VIETNAM JOURNAL OF HYDROMETEOROLOGY

Research Article

Assessing surface water quality of main rivers in Binh Thuan province by WQI index and proposing solutions to protect water resources

Huynh Phu[1*], Nguyen Thanh Do[2], Huynh Thi Ngoc Han[3], Tran Thi Minh Ha[4]

[1] HUTECH University; h.phu@hutech.edu.vn
[2] Department of Natural Resources and Environment Binh Thuan Province; nthanhdo160@gmail.com
[3] Hochiminh City University of Nature Resources and Environment; htnhan_ctn@hcmunre.edu.vn
[4] Tay Nguyen University, Buon Ma Thuot – Dak Lak, ttmha@ttn.edu.vn

*Correspondence: htnhan_ctn@hcmunre.edu.vn; Tel.: +84–975397953

Received: 5 October 2022; Accepted: 23 December 2022; Published: 25 December 2022

Abstract: The study was conducted to evaluate 5 main river basins: Long Song River, Luy River, Cai Phan Thiet River, Ca Ty River and Phan River in Binh Thuan province has a great impact on the province's socio–economic development. By method of survey, sampling and analysis of physico–chemical parameters and WQI method with hydrological regimes, typical minimum flow, the research has carried out the following contents: (1) An overview analysis of the water quality situation in the study area in the years 2018–2020; (2) Calculating the WQI index to determine the overall status of the water environment of 5 river basins; (3) Determine the environmental flow that needs to be maintained in the river to ensure the daily activities and production of people in the area. The research results have determined the current status of the water environment in rivers and canals and assessed the responsiveness of water sources to socio–economic activities in the locality. From there, propose solutions to effectively use surface water in river basins of Binh Thuan province in the direction of sustainable development.

Keyword: Hydrological mode; Surface water quality; The main rivers of Binh Thuan; WQI index.

1. Introduction

Binh Thuan province is one of the arid regions of Vietnam [1]. Binh Thuan is also a province with quite developed agro-forestry and aquaculture industries. The current situation of drought and water shortage is complicated, which has reduced crop productivity and greatly affected people's lives. In addition to economic achievements, the regional water environment has been affected by increasing agricultural, industrial and domestic waste [2–3]. The problem of water pollution is a global problem, not just one country, or any one territory. Therefore, research and finding solutions to protect water resources are always focused. To take specific measures to protect water resources, it is essential to assess the current state of water quality. Currently, there are many ways to assess water quality, such as: modeling, environmental monitoring, WQI water quality index, etc [4–7]. In Vietnam, the application of WQI to water quality assessment is quite popular [8–9]. The study was carried out in 5 main rivers: (1) Long Song River, (2) Luy River, (3) Cai Phan Thiet River, (4) Ca Ty River, (5) Phan River. These are rivers that have a great impact on the socio–economic development of the province.

The geographical location of river basins stretches across the province, including most cities, towns and townships such as: Phan Thiet City, Ham Thuan Nam district, Ham Thuan Bac district, Tuy Phong district, Bac Binh district, Ham Tan (part of townships and communes: Tan Nghia, Song Phan, Tan Phuc), Lagi town (part of Tan Hai and Tan Tien communes), Tanh Linh district (part of Duc Binh and Duc Thuan, Suoi Kiet). Consequently, the natural and socio–economic conditions of Binh Thuan province are also the natural and socio–economic conditions of the river basins [10–11]. The scientific basis for assessing surface water quality in the main river basins of Binh Thuan province includes: physicochemical parameters, water quality index (WQI) and minimum flow, hydrometeorological factors of the water environment to ensure water quality for the existence and development of ecosystems and human activities.

2. Materials and methodology

2.1. Study area

Binh Thuan province has a geographical location [12]: The Northeast and the North borders Ninh Thuan province; The North and the Northwest borders Lam Dong province; The West borders Dong Nai province; The Southwest borders Ba Ria–Vung Tau province; The East and Southeast borders the East Sea (Figure 1).

Figure 1. Location of the study area.

2.2. Study methods

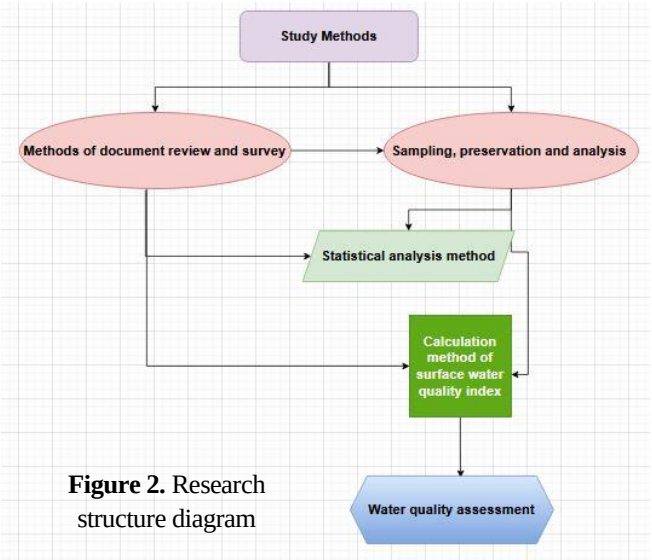


Figure 2. Research structure diagram

2.2.1. Methods of document review and survey

This method will inherit information from previous documents, investigation results or related studies to analyze and synthesize necessary information.

2.2.2. Methods of sampling, preservation and analysis of the physicochemical index composition of the sample

Sampling surface water according to Vietnam Standard (TCVN) 5996:1995 – "Water quality, sampling–Guidelines for sampling in rivers and streams". 1000 ml polyethylene, polypropylene or polycarbonate bottles for sampling were used. The dark and signed glass flasks were sterilized before sampling for microbiological analysis. Each flask was taken about 250 ml.

2.2.3. Statistical analysis method

Selectively collect and inherit documents, materials and results of domestic and international research works related to research contents applicable to river basins.

2.2.4. Calculation method of surface water quality index

The Water Quality Index (WQI) is an index calculated from the observed physicochemical parameters of water quality. The WQI is used to provide a quantitative description of water quality and its usability; represented by a scale. The WQI value scale is divided into certain intervals, each of which corresponds to a certain water quality rating. The study used the calculation of water quality index according to No. 1460/QD–TCMT dated November 12, 2019.

3. Results and discussion

3.1. Physicochemical parameters of water quality in rivers

On the basis of analysis of physicochemical criteria and comparison with national standards for each water source QCVN 08–MT:2015/BTNMT (abbreviated QC.08), the quality of water environment is assessed through physical and chemical parameters: chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), Total suspended solids (TSS), Cl^-, SO_4^{2-}, PO_4^{3-}, F^-, Fe^{2+}, Mn^{2+}, Nitrogen compounds, etc.

3.1.1. Long Song River

Sampling water at 8 sites (NM–LS1–8), analysis results are as follows:

pH: The results of pH measurement at sampling sites in the Long Song River basin ranged from 7.76 to 8.35 mg.l^{-1}. The pH value at all sites reached the abbreviation QC.08–A2 and the pH value is suitable for all uses in the river basin (Figure 3a).

