Assessing changes in surface water quality and pollutant load in Dong Nai province

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ABSTRACT

This study aims at assessing changes in the surface water quality in Dong Nai province (2010-2014). In addtion, the pollutant loads of wastewater sources were calculated till 2020–2030 with 03 wastewater treatment scenarios serving for the local environmental management. The water quality index (WQI) showed the surface water quality of Dong Nai Province to be gradually improved during the dry season but significantly declined in the rainy season in the last 5 years due to high concentrations of suspended solids (SS), Fe and microorganism - especially in the 3rd segment of Dong Nai river through Bien Hoa City. This current status certainly relates to pollutant loads from waste water sources in the province. Pollutant loads of domestic and industrial wastewater in Bien Hoa city are the highest (40 % per source), livestock activities in Xuan Loc district account for 20 %; aquaculture activities in Nhon Trach district contribute more than 75 % of the corresponding total loads, etc. in which loads of BOD5, COD and SS are significant, about 581,570 tons, 1,035,403 tons and 639,153 tons per year, respectively, and tend to increase in the future, requiring appropriate solutions.

***Keywords**: pollutant load, surface water, water quality, water quality index*

INTRODUCTION

According to Cooke et al. [1], surface water quality can be assessed through the pollutant loads and concentration. Previously, the river water quality is assessed through the concentration of individual pollutant compared to local standards, thence compared to general evaluation approaches through Water Quality Index (WQI) as NSF WQI (USA), Bhargava-WQI (India), CCME-WQI (Canada), etc. The related WQI researches and applications in Vietnam [2–5] are the basis for building suitable surface water quality model for the study area. In 2011, the General Department of Environment issued WQI calculations Handbook for using in Vietnam.

About pollutant loads, many studies have been implemented [6–8]. In Vietnam, the pollutant loads calculation is approached in two ways: (1) Rapid Assessment [9–11], (2) Based on specific concentration of waste sources (C) and the waste flow (Q) [12–14].

The relationship between changes in surface water quality and pollutant loads is an important basis for planning the management measures, especially in Dong Nai province - one of the fastest growth localities in the Southeast of Viet Nam. Accordingly, this research focuses on assessing the changes in surface water quality in the main river (2010–2014) and calculating the pollutant loads which arise from natural and artificial waste sources (2013, 2020, 2030) in Dong Nai province, thereby providing valuable scientific information to serve local surface water management, contributing positively in ensuring sustainable development and creating basis for further studies on water resources as calculating load capacity, etc.

METHODS

Gathering data

The monitoring data of surface water quality (2010–2014) from the Department of Natural Resources and Environment of Dong Nai province (Fig. 1), the pollutant emission coefficient, the local statistical figures and development plan, etc.

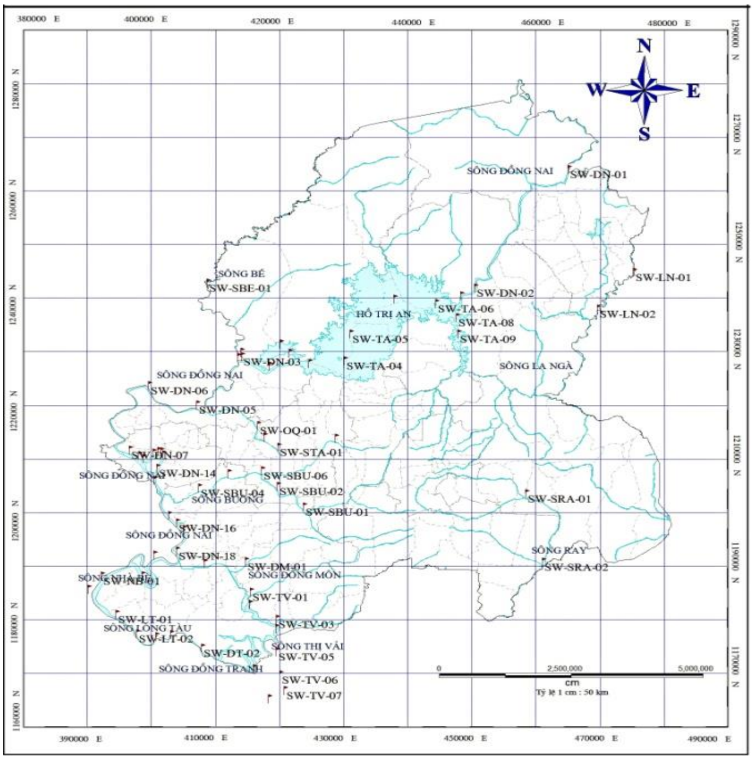

Fig. 1. Map location of monitoring stations on surface water quality of Dong Nai Province in 2014

