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# Water quality assessment using the Pollution Index (PI) and statistical tools: a case study of Thi Vai river, Dong Nai, Vietnam

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***Abstract:***

**The quality of river water is influenced by two factors: nature and man. The aims of this paper are to determine the influence of anthropogenic sources of pollution on water quality, by assessing integrated measurements from use of the Pollution Index (PI) of Indonesia and diverse statistical techniques, including one-way analysis of variance (ANOVA) and ArcGIS. In this study, 10 physicochemical parameters for the determination of water quality, from surface water taken the Thi Vai river, are examined: dissolved oxygen (DO), biochemical oxygen demand ($BOD_5$), chemical oxygen demand (COD), ammonium ($NH_4^+$-N), phosphate ($PO_4^{3-}$-P); total dissolved solids (TSS), pH, nitrite ($NO_2^-$), nitrate ($NO_3^-$), total coliforms, and fecal E. coli. The samples were collected from seven monitoring sites, for assessing spatial and temporal water quality, in the three years 2015 to 2017.**

**The findings revealed that water quality index values within the study area showed a significant pollution level for nitrite, and fecal E. coli. Water quality was detrimental at the sites TV2, TV3, and TV4. A further finding was that there was significant variation recorded between the two methods of measuring PI - that of the Ministry of the Environment, Indonesia, and that of Vietnam. Finally, this integrated technique could, it is suggested, be an effective approach for communicating information on water quality for sustainable waste management in Thi Vai river.**

***Keywords:*** **affect, assessment, Dong Nai, environment, Pollution Index, surface water, Thi Vai, Water Quality Index.**

***Classification number:*** **5.1**

## Introduction

Human beings in modern society adversely affect the quality of surface water through various areas of activity, such as agriculture and industry. Natural forces such as stormwater run-off events, can also cause problems, such as the seasonal phenomenon of soil erosion, which is largely affected by factors such as climate, land cover, land slope, and soil resilience [1].

Without doubt, a variety of physical, chemical, and biological factors can be harmful to human health, if they occur over and above permissible limits [1-3]. The PI is one of the most effective methods for assessing the status of water. The values of the Water Quality Index (WQI) or PI (PI) can be used to modify policies and to forward feasible measures for management and use of surface water resources, as formulated by various environmental monitoring agencies [4-6].

River water quality is readily affected by both anthropogenic impacts and natural processes, leading to degradation of surface water, which in turn fails to meet various purposes [1, 2]. Furthermore, the WQI has been considered to pose sorting water quality [6, 7].

Statistical techniques are useful for verifying changes over time and space that are caused by natural and anthropogenic processes [1, 2]. Of these, Analysis of Variance (ANOVA) was applied to evaluate the significant disparity between groups of monitoring stations and across seasons. Assessing the relationships between dependent and independent variables by use of Spearman's Correlation Analysis (SCA) has been popular in scientific research [2-4, 8].

QCVN 08-MT:2015/BTNMT is presently being harnessed as the national technical regulation on evaluation of surface water in Vietnam. This monitoring programme

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requires numerous parameters to be measured, analyzed, and explained, through the multivariate approach. The Water Quality Index (WQI), which involves a single number expressing water quality by integrating measurement values across many physicochemical parameters, is used to indicate the overall status of surface water quality [4-7].

The Ministry of Natural Resources and Environment of Vietnam (MONRE) has developed the WQI approach, as explained in Decision No. 879/QD-TCMT, to create guidelines on surface water quality for the protection and management of water resources. The WQI, which suits conditions in Vietnam well, evolved from the combination of weighted arithmetic WQI values with River Status Index (RSI) [4]. Accordingly, nine water quality parameters, those of temperature, DO, $BOD_5$, COD, $NH_4^+$-N, $PO_4^{3-}$-P; TSS, pH, and total coliforms, were chosen to calculate WQI. The WQI number ranges, which are colour-banded, are from 0 to 100; the higher the number, the better the water quality. This study also monitors additional indicators such as $NO_2^-$, $NO_3^-$ and fecal E. coli. Hence, another method, that of the PI (PI) of Indonesia, is also used to evaluate water quality. This method is based on the Indonesian Ministry of the Environment's Decree No115/2003 regarding the "Guidelines for determination of water quality status".

This topic will offer support for scientists as well as managers in the field, such as those working in ecology, resources, and environmental protection, who can use this study for monitoring the ecological health of Thi Vai river, Dong Nai province [9].

