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Assessment of surface water quality in Cao Bang city using Vietnam water quality index (VN_WQI)

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1. Introduction

Water, although renewable, is a finite and irreplaceable resource. Currently, the surface water quality of rivers, streams, and lakes is often affected and changed by human activities. Many studies have shown that: the impact of human activities has been clearly affecting the nature of water resources, especially surface water in urban areas, that have a high concentration of population [2]. In addition to artificial factors, extreme weather events also affect the properties of surface water.

Cao Bang city is a new economic development area in the northern mountainous region of Vietnam with a high economic growth rate, with large industrial, business, and service activities. However, economic development has not been synchronized with the technical infrastructure conditions on the environment; many handicraft production establishments have not yet been invested in a centralized wastewater treatment system [1]. Along with the socio-economic development, the surface water quality is increasingly declining due to receiving domestic and industrial wastewater and agriculture in the area. Domestic and industrial wastewater might contain hazardous substances that could exist in runoff and flow into surface water. Especially, the surface water of Cao Bang city has been exposed to many risks of water pollution in the Hien river, Bang river, and Cun stream. Therefore, it is necessary to regular water quality monitoring in areas affected by socio-economic development activities. Monitoring water quality not only helps assess and predict pollution but also provides information for planning the sustainable use of water resources [6]. This study applied the Vietnam water quality index (VN_WQI) to analyze surface water quality fluctuations using data from 5 monitoring locations at the rivers in Cao Bang city. The research results could provide useful information for the Cao Bang province environmental management agency in reviewing and reevaluating the effective monitoring system of surface water quality.

2. Materials and methods

2.1. Water sampling and analysis

Cao Bang city, located in the center of Cao Bang province, is one of the driving forces of the Northeast Vietnamese mountain's core economic zone. Monitoring of surface water quality was carried out at 5 locations including Bang river (2 locations, NM01-NM02), Cun stream (1 location, NM03), Hien river (1 location, NM04), and Na Di stream (1 location, NM05). The sampling location is shown in Figure 1 and Table 1. Water samples were collected monthly from January to December in 2020 (three times per year) using 18 parameters to assess the water quality. Water samples were collected and preserved according to the instructions in Vietnamese standards (TCVN 6663 Water quality-Sampling). The temperature, electrical conductivity (EC), pH, dissolved oxygen (DO), and total dissolved solids (TDS) were measured on-site using multiparameter Hanna HI98130 and HI9142 (USA). The turbidity and suspendid solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonium nitrogen (N-NH_4^+), nitrite nitrogen (N-NO_2^-), nitrate nitrogen (N-NO_3^-), phosphate (P-PO_4^{3-}), total Coliform, zinc (Zn), iron (Fe), copper (Cu), lead (Pb), and mercury (Hg) were measured in the laboratory using standard methods, in which the heavy metal was analyzed by Atomic Absorption Spectrophotometer.

Monitoring results are evaluated using national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT), column A_2 [2].

Table 1. Details of the Investigated suface water Sampling Locations.

No.	River	Location	Symbol	Coordinates	
				X	Y
1	Bang river	Mang river bridge	NM01	2510337	546418
		Hoang Nga bridge	NM02	2506236	553169
2	Cun stream	Temporary bridge	NM03	2507419	552520
3	Hien river	Hien river bridge	NM04	2507429	551660
4	Na Di stream	Chu Trinh commune	NM05	2501376	556629