Investigating, actual surveying

Identifing and verifing the problem studies

WQI Calculating

There are many ways to calculate WQI such as NSF-WQI (USA), Bhargava (India), etc. and several ways based on or developed from these approaches. In this work, WQI was calculated in accordance with Decision No. 879 / QĐ-TCMT on the basis of 10 parameters of monitored data: pH, Temperature (^oC), DO, COD, BOD5, TSS, N-NH^{4+}, P-PO_4^{3-} (mg/L), Turbidity (NTU), Coliform (MPN/100mL) - as a legal document for calculation and assessment of surface water quality in Vietnam. Table 1 shows the scale to assess water quality according to the WQI index.

Table 1. Scale to assess water quality according to the WQI index

Value of WQI	The level of water quality assessment	Colour
91 – 100	Used well for domestic water supply purposes	Blue
76 – 90	Used for domestic water supply purposes, but need the appropriate treatment measures	Green
51 – 75	Used for irrigation purposes and other similar purposes	Yellow
26 – 50	Used for water transportation and other similar purposes	Orange
0 – 25	Seriously polluted water, needing necessary measures to handle in the future	Red
(Source: Water Quality Index Calculation Handbook – QĐ 879/QĐ-TCMT)		

Method of calculating pollutant loads in domestic wastewater (Dom):

$$\mathbf{L}_{\mathbf{i}-Dom} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{waste} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{\text{supply}}.\mathbf{K}_{\mathbf{h}} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{\text{supply}\,\text{Dom}}.\left(\mathbf{1} + \text{Rate by } \mathbf{Q}_{\text{supply}\,\text{Dom}-service}\right).\mathbf{K}_{\mathbf{h}}$$

$$\mathbf{Q}_{\text{supply}\,Dom} = \sum(\mathbf{K}_{\text{supply}}.\mathbf{N})$$

Where: $L_{i\text{-Dom}}$: Load of i parameter in domestic wastewater (tons/year)

C_i: The average concentration of the i parameter (tons/liters)

Q_{supply}: Water supply flow (liters/year); Q_{waste}: Wastewater flow (liters/year)

K_h: The loss coefficient of wastewater compared to use water (K_h=1)

Rate by $Q_{\text{supply Dom - service}}$ = 0.1; N: Population

K_{supply}: Domestic water supply per capita coefficient (liters/person.year)

Method of calculating pollutant loads in industrial wastewater (Ind):

$$\mathbf{L}_{\mathbf{i}-Ind} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{Ind-\text{waste}}$$

Where: $L_{i\text{-Ind}}$: Load of i parameter in industrial wastewater (tons/year)

Ci: The average concentration of the i parameter (tons/liter)

$Q_{\text{Ind-waste}}$: Industrial wastewater flow (liters/year)

For the industrial zones (IZs): $\mathbf{Q}_{IZs-\text{waste}} = \mathbf{K}_{\mathbf{h}}.\sum(\mathbf{T}_{\text{supply}}.\mathbf{S})$

Where: T_{supply}: Water supply standard for one unit IZ area (m^3/ha/day)

S: The manufacturing industrial land area (ha)

For small production facilities (Small): $\mathbf{Q}_{Small-\text{waste}} = \mathbf{K}_{\mathbf{h}}.\sum(\mathbf{Q}_{\text{supply}-Dom}.\boldsymbol{\alpha})$

Where: $Q_{\text{supply - Dom}}$: Domestic water supply flow (liters/year)

α: Conversion coefficient between domestic water supply and small production facilities' water supply

Kh: The loss coefficient of wastewater compared to use water (K_h=0.8)

Method of calculating pollutant loads in livestock wastewater (Liv):

$$\mathbf{L}_{\mathbf{i}-Liv} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{Liv-\text{waste}} = \mathbf{C}_{\mathbf{i}}.\sum\left(\mathbf{K}_{\text{waste}}.\mathbf{N}.\mathbf{T}/\mathbf{12}\right)$$

Where: $L_{i\text{-Liv}}$: Load of i parameter in livestock wastewater (tons/year)