DO: The results of DO analysis at sampling sites in the Long River basin ranged from 4.26 to 5.18 mg.l^{-1}. In areas serving the purpose of domestic water supply: DO content measured at site NM–LS1 did not meet QC.08–A2, 0.95 times lower than the allowed standard. In areas serving irrigation and irrigation purposes: the measured DO content at all sites met QC.08, level B1 (Figure 3b).

BOD_5 and COD: The measured values of BOD_5 and COD ranged from 09–25 mg.l^{-1} and 17–47 mg.l^{-1}. In areas serving the purpose of domestic water supply: the measured organic matter content did not meet QC.08–A2, BOD_5 exceeded the permitted standard by 5.00 times, COD exceeded the permitted standard 3.13 times. In areas serving irrigation and irrigation purposes: the measured organic matter content reached QC.08–B1 (Figures 3c–3d).

TSS: The results of TSS analysis have shown that there are uneven fluctuations in the river basin. TSS values ranged from 05–132 mg.l^{-1}. The TSS values were particularly high

at sites NM–LS5, NM–LS8. In areas serving the purpose of domestic water supply: TSS value reaches QC.08–A2. In areas serving irrigation and irrigation purposes: TSS content in most sites (05/07 locations) reached QC.08 – B1. Particularly at sites NM–LS5 and NM–LS8, TSS content exceeded QC.08–B1 standards by 1.40 and 3.30 times, respectively (Figure 3e).

Coliform: According to analysis results, Coliform value ranged from 20–2400 MPN.100ml^{-1}. Coliform values at all sites reached QC.08–A2. The Coliform content is suitable for all used purposes in the river basin (Figure 2f).

Phosphate (P–PO_4^{3-}), Ammonium (NH_4^+–N): According to the analysis results, the Phosphate (P–PO_4^{3-}) and Ammonium (NH_4^+–N) values fluctuated in the range of 0.019–0.048 mg.l^{-1} and 0.047–0.184 mg.l^{-1}, respectively. Phosphate and Ammonium values at all sampling sites (08/08 sites) in the Long Song River basin reached QC.08–A2. The nutrient content is suitable for all used purposes in the river basin (Figures 3g–3h).

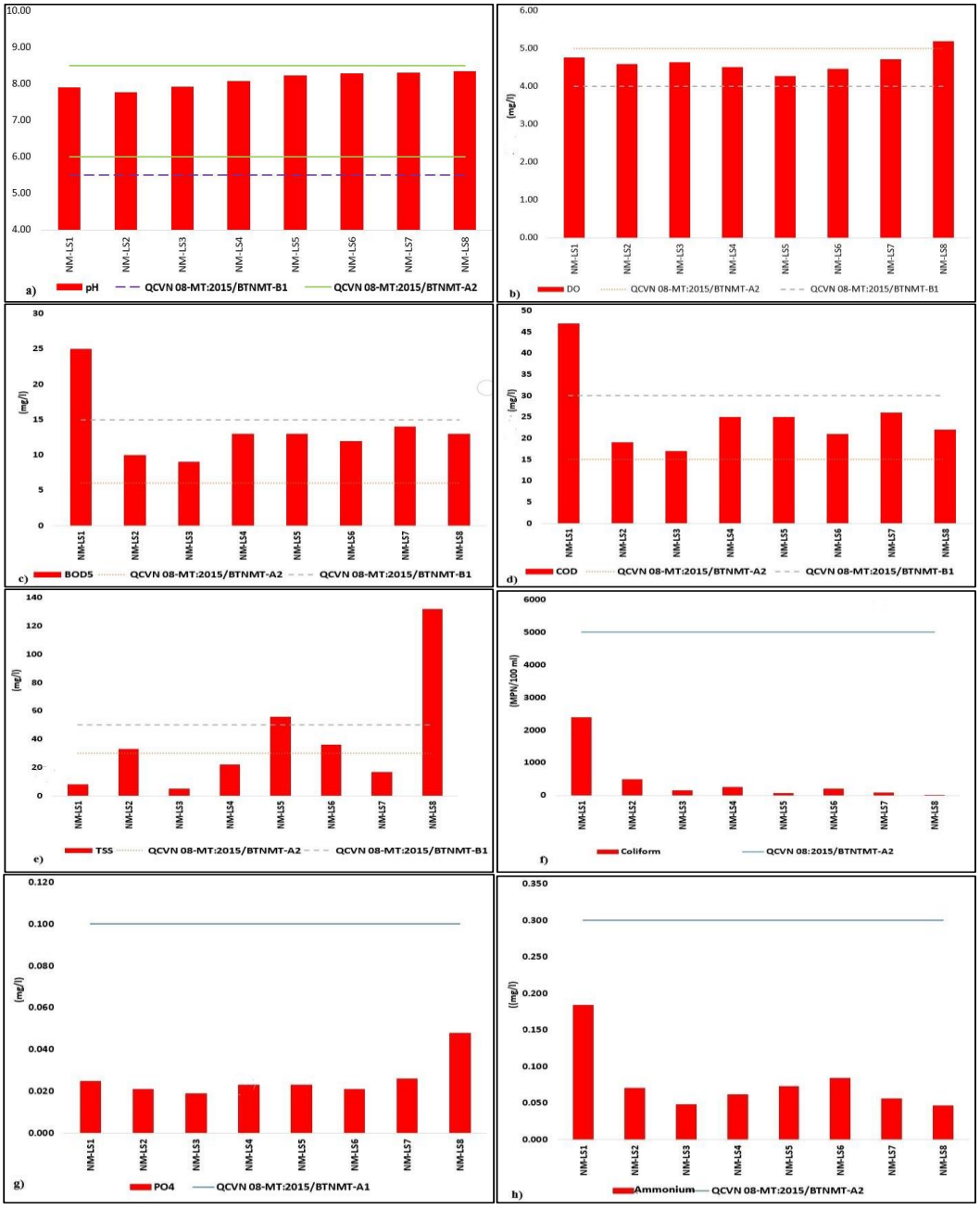


Figure 3. Measured values of water quality parameters at sampling sites on Long Song River basin: (a) pH parameter; (b) DO parameter; (c) BOD_5 parameter; (d) COD parameter; (e) TSS parameter; (f) Coliform parameter; (g) Phosphate parameter; (h) Ammonium parameter.

3.1.2. Luy River basin

Water samples were taken on the Luy River at 20 sites; (NM–L1–20). The samples were analyzed for physicochemical parameters, following results:

pH: According to the analysis results, the pH at the sampling sites on the Luy River basin ranged from 7.02 to 8.45 mg.l^{-1}. The pH value at all surface water sampling sites for domestic water supply purposes reached QC.08–A2. The pH values at all sampling sites of surface water for irrigation and irrigation purposes reached QC.08–B1 (Figure 4a).

DO: According to the analysis results, the DO concentration at sampling sites in the Luy River basin ranged from 4.52 to 5.27 mg.l^{-1}. In areas serving domestic water supply purposes: 10/14 samples did not meet QC.08, level A2. The DO value at sites NM–L2, NM–L3, NM–L6, NM–L7, NM–L8, NM–L10 and NM–L14 was lower than the allowed standard from 0.90 to 0.99 times, lowest at NM–L13–downstream of Ca Giay Lake. In areas for irrigation and irrigation purposes: DO values at all sampling sites met QCVN 08–MT:2015/BTNMT, level B1 (Figure 4b).