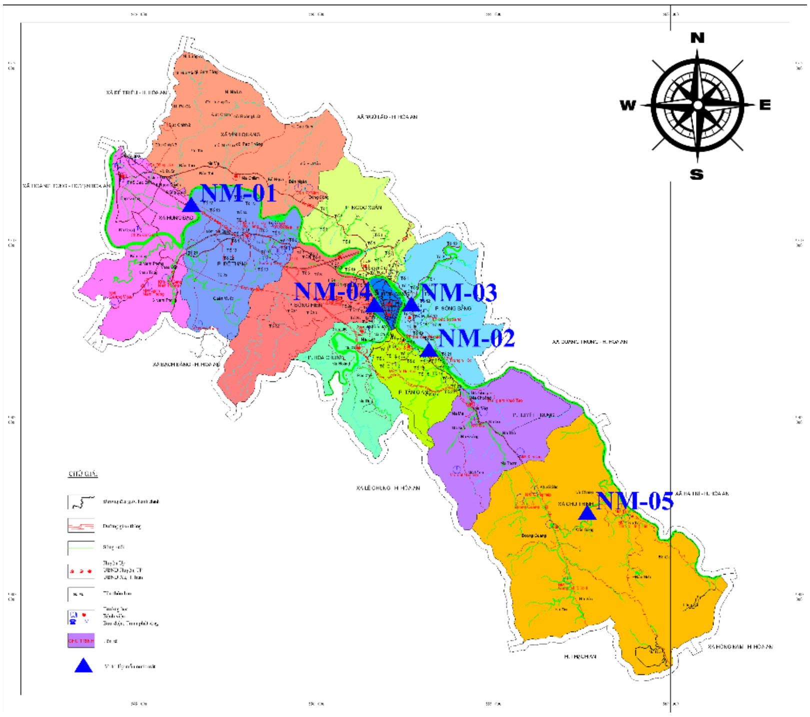

Figure 1. The study sites with sampling locations.

2.2. VN_WQI Calculation

From the multiple water quality parameters, the VN_WQI is utilized to classify the surface water quality of Cao Bang city. This index was calculated based on the Decision 1460/QD-TCMT and comparing the water quality assessment as shown in Table 2. VN_WQI was calculated from five groups of parameters including (Group I) pH index; (Group II) Crop protection agent; (Group III) heavy metal parameters; (Group IV) organic and nutrient parameters; and (Group V) microorganism parameters [5].

To calculate the WQI, it is necessary to select at least three out of five specified groups (from Group I to Group V), of which three parameters from Group IV are required. Therefore, this study chooses to calculate seven criteria: pH (group I); Zn, Cu, Pb, Hg (group III); DO, BOD_5, COD, NH_4^+, NO_3^-, PO_4^{3-} (group IV); and total Coliform (group V). The summary formula of VN-WQI is shown as equation 1.

$$\mathrm{WQI} = \frac{\mathrm{WQI_I}}{100} \times \frac{\left(\prod_{i=1}^{n} \mathrm{WQI_{II}}\right)^{1/n}}{100} \times \frac{\left(\prod_{i=1}^{m} \mathrm{WQI_{III}}\right)^{1/m}}{100} \times \left[\left(\frac{1}{k}\sum_{i=1}^{k} \mathrm{WQI_{IV}}\right)^{2} \times \frac{1}{l}\sum_{i=1}^{l} \mathrm{WQI_{V}}\right]^{1/3}, \quad (1)$$

where WQI_I, WQI_{II}, WQI_{III}, WQI_{IV}, and WQI_V are the results of WQI by groups I to V, respectively.

Table 2. Surface water quality classified by VN-WQI.

WQI value range	Water quality	Utilization purpose	Color
91 – 100	Very good	Good use for domestic water supply purposes.	Blue
76 – 90	Good	Used for domestic water supply purposes but need appropriate treatment measures.	Green
51 – 75	Average	Use for irrigation purposes and other similar purposes.	Yellow
26 – 50	Poor	Use for waterway transport and other similar purposes.	Orange
10 – 25	Very poor	Heavily polluted water, needing treatment measures in the future.	Red
<10	Heavily polluted	Toxic water, need to take measures to overcome and treat.	Brown

3. Results and discussions

3.1. Evaluating surface water quality in Cao Bang city

Descriptive statistics of the parameters are given in Figure 2. On the basis of the averages of the measured parameters, their changes during the year were examined. According to these results, the pH values showed a downward trend until August then entered a period to rise until the time of the last sampling. This may be related to the increased activity of photosynthetic organisms. However, the pH values were all within the safe limit (6.0–8.5).

The DO values fluctuated greatly by months and sampling sites in the range of 6.47÷8.92 mg/l (Figure 2a). It showed an increase in the period between August and November because in cold seasons due to the fact that low temperatures increase oxygen solubility and living organisms reduce a large number of their activities that require oxygen consumption.

TSS at sites and months fluctuated from 8 to 196 mg/l (Figure 2b). TSS at most locations exceeded the allowable limit (30 mg/l). TSS has seasonal variation in which the rainy season is usually higher than that of the dry season. Although high TSS values are associated with household waste, waste disposal, industrial sewage from agricultural fields, and stock farming activities, the increases observed in the summer are thought to be the result of floods and sand mining activities.