C_i: The average concentration of the i parameter (tons/liter)

$Q_{\text{Liv-wate}}$: Livestock wastewater flow (liters/year)

N: The number of livestocks according to each local species

T: The average breeding period (months)

K_{waste}: Wastewater emission coefficient for each of the species (liters/livestock.year)

Method of calculating pollutant loads in aquaculture wastewater (Aqua):

$$\mathbf{L}_{\mathbf{i}-Aqua} = \mathbf{\Sigma}\left(\mathbf{N}_{\mathbf{j}}\mathbf{x}\ \mathbf{e}_{\mathbf{ij}-Aver-waste}\right)$$

Where: $L_{i\text{-}Aqua}$: Load of i parameter in aquaculture wastewater (tons/year)

N: Number of aquaculture according to each local j species

$e_{ij\text{-}Aver\text{-}waste}$: Emission coefficient of i parameter for one species j (tons/year)

Method of calculating pollutant loads in rainwater runoff (Runoff):

$$\mathbf{L}_{\mathbf{i}-Runoff} = \mathbf{C}_{\mathbf{i}}.\mathbf{Q}_{Runoff}{}^{1}$$

$$\mathbf{Q}_{Runoff}{}^{2} = \mathrm{c.i.A}$$

Where: $L_{i\text{-}Runoff}$: Load of i parameter in Rainwater runoff (tons/year)

C_i: The average concentration of the i parameter (tons/liter)

$Q_{Runoff}{}^{1}$: Rainwater runoff's flow (liters/year)

$Q_{Runoff}{}^{2}$: Rainwater runoff's flow (ft^3/s)

c: Runoff coefficient by Rational method (Agriculture land (Agri): c = 0.25; Urban land (Urban): c = 0.53, Industrial land (Ind): c = 0.18)

A: Runoff area (arce)

i: The average precipitation (in/h).

The pollutant loads scenarios

Table 2 presents pollutants' concentration and emission coefficient for each wastewater source, used for calculating pollutant loads. The pollutant loads scenarios arising in 2020 - 2030 are built respectively as follows:

The first Scenario - high emissions scenario: the concentration of pollutants remains unchanged in comparison with the current, denoted as H.

The second Scenario - medium emissions scenario: the concentration of pollutants is treated in a certain way; accordingly, the current wastewater will be treated to meet the category B; denoted as B.

The third Scenario - low emission scenario: All wastewater is treated to meet the category A; denoted as A.

emissions scenarios are simplified; (**): At the present, Dong Nai province has not published land use plan, so the assumption is no significant changes in the land use in the future.

Table 2. Synthesis of pollutants' concentration and emission coefficient

Parameter	Concentration of Pollutant (mg/L)									Emission Coefficient (kg/ton/year)		
	Dom	Ind		Liv			Runoff			Aqua		
		IZs	Small	Cattle	Pig	Poultry	Ind	Urban	Agri	Intens shrimp	Improv shrimp	Others
BOD_5	206.6	180	35.72	1,543	712	86	17.3	79.9	28	32	137	4.5
COD	404.2	320	130.72	2.200	1.968	103	125	99.4	51.1	62	278	15.9

TSS	235.0	210	149.03	2,188	1,300	103	69	85	30	867	353.6	9.4
TN	112.5	50	27.76	150.9	778.4	13.21	1.179	1.9	0.965	30	114	1.31
TP	30	6	1.61	7	6.1	5.5	0.201	0.383	0.121	17	67	0.32
Sources	[15, 16]	[17,18]		[19]			[20]			[12, 14]		
Scenario A	Column A QCVN 14:2008	Column A QVCN 40:2011		Column A QVCN 01-79:2011			Assuming pollutants' concentration, land area and precipitation as current (**)			Using emission coefficient as current (*)		
Scenario B	Column B QCVN 14:2008	Column B QVCN 40:2011		Column B QVCN 01-79:2011								

RESULTS AND DISCUSSION

Assessing changes in surface water quality on the main rivers in Dong Nai province

The changing trend in surface water quality seemed relatively similar over the years (2010-2014). Besides, the water quality fluctuated significantly seasonally: water quality in the dry season was better than that in the rainy season; the water quality differences between the two seasons can be seen clearly in 1 and 4 segments of the Dong Nai river (Fig. 2).