BOD_5 and COD: According to the analysis results, BOD_5 and COD values ranged from 07–20 mg.l^{-1}and 13–38 mg.l^{-1}, respectively. In areas serving domestic water supply purposes: the organic matter content in all sites did not meet QCVN 08–MT:2015/BTNMT–A2, the BOD_5 content exceeded the allowable standard from 1.5 to 2.83 times, the COD value exceeded the allowable standard from 1.07 to 2.07 times. In areas serving irrigation and irrigation purposes: organic matter content in most sites (04/06 sites) reached QC.08–B1. BOD_5 values at sites NM–L18 and NM–L19 exceeded the allowable standards by 1.07 and 1.33 times, respectively; COD values at sites NM–L18, NM–L19 exceeded allowable standards by 1.03 and 1.27 times, respectively (Figures 4c–4d).

TSS: The TSS value fluctuated at sites on the river basin, ranging from 04–273 mg.l^{-1}. This is consistent with the fact that the further downstream, the higher the concentration of suspended solids in the water. In which, most of the sites (16/20 sites) on the Luy River had TSS values of QC.08–A2. However, some sites at the downstream end that are in residential areas (NM–L17 and NM–L20) had significantly increased TSS values compared to other sites in the basin and all exceeded QC.08–B1 from 1.12 to 5.46 times (Figure 4e).

Coliform: According to analysis results, Coliform value ranged from 17–170 MPN.100ml^{-1}. All values of Coliform at the sites reached QC.08–A2. Therefore, the Coliform content is suitable for all water uses. By comparing the analytical criteria with the permitted standards, it shows that the water quality in the upstream and midstream on the Luy River has signs of high organic pollution, affecting the water resources and purposes of use. Further down the river, the concentration of suspended solids increases. The high concentration of pollutants in this area may be due to the concentration of many production and business activities and daily activities of people in the basin (Figure 4f).

Phosphate ($P–PO_4^{3-}$), Ammonium (NH_4^+–N): According to the analytical results, the Phosphate ($P–PO_4^{3-}$), Ammonium (NH_4^+–N) values fluctuated in the range of 0.018–0.072 mg.l^{-1} and 0.035–0.109 mg.l^{-1}, respectively. All sampling sites (20/20 sites) in Song Luy basin met QC.08–A2. The nutrient content in the river basin is therefore suitable for all used purposes (Figures 4g–4h).

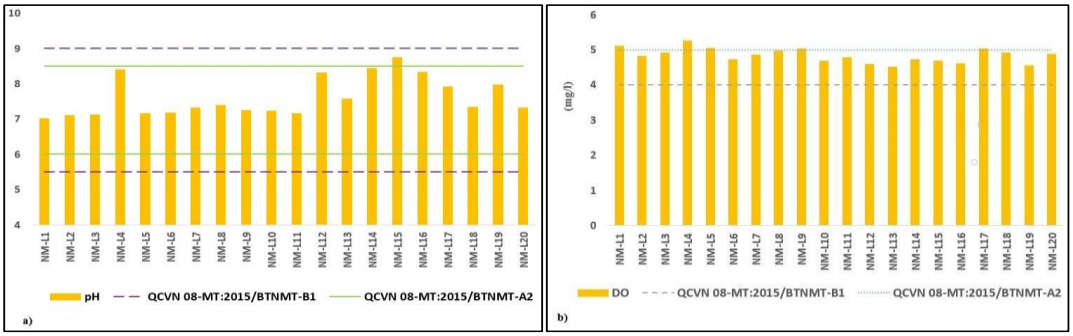


Figure 4. Measured values of water quality parameters at sampling sites on Luy River basin: (a) pH parameter; (b) DO parameter; (c) BOD_5 parameter; (d) COD parameter; (e) TSS parameter; (f) Coliform parameter; (g) Phosphate parameter; (h) Ammonium parameter.

3.1.3. The Cai River basin in Phan Thiet

Water samples were taken on the Cai River in Phan Thiet at 12 sites. The samples were analyzed for physicochemical parameters, following results:

pH: According to the analysis results, the pH at the sampling sites on the Cai River basin in Phan Thiet ranged from 6.71 to 8.41 $mg.l^{-1}$. All pH values at the sites reached QC.08–A2, pH suitable for all purposes on river basin (Figure 5a).

DO: DO at sampling sites on Cai River basin in Phan Thiet ranged from 2.17 to 5.15 $mg.l^{-1}$. In areas that serve the purpose of domestic water supply: DO content only reached QC.08–A2 at site NM–CPT3. In areas that serve irrigation and irrigation purposes: DO in most sites (07/09 sites) met QC.08–B1. Particularly at sites NM–CPT1 and NM–CPT2 that used for irrigation purposes, DO did not meet QC.08–B1 (Figure 5b).

BOD_5 and COD: According to the analysis results, BOD_5 and COD values ranged from 7–20 $mg.l^{-1}$ and 13–38 $mg.l^{-1}$, respectively. In areas serving domestic water supply purposes: the organic matter content in all sitens exceeded QC.08 – A2 from 2.00 to 4.17 times. In areas serving irrigation and irrigation purposes: organic matter content in most sites (07/09 sites) reached QC.08–B1 (Figures 5c–5d).

TSS: According to analysis results, TSS values at surface water sampling sites ranged from 02–235 mg.l^{-1}. TSS value has tended to increase gradually from upstream to downstream. In areas serving the purpose of domestic water supply: TSS values at all sites met QC.08–A2. In areas serving irrigation and irrigation purposes: TSS values exceeded the standard at sites NM–CPT1, NM–CPT2, NM–CPT10, NM–CPT11 and NM–CPT12 from 3.08 to 6.2 times (Figure 5e).

Coliform: According to the analysis results, Coliform values fluctuated unevenly at sampling sites across the basin, ranging from 70–4300 MPN.100ml^{-1}. All sites met QC.08–A2. The Coliform content was suitable for all used purposes on the river basin (Figure 5f).

Phosphate (P–PO_4^{3-}), Ammonium (NH_4^+–N): According to the analysis results, the Phosphate and Ammonium values ranged from 0.008–0.241 mg.l^{-1} and 0.072–0.254 mg.l^{-1}, respectively. In areas serving the purpose of domestic water supply: the content of nutrients in all sites reached QC.08–A2. In areas serving irrigation and irrigation purposes, the content of nutrients and nutrients reached QC.08–B1 (Figures 5g–5h).