## Materials and methods

### *Study area*

The Thi Vai river starts in the Nhon Tho town of Dong Nai's Long Thanh province, running through the Tan Thanh district of Ba Ria - Vung Tau province and the Can Gio district of HCMC before flowing into the Eastern Sea. Its total length is approximately 76 kilometers and its total basin area around 300 square kilometers. The river receives around 34,000 cubic meters of discharged untreated wastewater daily, from nearly 200 operating enterprises situated along the basin; it also receives untreated wastewater from populated areas, aquaculture, fish farming, and cattle-raising farms.

The rainy season in the Thi Vai river area begins at the end of May and ends in the last week of October. This accounts for 90% of the whole year's rainfall; the remainder of the year is the dry season.

The total discharged volume into Thi Vai river directly from industrial activities in Dong Nai and Ba Ria - Vung Tau provinces, is 36,357 $m^3$/day. Besides the direct sources mentioned above, the river also receives indirect wastewater from production facilities and industrial zones in Long Thanh and Nhon Trach districts, through canals which flow into the river. One of the most common sources of pollution is that of water pollution, which is characterized by the presence of organic pollutants ($BOD_5$, COD), TSS, nutrients, oils, and microorganisms in the water. At present, urban centres in Dong Nai province do not have concentrated wastewater treatment systems, and wastewater is drained into the common drainage system. The results of a survey of 50 households situated along the Thi Vai river indicated that these households use groundwater, which is then discharged untreated directly into the canal, draining into Thi Vai river.

Most canals in the upstream area of the Thi Vai river have poor water quality. The parameters for COD, $BOD_5$, ammonium, nitrite, coliform, and E. coli exceed those specified in QCVN 08-MT:2015/BTNMT, column $B_1$, on multiple occasions.

### *Sampling, measuring, and analysis*

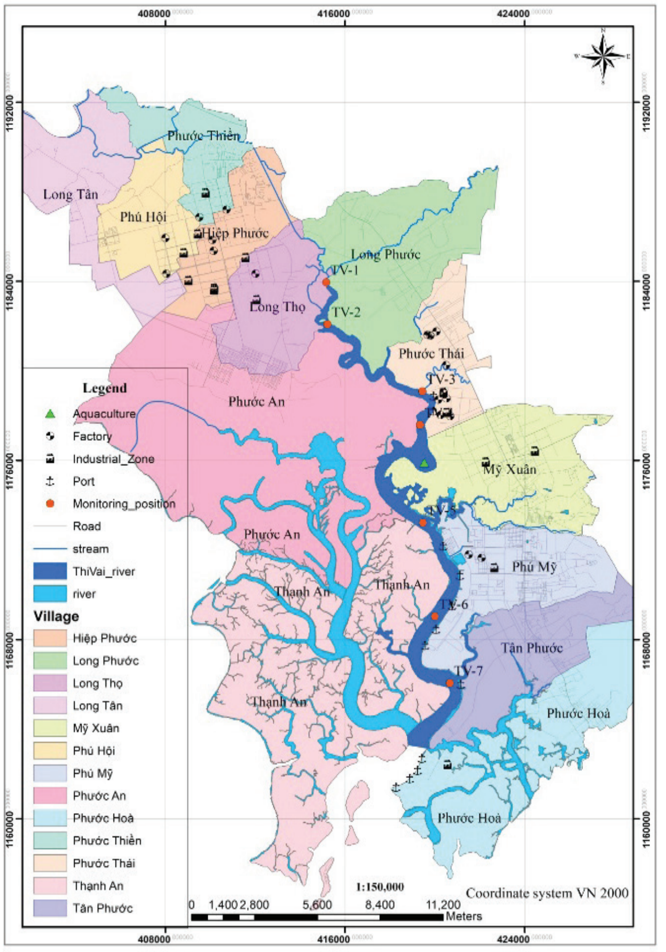


**Fig. 1. Map of Monitoring Positions on Thi Vai river.**

Where: TV1: confluence of Ba Ky canal on Thi Vai river; TV2: Long Tho Ward; TV3: Vedan large water ditch; TV4: Go Dau port; TV5: float number 23; TV6: Phu My Thermal Power Plant; TV7: float number 7.