The first segment of Dong Nai river (SW-DN-01-02) is a receive-water area from DakLua and DakTop streams (Lam Dong), has a stable annual water quality affected by seasons. Water quality in the dry season reached good to very good level and ranged poor to very poor in the rainy season, caused by the increasing concentration of pollutants, notably the TSS (double the standards), turbidity, microorganisms (*E. Coli*), Fe, etc. Similar to the 1st segment, water quality in the second segment (Vinh Cuu district - SW-DN-03-06) is clearly distinguished between dry and rainy seasons: water quality in the dry season fluctuated around the very good level and; therefore, suited for household water supply, but was in the downward tendency (to good level) in the rainy season due to the increase of turbidity, TSS, and microorganisms. It could be explained by large amounts of silt and nutrients from upstream water flowing down in the rainy season. The third segment flows through Bien Hoa city (from Hoa An bridge to Dong Nai bridge - SW-DN-07- 15) has an important role in water supply. However, water quality here was not good, even declining, especially in the rainy season. Water quality in San Mau stream - Cai River and Linh stream - Cai River only met irrigation purposes and other similar purposes, requiring a treatment. The fourth segment (from the confluence of Buong - Dong Nai river to the confluence of Sai Gon - Dong Nai river - SW-DN-16-19) received industrial and household wastewater, and also be affected by tidal forces. Water quality here generally seemed quite good: good in the dry season and medium in the rainy season.

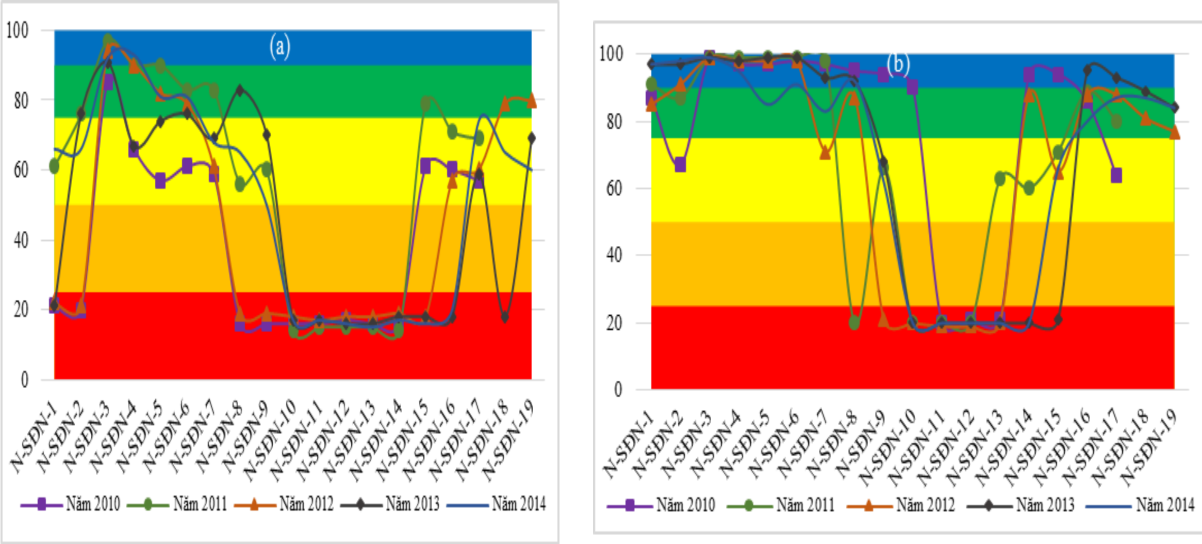

Fig. 2. The changes in surface water quality (according WQI) of Dong Nai River (2010-2014): The rainy season; (b) The dry season

Calculating and forecasting pollutant load in Dong Nai province

Pollutant loads calculation results in 2013 by administrative units and by source of waste is presented in Figure 3 and Table 3, respectively. Pollutant loads in Nhon Trach, Vinh Cuu, Tan Phu, Dinh Quan, Xuan Loc districts and Bien Hoa city hit the highest records of the 11 administrative units in 2013 (Fig. 3). Vinh Cuu, Tan Phu, Dinh Quan, Xuan Loc district emitted a huge COD, BOD5, TSS loads, accounted for nearly 47 %; TN and TP loads were approximately 36 % of total loads of Dong Nai. The main cause was the rainfall runoff.