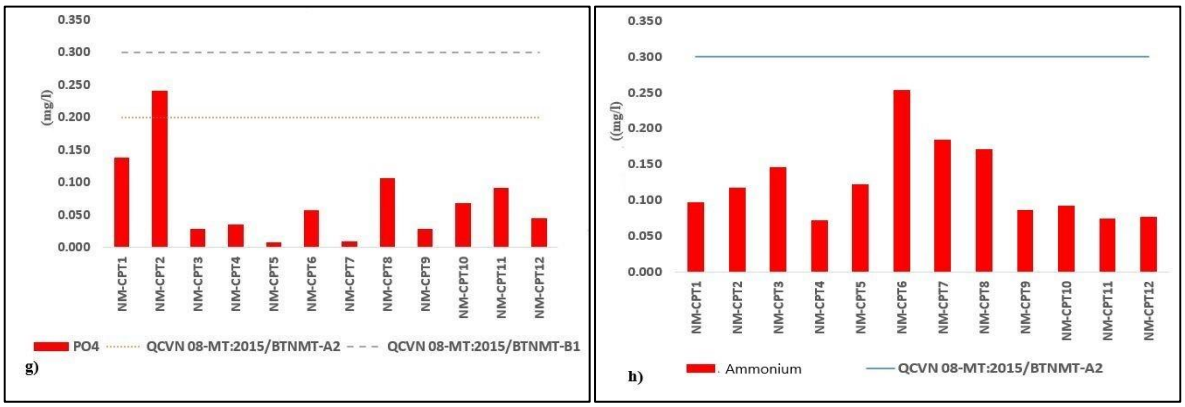


Figure 5. Measured values of water quality parameters at sampling sites on Cai River basin in Phan Thiet: (a) pH parameter; (b) DO parameter; (c) BOD_5 parameter; (d) COD parameter; (e) TSS parameter; (f) Coliform parameter; (g) Phosphate parameter; (h) Ammonium parameter.

Comment: Phan Thiet Cai River is the main river and provides water for production activities in Ham Thuan Bac district, Phan Thiet City; It also regulates the climate to create a landscape for the city center. However, the surface water quality of the Phan Thiet Cai River basin is being polluted by organic matter, with high BOD_5 and COD levels at almost all sites in the river basin, especially in the downstream area. Located in the city center location Phan Thiet City, the downstream area of Phan Thiet Cai River (from the confluence of Suoi Tien, Ben Loi river to Cau Ke bridge area, Phu Hai port) has shown signs of moderate to severe pollution (in terms of organic matter and suspended solids). The water quality in these areas is not suitable for used purposes.

3.1.4. Ca Ty River basin

Water samples were taken on the Ca Ty river at 15 sites. The samples were analyzed for physicochemical parameters, following results:

pH: According to the analysis results, the pH at sampling sites on Ca Ty River basin ranged from 6.56 to 7.77 $mg.l^{-1}$. All sites met QC.08–A2. The pH is suitable for all uses on the river basin (Figure 6a).

DO: According to analysis results, DO at sampling sites on Ca Ty River basin ranged from 1.40 to 5.18 $mg.l^{-1}$. In areas serving domestic water supply purposes: DO values achieved QC.08–A2 at sites NM–CT2, NM–CT8 and NM–CT10 (3/7 sites). In the areas serving irrigation purposes, DO in most of sites (6/8 sites) met QC.08–B1 (Figure 6b).

BOD_5 and COD: According to the analysis results, the BOD_5 and COD values ranged from 10–39 $mg.l^{-1}$ and 18–60 $mg.l^{-1}$, respectively. In areas serving domestic water supply purposes: organic matter content at all sites exceeded QC.08–A2. Specifically, BOD_5 exceeded 2.00 to 2.50 times, COD exceeded 2.08 to 2.75 times. In areas for irrigation purposes, the organic matter content exceeded at sites NM–CT6, NM–CT9, NM–CT11, NM–CT12 (4/8 sites). Specifically, the BOD_5 value exceeded 1.40 to 2.60 times and the COD exceeded 1.03 to 2.00 times (Figures 6c–6d).

TSS: According to the analysis results, the TSS values fluctuated unevenly, ranging from 04–265 $mg.l^{-1}$. In areas serving the purpose of domestic water supply: 03/07 the sites (sites NM–CT1, NM–CT5 and MN–CT10) exceeded QC.08–A2 from 1.60 (NM–CT5) to 5.13 (NM–CT10) times. In areas serving irrigation purposes: most of the TSS values (5/8 sites) exceeded QC.08–level B1 from 2.64 to 5.30 times (Figure 6e).

Coliform: According to the analysis results, the values of Coliform varied unevenly across the basin, ranging from 15–9500 $MPN.100ml^{-1}$. Most of the sites (14/15 sites) met QC.08–A2, suitable for used purposes, especially the NM–CT11 exceeded QC.08–A2 (area for the purpose of landscape conservation) 1.90 times. From the results of the assessment of

each indicator of surface water pollution in the Ca Ty River basin, it has been shown that the water quality is showing signs of organic pollution and suspended solid, especially towards the downstream of the river, from Cau Ca Ty to Phan Thiet Fishing Port, the section from Suoi Cat area, Ong Nhieu bridge flows into Ca Ty River (Figure 6f).