Technical guidance for sampling water and sample treatments is specified in TCVN 6663-6:2008 (ISO 5667-6:2005), TCVN 6663-3:2003 (ISO 5667-3:1985), and TCVN 6663-6:2008 (ISO 5667-6:2005) respectively. The measurements for pH and DO were analyzed in the field; others samples were brought to the laboratory for analysis.

The data on 11 physical and chemical parameters for surface water quality were collected at seven sampling locations in the Thi Vai river basin, during the period 2015-2017, by the Centre for Monitoring Natural Resources and Environment (DONRE) of Dong Nai province (Fig. 1.) After collection, physicochemical parameters including DO, $BOD_5$, COD, $NH_4^+$-N, $PO_4^{3-}$-P, TSS, pH, $NO_2^-$, $NO_3^-$, total coliforms, and fecal coli were analyzed according to the procedures laid down in APHA, 1999 [10]. The data were then structured through use of the SPSS software program for statistical analysis.

***Statistical analysis and ArcGIS***

The box-and-whisker plot statistical technique was used to evaluate seasonal variance in the pollution status of the Thi Vai river basin. One-way Analysis of Variance (0.01≤alpha≤0.05) was used to investigate the substantial disparity in the mean of the PI across locations and seasons [2, 4]. Furthermore, Spearman's Correlation Analysis (SCA) was used to evaluate the relationships between the WQI (or PI) and physicochemical parameters. This study also monitored additional indicators such as $NO_2^-$, $NO_3^-$, and fecal E. coli. The PI of Indonesia was used to evaluate water quality, and was essential for this research. In this study, all statistical procedures were executed by using the SPSS 22.0 tool. In addition, ArcGIS 10.0 was also applied, to distinguish water quality for specific purposes [3, 4, 6, 7].

***Water quality index (WQI)***

The Vietnamese WQI Decision No. 879/QD-TCMT is used to determine water quality based on nine parameters: DO, $BOD_5$, COD, $NH_4^+$-N, $PO_4^{3-}$-P; TSS, pH, temperature, and total coliforms [8].

$$WQI = \frac{WQI_{pH}}{100}\left[\frac{1}{5}\sum_{a=1}^{5} WQI_a x \frac{1}{2}\sum_{b=1}^{2} WQI_b x WQI_c\right]^{\frac{1}{3}}$$

where: $WQI_a$ is determined through five parameters: DO, $BOD_5$, COD, $NH_4^+$-N, and $PO_4^{3-}$-P; $WQI_b$ is calculated by TSS and turbidity; $WQI_c$ was calculated with total coliform parameter, and $WQI_{pH}$ is determined by pH parameter.

WQI is distinguished according to a range from 0 to 100, the values corresponding to specific colours, and higher numbers signifying better water quality. The WQI process of water quality ranking was performed as in Table 1.

**Table 1. Surface water quality classification based on WQI.**

| WQI range/colour | Water quality rating |
|---|---|
| 91-100 (Blue) | Excellent water quality |
| 71-90 (Green) | Good water quality |
| 51-70 (Yellow) | Medium water quality |
| 26-50 (Orange) | Poor water quality |
| 0-25 (Red) | Very bad water quality |

The analysis of river water quality according to the PI followed the guidelines designated by the Ministry of Natural Resources and Environment's Decree No 115/2003, which uses the equation below:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^{\ 2} + (C_i/L_{ij})_R^{\ 2}}{2}}$$

where: $L_{ij}$ is the concentration of water quality parameters; $C_i$: concentration of water quality parameters; $PI_j$: PI of water; R: average; M: maximum.

Assessment of the PI estimate is: $0 \le PI_j \le 1.0$: meets standards of excellent quality; $1.0 < PI_j \le 5.0$: slightly polluted; $5.0 < PI_J \le 10$: steadily polluted; $PI_j > 10$: drastically polluted.

## Results and discussion

***Water quality assessment based on physicochemical parameters***

Table 2 and Figure 2 below compare the disparity in the percentage of samples that failed to meet Vietnamese technical requirements regarding surface water quality QCVN 08-MT:2015:BTNMT (B1) during the period 2015 to 2017.

