to be converted to another shape such as diamond shape (4 parameters) or star shape (5 parameters). The 6 parameters can provide general water quality but cannot identify specific pollutants, including regulated contaminants and pathogen pollution. In this sense, Eco-Heart Index should not be used beyond general water quality monitoring and assessment, but it will be helpful to indicate the necessity of further analyses for specific pollutants, based on the drawn figures.

Eco-Heart Index as well as the community-based water quality monitoring kits has been introduced to some rural and urban communities in Malaysia and it works well for them to perform with a brief instruction and hands-on training, although the categorization with 5 shapes has not been introduced to the communities. Connection of 6 marks (Fig. 2) and identification of drawn figures, particularly broken hearts (Fig. 7b-e) and uncategorized shapes, needs to be validated with feasibility studies because individual differences in drawing and/or perception may affect the evaluation. For the sake of correct drawing and identification, a standard instruction as well as a training module needs to be developed so that Eco-Heart Index will provide a best performance as a locally-adapted water quality indicator. Finally, this study did not take into account methodologies of community engagement (*e.g.*, involvement, education, empowerment *etc.*), but it will need to be developed in the future since Eco-Heart Index was designed to be used by communities worldwide as end-users.

4. Conclusions

This study developed Eco-Heart Index for the community-based water quality monitoring and assessment that meets a user-friendly, economical and accurate measurement, a policy-relevant output, and a universally impactful indication. The findings are summarized in the following:

4.1. User-friendly, economical and accurate measurement

The collection of hydrological data often requires advanced technology and a high cost, however Eco-Heart Index is based on affordable and user friendly water quality monitoring kits that are commercially available. The monitoring kits used in this study can be easily handled by dipping the plastic tube/analyzer into the water sample with a quick generation of results. The cost of Pact Test was approximately 6 Malaysian Ringgit (or 1.50 USD) per single analysis, and moreover there was no additional cost for pH, DO and transparency measurements other than their initial costs. The total cost is much cheaper than that of standard methods applied in this study, which need reagents, laboratory apparatus, instruments *etc*. The data obtained by the monitoring kits are quite accurate and strongly correlated with those obtained by standard methods.

4.2. Policy-relevant output

Results of Eco-Heart Index have shown a strong correlation with the WQI. This fact means that Eco-Heart Index can provide a policy-relevant output that can be obtained by the user-friendly and economical monitoring kits, and that the numerical way of evaluation (*i.e.,* total count of Eco-Heart Index) can be used as an alternative tool for the water quality categorization. The interpretation of the water quality situation using Eco-Heart Index is more attractive and informative than the WQI, which can only show an integrated value calculated from 6 water quality parameters. Potentially, this numerical evaluation of Eco-Heart Index can be applied to other water quality indices adopted in the world.

4.3. Universally impactful indication

The symbolic representation of water quality by full or broken heart shapes provides a more impactful indication that could increase the public interest and awareness of the water quality situation as well as facilitate community engagement. The water quality map in the Langat River basin using Eco-Heart Index clearly visualized that the upstream areas showed a full heart shape (clean water), whereas mid-stream and downstream areas, particularly populated and land development areas, showed broken-heart shapes (polluted water). The study categorized five shapes that are connected to a specific condition of water quality: clean water, nutrient-rich water, turbid water, nutrient-rich and turbid water and dark brown water from peatland. The heart shape is a universal symbol of peace and love that can easily resonate with a diversity of people and communities. This universality of Eco-Heart Index is quite impactful for generating a sustainable heartware foundation, particularly in multi-religious and/or multi-ethnic Malaysian society. Additionally, the interpretation of Eco-Heart Index has been contextualized to the local language in Malaysia and has impacted the emotive sensitivity through the local word '*patah hati*' (broken heartedness).

Overall, Eco-Heart Index is a multi-functional community-based water quality indicator. The policy-relevant output expressed by the universally recognized symbol of peace and love has great potential to achieve a breakthrough in community engagement as well as in creating a heartware foundation that is indispensable for IWM.

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