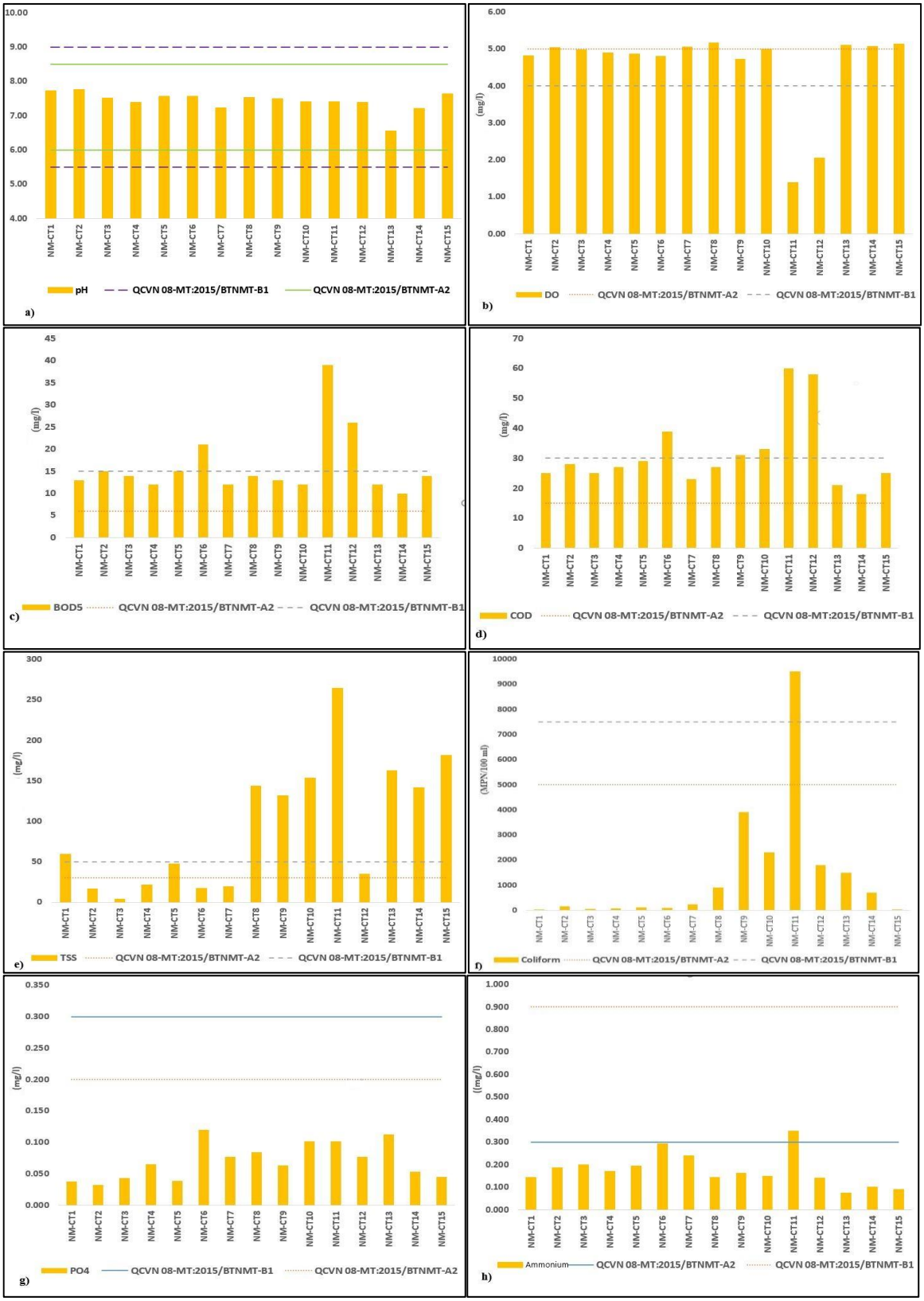


Figure 6. Measured values of water quality parameters at sampling sites on Ca Ty River: (a) pH parameter; (b) DO parameter; (c) BOD_5 parameter; (d) COD parameter; (e) TSS parameter; (f) Coliform parameter; (g) Phosphate parameter; (h) Ammonium parameter.

Phosphate ($P–PO_4^{3–}$), Ammonium ($NH_4^+–N$): According to the analysis results, the Phosphate and Ammonium values ranged from 0.032 to 0.120 mg.l^{-1} and from 0.076 to 0.350 mg.l^{-1}, respectively. In areas serving domestic water supply purposes: the nutrient content at all sites reached QC.08–A2. In areas serving irrigation purposes: the content of nutrients and nutrients reached QC.08–B1 (Figures 6g–6h).

3.1.5. Phan River basin

Water samples were taken on the Phan River at 15 sites. The samples were analyzed for physicochemical parameters, following results:

pH: According to the analysis results, the pH at sampling sites on the Phan River ranged from 7.25 to 8.12 mg.l^{-1}. All sites met QC.08–A2. The pH is suitable for all used purposes on the river basin (Figure 7a).

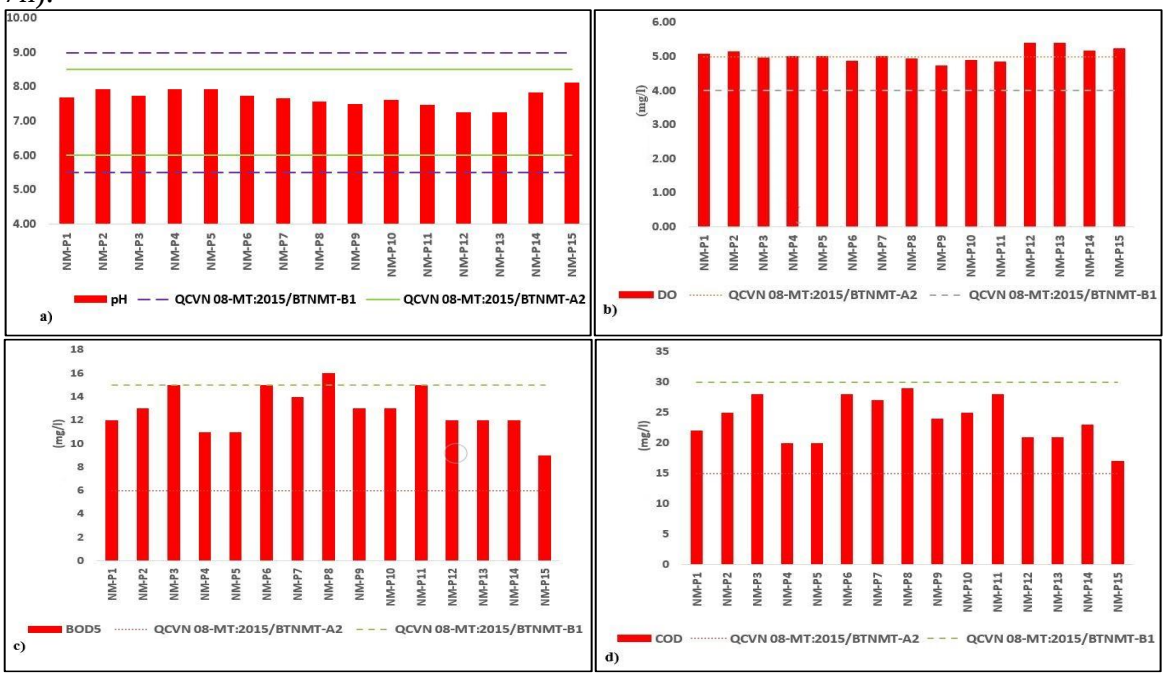
DO: DO at sampling sites on the Phan River ranged from 4.73 to 5.40 mg.l–1. In areas serving the purpose of domestic water supply: DO values in most sites (02/03 sites) met QC.08–A2. In the areas serving irrigation and irrigation purposes: DO values at all sites met QC.08–B1 (Figure 7b).

BOD_5 and COD: In areas serving domestic water supply purposes: organic matter content at all sites exceeded QC.08–A2; specifically, BOD_5 values exceeded 2.00 to 2.17 times, COD values exceeded 1.47 to 1.67 times. In areas serving irrigation and irrigation purposes: the organic matter content in most sites (10/12 sites) reached QC.08–B1 (Figure 7c–7d).

TSS: According to the analysis results, the TSS values increased gradually from upstream to downstream ranging from 0 –218 mg.l^{-1}. In areas serving domestic water supply purposes: all sites met QC.08–A2. In areas serving irrigation and irrigation purposes: sites from NM–P11 to NM–P15 (05/12) exceeded QC.08–B1 by 1.08 to 4.36 times (Figure 7e).

Coliform: According to analysis results, Coliform values ranged from 26–460 MPN.100ml^{-1}. All sites met QC.08– A1. Coliform within limits for all used purposes on river basin (Figure 7f).

Phosphate ($P–PO_4^{3–}$), Ammonium ($NH_4^+–N$): According to the analysis results, the Phosphate and Ammonium values fluctuated in the range of 0.024–0.153 mg.l^{-1}and 0.058 – 0.237 mg.l^{-1}, respectively. All sampling sites (15/15 sites) on Phan River met QC.08–A2. Nutrient content on river basin is suitable for all used purposes on river basin (Figures 7g–7h).