Overall, what is striking from looking at the table and graphs is that surface water is polluted significantly by concentrations of COD, $NO_2^-$, and E. coli. In fact, COD concentrations in both the dry and the rainy season failed to meet admissible standards and varied considerably, at 33.33% and 46.33% respectively, with great variance between the seasons. Likewise, there was an upward trend in E. coli, the samples of which exceeded the permissible levels in the dry season and the wet season, at 13.10 and 24.14, respectively, again with a great difference between the two seasons. With regards to $NO_2^-$, almost 100% of the sampling sites failed to meet acceptable standards, with an

**Table 2. The proportion of samples that failed to meet the necessary standards.**

| Parameter | QCVN* | TV-1 | | TV-2 | | TV-3 | | TV-4 | | TV-5 | | TV-6 | | TV-7 | | Mean | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* | *Dry (%)* | *Wet (%)* |
| pH | 5,5-9 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| DO | ≥4 mg/l | 0.00 | 0 | 12.50 | 12.5 | 0.00 | 12.5 | 12.50 | 25 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 1.79 | 3.57 |
| $BOD_5$ | <15 mg/l | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| COD | <30 mg/l | 50.00 | 50 | 50.00 | 50 | 37.50 | 62.5 | 37.50 | 62.5 | 62.50 | 62.5 | 16.67 | 60 | 16.67 | 40 | 33.33 | 46.43 |
| $NH_4^+$-N | <0.9 mg/l | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| TSS | <50 mg/l | 12.50 | 0 | 12.50 | 12.5 | 12.50 | 0 | 0.00 | 0 | 0.00 | 0 | 16.67 | 0 | 0.00 | 0 | 7.74 | 1.79 |
| $NO_2^-$-N | <0.05 mg/l | 100.00 | 100 | 100.00 | 100 | 100.00 | 100 | 100.00 | 100 | 100.00 | 100 | 83.33 | 80 | 50.00 | 60 | 76.19 | 77.14 |
| $NO_3^-$-N | <10 mg/l | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| $PO_4^{3-}$-P | <0.3 mg/l | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| E. Coli | <100 mg/l | 37.50 | 50 | 25.00 | 50 | 0.00 | 37.5 | 12.50 | 37.5 | 12.50 | 12.5 | 16.67 | 20 | 0.00 | 20 | 13.10 | 27.14 |
| Coliform | <7,500 mg/l | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 |

Note: QCVN*: national technical regulations on surface water quality, QCVN 08-MT:2015/BTNMT (B1). B1 is the surface water source for irrigation or other purposes.
Dry: dry season; Wet: wet season.