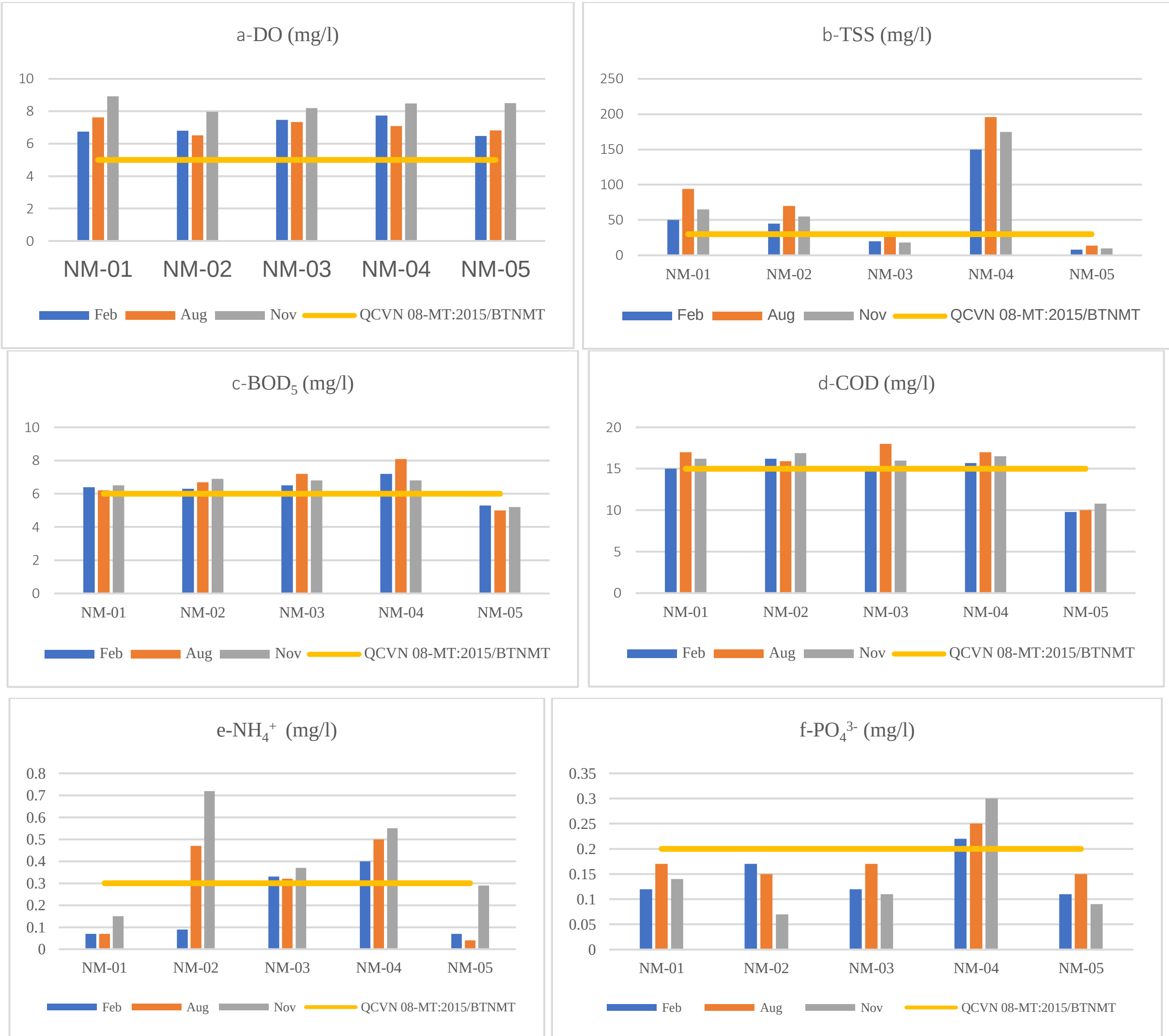

Figure 2. Changes in values of parameters over 1 year.

The BOD at the sampling periods and locations fluctuated from 5.0 to 8.1 mg/l. BOD in the rainy season month (August) fluctuated more than that in the dry season months (Figure 2c). BOD at most locations exceeded the allowable limit of 6 mg/l. Similarly, COD between months and sampling sites ranged from 9.8 to 18.0 mg/l (Figure 2d). The COD has exceeded the allowable limit (15 mg/l) of QCVN 08-MT:2015/ BTNMT, column A2. This increase in the summer months can be explained by increased primary production. COD is widely used to determine domestic, industrial and agricultural waste concentrations. Inorganic chemicals that consume oxygen during degradation cause increasing COD levels, whereas high BOD values are based on anthropogenic activities associated with aquaculture and domestic wastes. Thus, surface water in Cao Bang city is mainly contaminated with organic matter from daily activities. Values also tend to be high at monitoring locations on the Bang river, Hien river and Cun stream, which are densely populated. The concentration of NH_4^+ between sampling months and sampling sites ranged from 0.04 to 0.72 mg/l (Figure 2e). The NH_4^+ in the study area has significant spatiotemporal fluctuations, at positions NM02, NM03, and NM04 higher than the allowed limit from 1.1÷2.4 times. According to QCVN 08-MT:2015/BTNMT column A2, the limit value of NH_4^+ is 0.3 mg/l. The PO_4^{3-} in water fluctuated in space and time with concentrations of 0.07÷0.30 mg/l (Figure 2f). In locations with high concentrations of NH_4^+, the PO_4^{3-} concentration accumulated and exceeded the allowable limit of 0.2 mg/l as at point NM04.