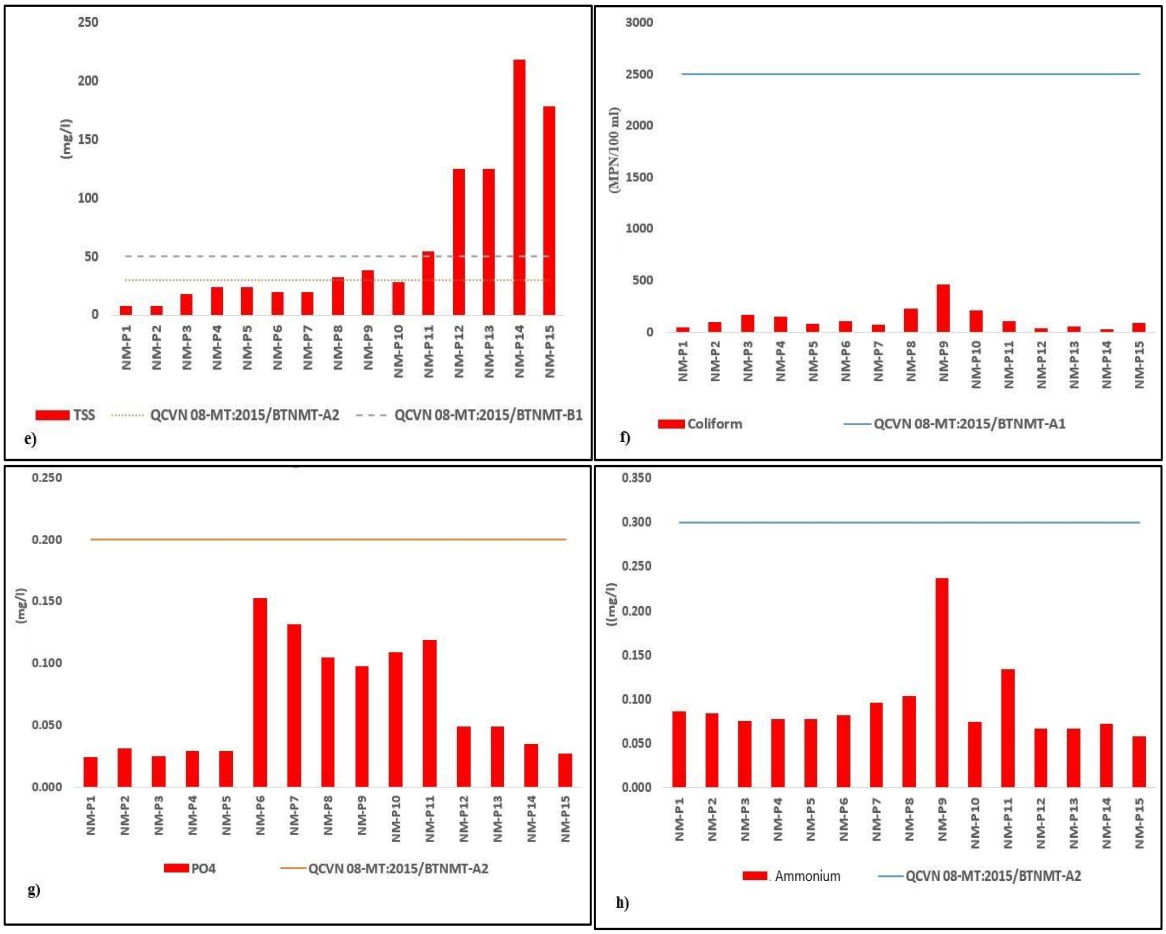


Figure 7. Measured values of water quality parameters at sampling sites on Phan River: (a) pH parameter; (b) DO parameter; (c) BOD_5 parameter; (d) COD parameter; (e) TSS parameter; (f) Coliform parameter; (g) Phosphate parameter; (h) Ammonium parameter.

3.2. Assessment of surface water quality in river basins according to the WQI index

The results of analysis of surface water quality with physicochemical parameters in river basins were carried out in February and March of the years 2018–2020. Analytical indicators: pH, DO, BOD_5, COD, TSS (Total suspended solids), N–NH_4, P–PO_4, Turbidity, Coliforms (the time of sampling surface water on the river system was taken at the same time of measuring and surveying the discharge, in accordance with No. 02/2009/TT–BTNMT of the Ministry of Natural Resources and Environment.

In order to have an objective view of the impacts of the current discharge on the investigated river and stream water quality, the consulting unit conducts an assessment of river water quality for each specific area through the analysis results. surface water samples for each river, stream and water quality index (WQI).

3.2.1. Long Song River Basin

Calculation results at sampling sites on the Long Song River showed that the WQI value does not change too much over time (Figure 8a). The water quality in the section flowing through Lien Huong town is suitable for irrigation purposes.

Water quality in the section flowing through Phong Phu in many times did not meet the purpose of domestic use. However, it is possible to ensure good use of water for irrigation (except for the dry season in 2018 which was heavily polluted due to high TSS content). The WQI index over time on the Long Song River is affected by TSS and turbidity, which makes the total WQI value quite low compared to the minimum value for domestic purposes.

3.2.2. Luy River basin

Calculation results at sites on the Luy River showed that the WQI values fluctuate greatly over time (Figure 8b). The water quality at Ca Giay reservoir location meets the purpose of using water for daily life. Water quality at locations from Xuan Quang dam to upstream is sometimes not good enough for domestic purposes, only meeting the needs of irrigation or navigation. At locations flowing through Luong Son residential area and downstream of Phan Ri Thanh, the WQI has great fluctuations; many times, the water quality is only suitable for navigation purposes. At the location of Xuan Quang dam, because it is located downstream of the agricultural area, the water quality is affected by agricultural production activities, with high TSS, organic matter and nutrients content. The WQI index is at most times only available for irrigation and navigation purposes. The WQI index over the periods on the Luy River is generally affected by TSS, turbidity and organic content due to daily activities and production of people living along the river. These parameters make the total WQI value quite low compared to the minimum value for domestic water supply purposes.

3.2.3. Cai Phan Thiet River basin

Calculation results at locations on the Cai River in Phan Thiet have shown that the WQI value has large fluctuations over time (Figure 8c). The quality of water for domestic use at the Phu Hoi dam site varies greatly between the rainy and dry seasons. In the rainy season, pollutants from agricultural production activities follow the rain to overflow into the river, making the river water quality unsuitable for domestic water use. The water quality in the downstream is only within the limits suitable for irrigation and navigation purposes. The WQI index over the period on the Cai River Phan Thiet is heavily influenced by TSS, turbidity and organic content. The total WQI value is quite low.

3.2.4. Ca Ty River basin

Calculation results at locations on the Ca Ty River have shown that the WQI values fluctuate greatly over time (Figure 8d). The water quality at the Ba Bau dam site is polluted mainly by TSS and the nutrient content is also quite high compared to the threshold for domestic water supply. The section crossing Chay bridge, the water quality in the period of 2019–2021 is good for the purpose of water supply for irrigation. The water quality in the section flowing into Phan Thiet City and Le Hong Phong bridge is only within the limits for irrigation and navigation purposes. The WQI index over the periods on the Ca Ty River is heavily influenced by TSS, turbidity and organic content, making the total WQI value quite low.