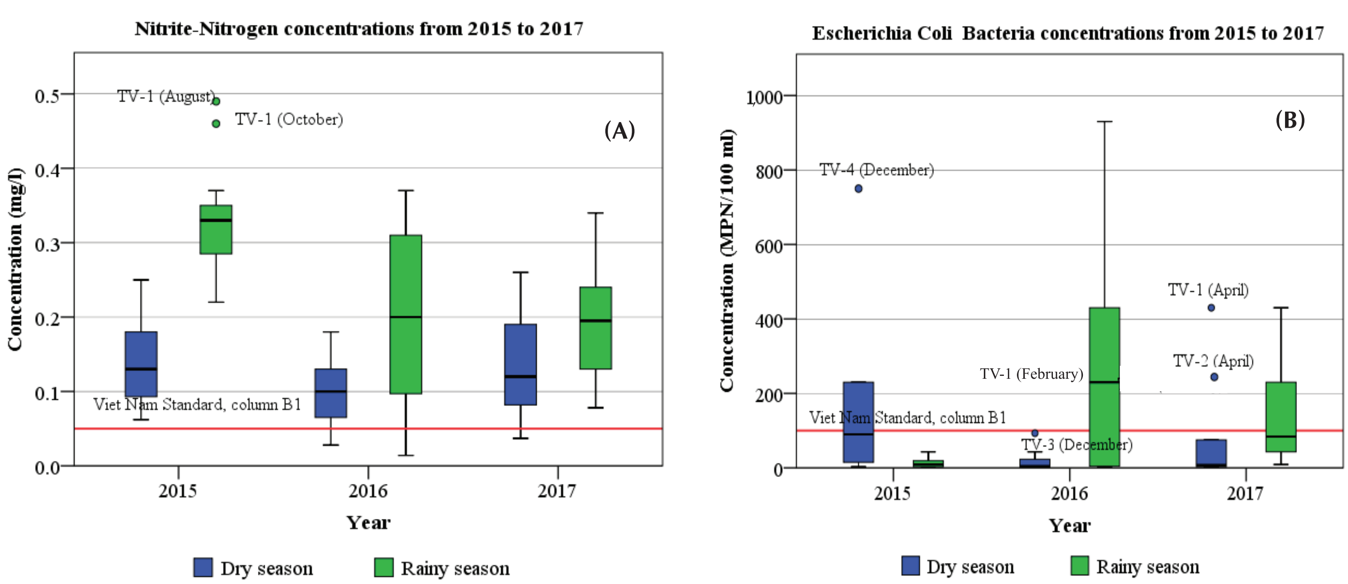


**Fig. 2. Nitrite (A) and E. Coli (B) concentrations across the seasons, in the observed period of 2015-2017.**

average range of 91.56±9.01 during the observed period, and significant seasonal variation. The causes of this issue could include the discharge of untreated wastewater from domestic use, seafood processing, aquaculture, fish farming, industrial activities, and agricultural run-off.

### *Water quality index assessment*

The Vietnamese WQI is calculated on nine parameters. These do not include $NO_2^-$, or $NO_3^-$. However, the water quality of the Thi Vai river was polluted by these indicators. Therefore, the results of the statistical analysis illustrate the great disparity between the WQI method of Vietnam and the PI of Indonesia. Hence, this study uses the Indonesian PI method for assessing water quality.

***PI analysis***

The striking observation from Fig. 3 is that the period in question witnessed a considerable downward trend in PI from upstream to downstream, corresponding to improved water quality (Fig. 3, Table 3). Furthermore, PI value was the highest in 2015, estimated at 2.09±0.68; this was followed by the PI value of 2017 (1.69±0.54); with the smallest estimation being 1.59±0.63 in 2016 (Table 3, Figs. 4, 5). Thus, the average difference between 2015, 2016, and 2017 was negligible (Fig. 4). Furthermore, the statistical analysis by ANOVA showed no dramatic difference in PI value between the three years.