In addition, surface water sources in Cao Bang city have not shown signs of pollution by heavy metals and coliforms. Zn, Fe, Cu, Pb, and Hg at all locations through the sampling sessions were within the allowable limits. Similarly, the total Coliforms in the study areas ranged from 700 to 2,400 MPN/100ml, also it was within the allowable limit of 5,000 MPN/100ml.

3.2. General surface water quality assessment by VN_WQI

To have a general assessment for the surface water quality, the VN_WQI was conducted and its result was classified according to the Decision 1460/QD-TCMT approved by Vietnam Environment Administration mentioned in the above VN-WQI in the above section [5]. The calculation results of VN_WQI in the study area are presented in Figure 3. VN_WQI in NM01 (81-90), NM02 (75-89), NM03 (87-89), NM04 (82-85), and NM05 (96-98) indicated that the surface water quality in Cao Bang city was classified from good to very good. In general, statistical results showed that there are two VN-WQI levels detected in the study area and have an uneven distribution. Water quality in the downtown area was classified as good, with VN_WQI ranged from 75 to 89 (NM02, NM03 and NM04). Meanwhile, surface water quality in downstream area was classified very good (VN_WQI NM05 =96-98).

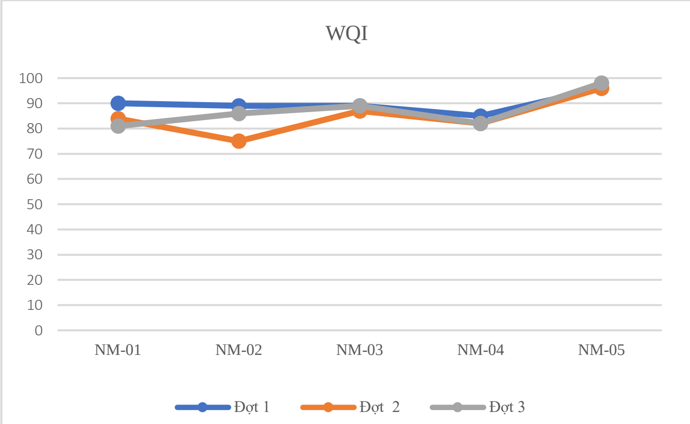

Figure 3. Change in VN_WQI values over 1 year at the monitoring locations.

One of the reasons to explain this situation is that the wastewater comes from industrial production establishments, services in the downtown area (wood processing facilities, building materials, and markets) that generate a lot of odors, exhaust gas, polluted wastewater. There is no centralized wastewater treatment system. The majority of the manufacturing facilities are near the river, and many of the dumping locations are beneath riverbank dwellings, making it difficult to regulate the discharge. Moreover, in residential areas, domestic wastewater and leachate from spontaneous landfills are discharged directly into rivers and streams of this city, also causing serious surface water pollution.

4. Conclusion

The results present that the surface water quality varies greatly according to the sampling locations, and the most polluted locations are in the downtown area where there are many industrial production establishments, services and densely populated. DO, TSS, BOD, COD, NH_4^+, and PO_4^{3-} have seasonal fluctuations. The surface water quality was contaminated with organic (high TSS, BOD, and COD), and nutrients (mainly NH_4^+). Heavy metals such as Zn, Fe, Cu, Pb, and Hg are within the allowable limits of QCVN 08-MT:2015/BTNMT, column A2.

The VN_WQI shows that surface water quality in Cao Bang city is classified from good to very good (WQI = 75-98), in which very good water quality is concentrated in the downstream area. Meanwhile, the good water quality is concentrated in the downtown area. At the time of the study, the surface water quality in Cao Bang city is mostly good. However, the downtown area still has many risks of causing environmental pollution, including the surface water environment.

In conclusion, the method of evaluating surface water quality by Vietnam water quality index is feasible, and the obtained results are highly accurate and are a reliable reference for other methods such as water quality assessment by multivariate statistical analyses. However, this method still has some limitations, such as depending on the quantity and accuracy of the actual measured data.

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