3.2.5. Phan River basin

Calculation results at locations on the Phan River show that the WQI values have large fluctuations over time (Figure 8e). The water quality at Tan Nghia dam site is suitable for the purpose of using water for irrigation. In the rainy season in 2018 and 2021, due to high TSS and turbidity, the WQI index only reached the threshold of water use for navigation. The river section passing the Vedan plant shows signs of water quality deterioration; many times, the water quality does not reach the threshold used for irrigation purposes. In the downstream (Tan Thuan and Cau Quang salt production areas) at most of the time of measurement, the WQI value is only within the limit suitable for irrigation and navigation purposes. The WQI index over the period on the Phan River is heavily influenced by TSS, turbidity and organic content, making the total WQI value at many times quite low.

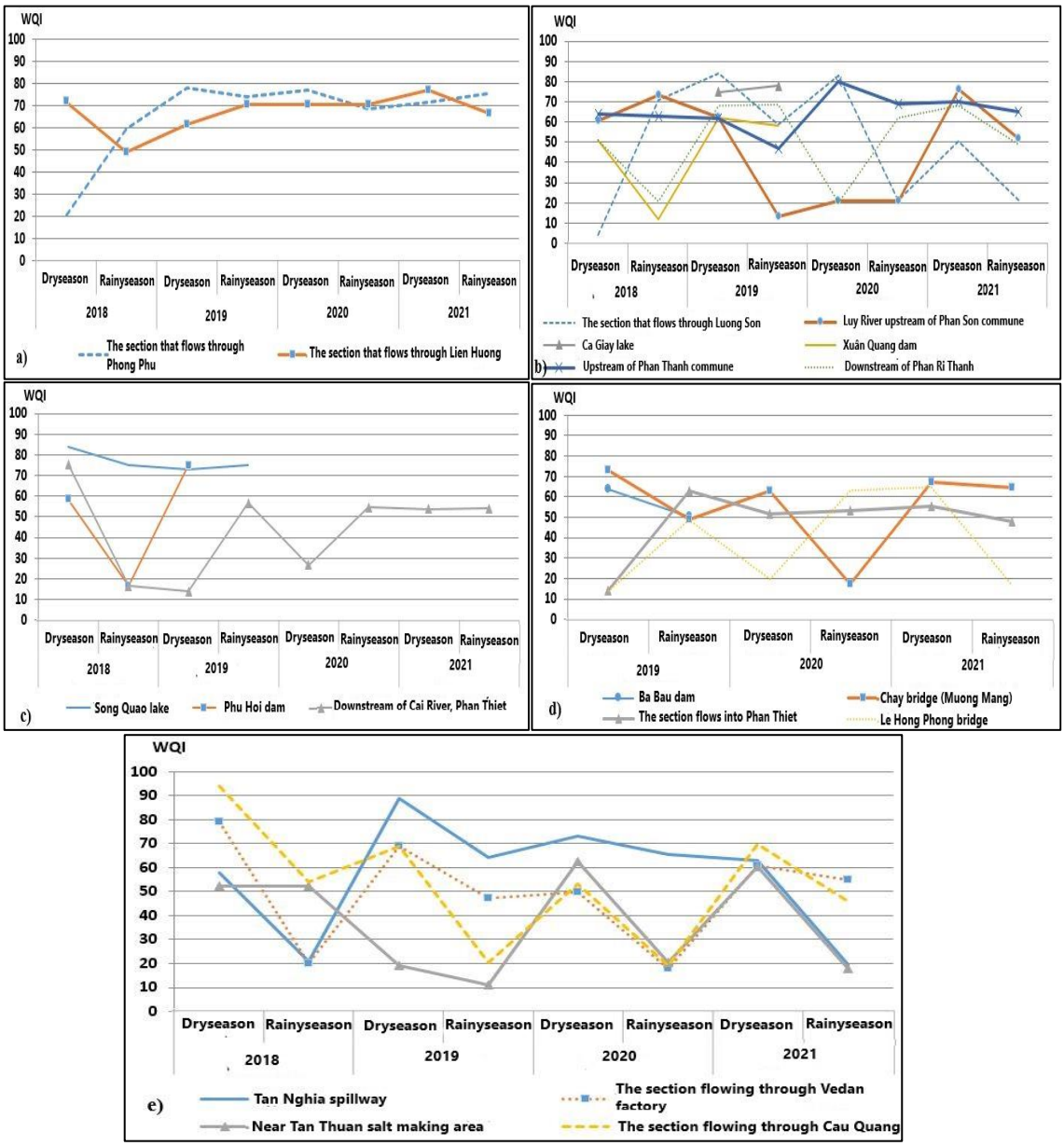


Figure 8. WQI values at sampling locations of surface water in rivers for the period 2018–2021: (a) Long Song River; (b) Luy River; (c) Cai Phan Thiet River; (d) Ca Ty River; (e) Phan River.

River water quality depends mainly on incoming flow, socio–economic development situation as well as discharge of wastewater into water sources in the basins. Usually in the flood season, the turbidity of the river is very high, the river level rises very quickly, the water overflows on the streets, alleys and concentrates on the culverts, canals, ditches and discharges into the river. At that time, the concentration of pollutants in the decreased significantly river in the rainy season because it was diluted many times compared to the dry season, typically the criteria: BOD_5, COD, SS, $N–NH_4^+$, etc.; but these parameters still exceed the water quality standards if not treated. In the dry season, the turbidity of sediment in the river is small, but the content of chemical and biological pollutants increases due to the poor dilution capacity of river water for wastewater from domestic and production activities.

The main wastewater receiving sources in Binh Thuan province within the scope of the investigation include: Nuoc Man River, Long Song River, Luy River, Cai Phan Thiet River, Ca Ty River, and Phan River. The common characteristics of rivers in Binh Thuan are short and steep. Therefore, the transport speed of pollutants that have the potential to cause water pollution after being discharged into the river is quite fast. Along the river basins, there are

many sluices with different discharges. When wastewater flows in, it will change the basic characteristics of natural water sources such as: changing the chemical composition of water, increasing the content of organic substances, mineral salts, appearance of toxic compounds, etc. changes in the ecosystem in the water, the appearance of different pathogenic bacteria and viruses. Previously, the water quality of river basins in the province was relatively good. In recent years, river water quality has been increasingly degraded due to impacts from socio–economic development activities.

3.3. Proposing solutions to protect water sources

3.3.1. Planting forests and trees

Improving land cover and rational use of land resources: The problem of water shortage in the dry season is also related to the protection of watershed forests. Binh Thuan province needs to continue to increase the area of forests and trees, restore ecosystems, and restore biodiversity. It is necessary to make use of the land fund of industrial production establishments to develop more green areas; at the same time renovating the parks to improve the quality of green areas in the area.

3.3.2. Solutions for zoning waste water in river basins

Purpose: zoning the receiving basin for different purposes of water use. From there, regulate the discharge level for each waste source to ensure the quality of water for water supply needs. For water areas used for domestic water supply purposes upstream, discharge sources in this area require mandatory wastewater treatment before discharging into the environment and meeting grade A standards compared to QCVN on waste water treatment. industrial, medical, domestic wastewater, etc. For water sources for non–domestic purposes, the discharge sources must be treated before being discharged into the environment and the quality of the wastewater is grade B compared with the current QCVN.