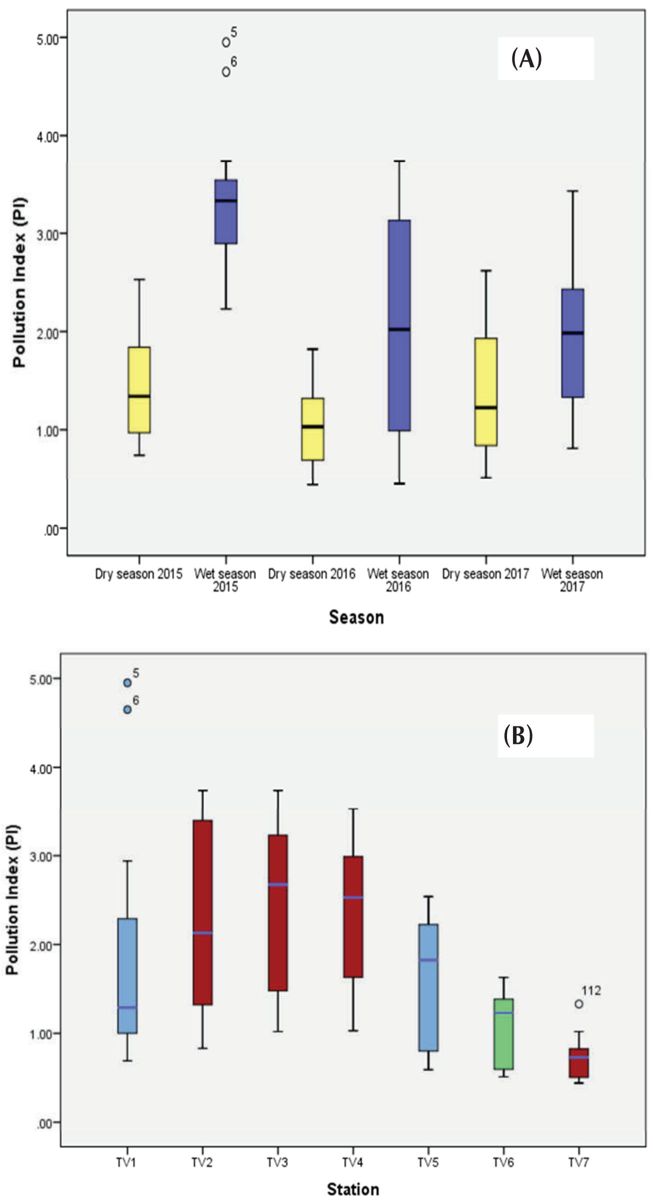


**Fig. 3. (A) was about seasonal changes; (B) was about spatial changes.**

The Box-and-whisker plots (Fig. 3) show that the PI values at the various sampling locations witnessed remarkable differences during the period 2015 to 2017, with PI values in the wet season being much greater than in the dry season. This seasonal change is most marked in 2016 (Fig. 3A). Moreover, in the wet season of 2015, the values for the two observations were outside the graph range. It is therefore important to determine the exact causes of this phenomenon, in order to bring in effective measures for the Thi Vai river. Furthermore, the PI value demonstrated a surge from TV1 to TV2, after which it declined slightly, from TV2 to TV4, then continued to drop rapidly to TV7. In general, pollution is seen to be mainly concentrated in the upstream areas of the river, such as the Ba Ky - Thi Vai canal, Long Tho, Vedan, and Go Dau areas. It is noteworthy that sites TV2 and TV3 receive a large quantity of untreated waste from industrial zones, fish farming, and aquaculture, which would have a detrimental effect on water quality.

The summary in Table 2 shows that at locations TV1, TV2, TV3, TV4, TV5, and TV6, water quality failed to meet permissible standards for the supply of residential domestic water, and was lightly polluted. The exception to this was site TV7, where water quality met the necessary standards (Table 3, Figs. 5, 6).

**Table 3. Average annual PI and rankings.**

| Code | Average annual PI | | | |
|---|---|---|---|---|
| | *2015* | *2016* | *2017* | *Ranking* |
| TV-1 | 2.68 | 1.45 | 1.36 | Lightly polluted (LP) |
| TV-2 | 2.55 | 2.25 | 1.88 | Lightly polluted |
| TV-3 | 2.56 | 2.32 | 2.49 | Lightly polluted |
| TV-4 | 2.48 | 2.30 | 2.21 | Lightly polluted |
| TV-5 | 1.89 | 1.14 | 1.87 | Lightly polluted |
| TV-6 | 1.34 | 0.94 | 1.20 | Lightly polluted |
| TV-7 | 0.77 | 0.75 | 0.85 | Met quality standards |
| Mean | 2.09±0.68 | 1.59±0.63 | 1.69±0.54 | |

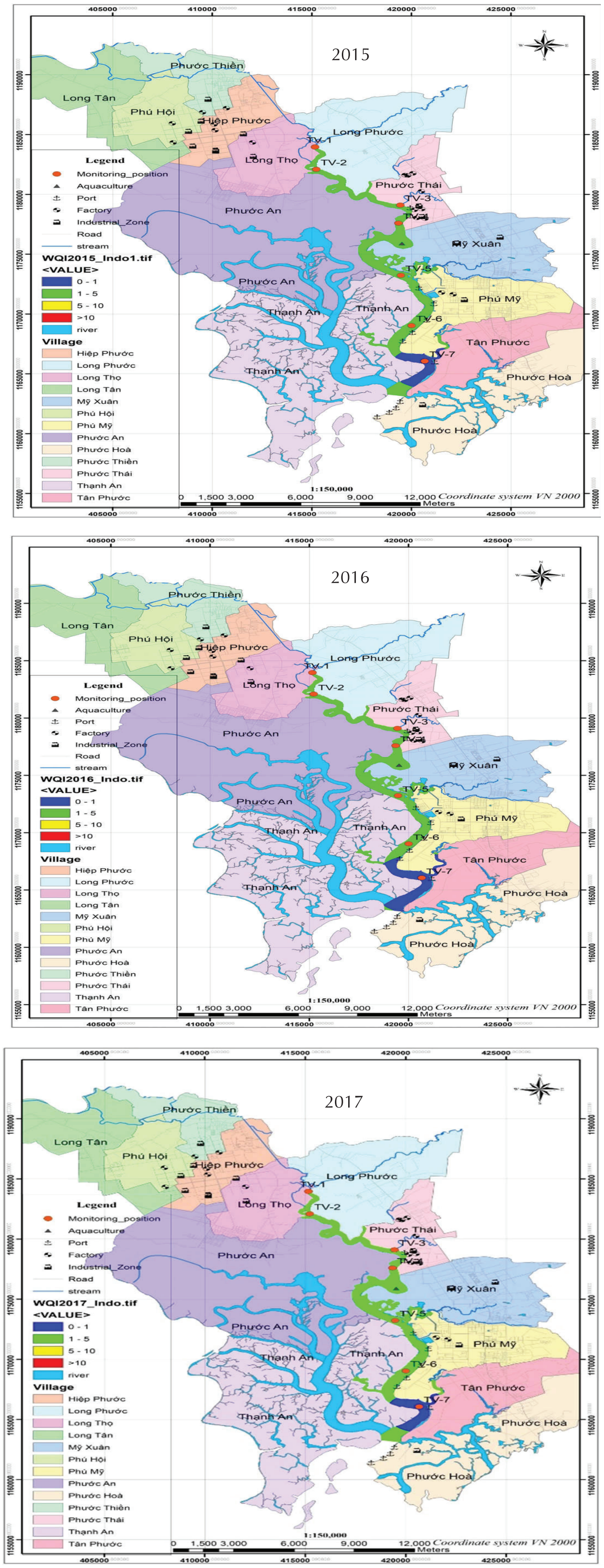


Fig. 4. PI of the Thi Vai river from 2015 to 2017.

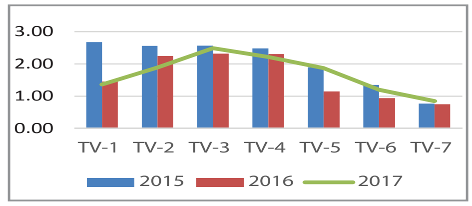


Fig. 5. Average annual PI.

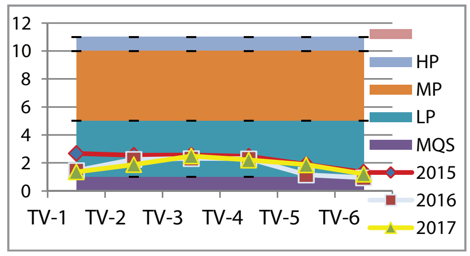


Fig. 6. Partition water quality according to PI.

***Spatial and temporal variations at the monitoring sites (ANOVA)***

The results of the one-way ANOVA analysis illustrate that the mean PI value in the dry season is dramatically different to that in the wet season (Table 4). Indeed, the statistical results indicate the seasonal changes were very distinct in 2015 and 2016, but not for 2017. The results also indicate the efficacy of the ANOVA tool in reference to this study. Seasonal factors strongly impact water quality in each of the studied areas (Sig.=0.000, α=0.05), which is a beneficial finding for the management of the water environment. A wide range of parameter concentrations and indications of pollution at the monitoring stations were recorded during the period in question. This indicates that the sources of pollution at each sampling site may be different (Table 5).

**Table 4. Differences in WQI value between the two seasons over the observed period.**

| (I) Season | | Mean difference (I-J) | 95% Confidence interval | |
|---|---|---|---|---|
| | | | *Lower bound* | *Upper bound* |
| Dry 2015 | Wet 2015 | -1.80467* | -2.61 | -1.00 |
| | Dry 2016 | .44 | -0.30 | 1.18 |
| | Wet 2016 | -.56 | -1.30 | 0.18 |
| | Dry 2017 | .13 | -0.69 | 0.95 |
| | Wet 2017 | -.51 | -1.33 | 0.30 |
| Wet 2015 | Dry 2016 | 2.24848* | 1.48 | 3.01 |
| | Wet 2016 | 1.24229* | 0.48 | 2.01 |
| | Dry 2017 | 1.93252* | 1.09 | 2.77 |
| | Wet 2017 | 1.29110* | 0.45 | 2.13 |
| Dry 2016 | Wet 2016 | -1.00619* | -1.71 | -0.31 |
| | Dry 2017 | -.32 | -1.10 | 0.47 |
| | Wet 2017 | -.95738* | -1.74 | -0.18 |
| Wet 2016 | Dry 2017 | .69 | -.09 | 1.47 |
| | Wet 2017 | .05 | -.73 | .83 |
| Dry 2017 | Wet 2017 | -.64 | -1.50 | .21 |

*The mean disparity is significant at 0.05.