3.3.3. Propaganda to raise awareness of the community and businesses

Implement public and business awareness raising through the media or through actual operational models. Propagating and mobilizing people to use pesticides and chemical drugs rationally in agricultural production; do not throw plant protection drug bottles, jars and packages into canals, ditches, ponds, lakes and canals; do not discharge wastewater, domestic and production waste into the river. Organize an extensive emulation movement in the community. Implement water protection plans at all levels, branches and establishments, and all classes of people with practical actions; at the same time, take appropriate measures to sanction actions that violate the law on water source protection.

3.3.4. Encourage establishments to reduce pollution

Proposing to state levels on funding and pilot application of cleaner production program for production and business establishments in Binh Thuan province. To encourage production enterprises to invest, renew production technology and import new modern and environmentally friendly machines and equipment. Encourage voluntary establishments to relocate their production sites to the planning area. Encourage businesses to actively apply the 3Rs (Recycle – Reuse – Recovery) program. These activities are fundamental to reducing waste and optimizing the production process.

3.3.5. Management of waste sources from agricultural activities

Promote the application of technical advances in crop production. Strengthen education, propaganda and dissemination of harmful effects caused by pesticide pollution in production

to contribute to reducing environmental pollution. To build and develop the collection of used plant protection drug packages and expired veterinary drugs for communes and townships throughout the province. Organize cooperatives or teams, groups or groups of environmental sanitation in each commune/district, to collect hazardous waste in rural areas. Converting from scattered, small–scale livestock to concentrated farm farming towards industrial and semi–industrial direction to facilitate wastewater collection and treatment.

For waste from farming activities, residues of fertilizers and pesticides are lost to the environment relatively large (especially for wet rice models). In agricultural extension work, provide documents and information related to farming techniques, in which fertilization techniques and use of plant protection chemicals are based on the 4 right principles (right type, right dose, right amount) method and at the right time) is essential. Encourage the use of environmentally friendly chemicals, strictly prohibit and strictly control the use of plant protection chemicals outside the permitted list.

4. Conclusion

People's lives and socio–economic development in Binh Thuan province is associated with rivers and river basins. Nature has provided a source of water for people to live, eat, drink, and produce. But the downside is that it is humans who have put waste into the water, whether intentionally or unintentionally over the years, making the water source polluted. By traditional research methods, survey and evaluation, the authors analyzed the physico–chemical indicators of surface water quality and determined the pollution level at the measurement and monitoring locations. Through that, the authors have identified the current status of pollution caused by socio–economic activities. Moreover, the authors have calculated the WQI index to provide data for water users as well as managers to see the full picture of the extent of polluted areas. Since then, a number of practical solutions have been proposed to protect water resources, aiming to manage and use water sustainably. In addition, the research results are limited because only the WQI index is evaluated, but the correlation between the pollution components of the 5 studied river basins has not been evaluated. In addition, research is limited to only 5 main river basins of the province, it is necessary to expand some more canals and groundwater sources.

Authors contribution: Constructing research idea: H.P., H.T.N.H.; Select research methods: H.P., H.T.N.H., N.T.D., T.T.M.H.; Data processing: H.P., H.T.N.H., N.T.D.; Sample analysis: H.P., H.T.N.H., T.T.M.H.; Take samples: H.T.N.H., T.T.M.H.; Writing original draft preparation: H.P., H.T.N.H.; N.T.D.; Writing review and editing: H.P., H.T.N.H.

Acknowledgments: This study was carried out under the sponsorship of the Binh Thuan main Rivers Water Quality Research Project, under the Phu My Water Resources and Environment Technology Development Institute.

Conflicts of interest: The authors declare that this article was the work of the authors, has not been published elsewhere, has not been copied from previous research; there was no conflict of interest within the author group.

References

1. Hydrometeorological Station of the South-Central Region. Hydro–climate characteristics of Binh Thuan province, 2021.
2. Cat, L.V.; Nhung, D.T.H.; Cat, N.N. Quality aquaculture water and quality improvement solutions. Science and Technology Publishing House, Hanoi, 2006, pp. 424.
3. Boyd, C.E. Water quality for pond Aquaculture. Department of Fisheries and Allied Aquacultures. Auburn University, Alabama 36849 USA, 1998, pp. 37.

4. Wu, Z.; Zhang, D.; Cai, Y.; Wang, X.; Zhang, L.; Chen, Y. Water quality assessment based on the water quality index method in Lake Poyang: The largest freshwater lake in China. *Sci. Rep.* **2017**, *7*, 17999.
5. Phu, H.; Manh, T.X.; Huong, N.H. Research project on simulation of flood flow in Ve river basin, 2013.
6. Jena, V.; Dixit, S.; Gupta, S. Assessment of water quality index of industrial area surface water samples. *Int. J. Chem Tech Res.* **2013**, *5(1)*, 278–283.
7. Toma, J.J. Water Quality Index for Assessment of Water Quality of Duhok Lake, Kurdistan Region of Iraq. *J. Adv. Lab. Res. Biol.* **2012**, *3(3)*, 19–24.
8. Son, C.T.; et al. Assessment of water quality in some rivers in Gia Lam district using WQI water quality index. *J. Sci. Technol. Univ. Nat. Resour.* **2019**, *200(07)*, 113–140.
9. Luu, P.T. Using water quality index (WQI) and biological index of algae (BDI) to assess water quality of Saigon River. *Sci. J. Pedagogy Univ.* **2020**, *17(9)*, 1558–1596.
10. Phu, H. Research on building data sets for the application of mathematical models to simulate water quality changes in La Nga river in Binh Thuan. *J. Hydrometeorol.* **2013**, pp. 26–32. (in Vietnamese)
11. Southern Institute of Irrigation Science. Irrigation development planning in Binh Thuan province for the period 2011–2020, 2012.
12. Binh Thuan Statistical Office (2018–2021). Binh Thuan Provincial Statistical Yearbook.
13. Government. Decree No. 80/2014/ND–CP dated 6/8/2014, Decree on drainage and wastewater treatment, 2014.
14. Binh Thuan Water Supply and Sewerage Joint Stock Company. Environmental monitoring report of Binh Thuan Water Supply and Sewerage Joint Stock Company, phase 1, 2015.
15. Hydrometeorological Station of the South Central Region. Hydro–climate characteristics of Binh Thuan province, 2021.
16. Uyen, N.T.T. Research and propose steamed anchovy wastewater treatment technology at My Tan Steamed Anchovy Village, Ninh Hai District, Ninh Thuan Province. Graduation Project from Technical University, 2010.
17. Phu, H. et al. Thesis Research, application and testing of hydro–hydraulic models for flood forecasting and flood warning of La Nga river, Binh Thuan province. Ministry level project, 2014.
18. Phu, H.; Manh, T.X.; Huong, N.H. Research project on simulation of flood flow in Ve river basin, 2013.
19. Binh Thuan Provincial People's Committee. Decision No. 634/QD–UBND dated February 25, 2014 on adjustment and supplementation of industrial cluster development planning in Binh Thuan province to 2020, 2014.
20. IUCN. Flow – the essentials of environmental flows, UK. Edited by: Megan Dyson, Ger Bergkamp and John Scanlon, 2003.
21. http://ncdsnet.anu.edu.au/pdf/jbennett/chmdrr01.pdf (2004).
22. http://wwf.panda.org/about_our_earth/about_freshwater/rivers/irbm/.