**Table 5. The difference in WQI values between monitoring sites during the observed period.**

| (I) Station | | Mean difference (I-J) | 95% Confidence interval | |
|---|---|---|---|---|
| | | | *Lower bound* | *Upper bound* |
| TV1 | TV2 | -.38 | -1.33 | 0.57 |
| | TV3 | -.55 | -1.51 | 0.40 |
| | TV4 | -.45 | -1.40 | 0.51 |
| | TV5 | .28 | -0.67 | 1.24 |
| | TV6 | .82 | -0.24 | 1.87 |
| | TV7 | 1.15432* | 0.10 | 2.21 |
| TV2 | TV3 | -.17 | -1.13 | 0.78 |
| | TV4 | -.07 | -1.02 | 0.89 |
| | TV5 | .66 | -0.29 | 1.62 |
| | TV6 | 1.19614* | 0.14 | 2.25 |
| | TV7 | 1.53432* | 0.48 | 2.59 |
| TV3 | TV4 | .107 | -.847 | 1.062 |
| | TV5 | .836 | -.118 | 1.791 |
| | TV6 | 1.37114* | 0.31 | 2.43 |
| | TV7 | 1.70932* | 0.65 | 2.77 |
| TV4 | TV5 | .73 | -0.23 | 1.68 |
| | TV6 | 1.26364* | 0.21 | 2.32 |
| | TV7 | 1.60182* | 0.54 | 2.66 |
| TV5 | TV6 | .53 | -0.52 | 1.59 |
| | TV7 | .87 | -0.18 | 1.93 |
| TV6 | TV7 | .34 | -0.81 | 1.49 |

*The mean disparity is significant at 0.05.

**Table 6. Summarized correlation between PI and seven physicochemical parameters.**

| | DO | TSS | COD | $BOD_5$ | $NH_4^+$-N | $NO_2^-$-N | $NO_3^{-}$-N | $PO_4^{3-}$-P | E Coli | Coliform | PI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DO | 1.000 | .017 | -.219* | -.287** | .112 | -.527** | -.115 | -.111 | -.279** | -.292** | -.529** |
| COD | -.219* | .315** | 1.000 | .912** | -.256** | .227* | -.321** | -.216* | -.120 | -.121 | .244* |
| $BOD_5$ | -.287** | .263** | .912** | 1.000 | -.200* | .309** | -.346** | -.131 | -.125 | -.121 | .326** |
| $NO_2^-$-N | -.527** | -.111 | .227* | .309** | -.007 | 1.000 | .220* | .034 | .268** | .301** | .999** |
| $NO_3^{-}$-N | -.115 | -.153 | -.321** | -.346** | .161 | .220* | 1.000 | .228* | .377** | .439** | .218* |
| E Coli | -.279** | .037 | -.120 | -.125 | .418** | .268** | .377** | .333** | 1.000 | .932** | .272** |
| Coliform | -.292** | -.043 | -.121 | -.121 | .412** | .301** | .439** | .270** | .932** | 1.000 | .305** |

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

***Statistical correlations between physicochemical parameters and the PI***

The correlation between PI and specific parameters is indicated in Table 6. The main observation from this is the considerable negative correlation between PI value and DO, at r=-0.53. Considerable positive correlations can be observed between PI values and COD, BOD, $NO_3^-$, E. coli, and coliform concentrations, at r=0.24, 0.33, 0.22, 0.27, 0.31, respectively. In particular, there was a strong positive correlation between PI and $NO_2^-$ concentration, at r=0.99, which indicates that $NO_2^-$ concentrations substantially impact PI value, followed by DO. Other parameters had a low correlation with PI, because these showed good quality and mostly met the required standards. Thus, it can be stated that declining $NO_2^-$ concentrations and increasing DO are the urgent issues.

## Conclusions

The PI and statistical tools are effective and useful methods for communicating information on, and managing, water quality, both with regard to citizens and policymakers. The surface water quality of the Thi Vai river can be clarified in the following order: TV7>TV6>TV5>TV1>TV4>TV3>TV2. Furthermore, in 2015 and 2016, a strong difference between parameter in the dry season and those in the wet season can be observed; in addition, concentrations in the wet season were consistently higher than in the dry season. This study also indicates the anthropogenic effects of activities such as aquaculture industries and fish farming, which are seen to be principal sources of pollution. Furthermore, the efficacy of the Indonesian PI method is clear when assessing water quality in the Thi Vai river. Based on investigation of PI results, it can be concluded that effective treatment solutions and appropriate management processes are urgently required to enhance the water quality of the Thi Vai river.

The authors declare that there is no conflict of interest regarding the publication of this article.

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