Pollutant loads in Nhon Trach district and Bien Hoa City also contained a large number of COD, BOD5 and TSS loads (average about 20 %), mainly from local household and industrial activities. Bien Hoa city was the area having the highest TN and TP emission (more than 24 % and 35 % of total local loads, respectively).

Among the five sources (Table 3), runoff (natural source) contributed a largest number of loads: BOD5, COD and TSS accounted for nearly 90 % of total loads; TN and TP were about 43 %. Domestic wastewater had high BOD5, TSS, TN and TP loads. Industrial wastewater emitted less of loads, approximately 6 % loads of artificial sources. Livestock wastewater's TN loads was nearly 40 % of TN from artificial sources; BOD5 and TSS fluctuated about 25 %; COD nearly 15 %. Although aquaculture contributes a small percentage of economic structure, COD loads were huge, especially COD.

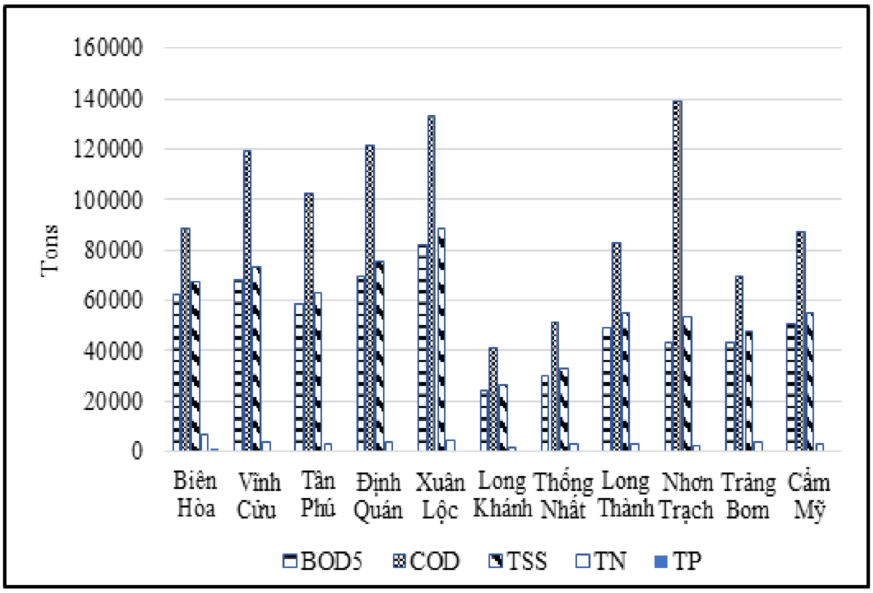

Fig. 3. Pollutant loads of Dong Nai province in 2013 by administrative units

Table 3. Pollutant loads of Dong Nai province in 2013 by source of waste (Unit: tons/year)

	BOD_5	COD	TSS	TN	TP
Domestic	21,514	42,090	24,471	11,715	3,124
Industrial	2,703	5,709	4,240	1,098	148
Livestock	8,444	21,838	15,166	8,151	126
Aquaculture	493	76,043	9,144	344	183
Rainwater runoff	548,417	889,724	586,132	16,859	2,459
Total	581,571	1,035,403	639,153	38,167	6,040

Pollutant emission scenarios in the period 2020–2030 were calculated and presented in Figure 4. The differences between H scenario and B scenario in 2020 are: BOD5, COD, TSS loads are higher nearly 8 % and TN, TP are about 50 %. By 2030, TN loads of B scenario falls approximately 57 %; BOD5, COD and TSS decline more 11 % compared to H scenario. However, pollutant loads of B and A scenarios are not greatly different (< 5 % for BOD5, COD, TSS loads and about 10-15 % for TN and TP loads). Analyzing the results of pollutant loads calculation and current surface water quality in Dong Nai River, some notable points are shown as follows:

The 1st segment of Dong Nai river and its tributaries: flowing through Tan Phu and Dinh Quan districts. In 2013, TSS loads of 2 areas was about 140.000 tons, COD was nearly 220.000 tons, and BOD5 was over 130.000 tons – in which runoff source emitted more 95 % of the total loads. The amount of rainfall from May to Oct ranged approximately from 1500 to 2000 mm, made water levels in rivers and streams rise; washed off rock and soil; increased concentrations of TSS and mud, etc.

The 2nd segment of Dong Nai river and its tributaries (flowing through Vinh Cuu district): Similar to the 1st segment, this area is sparse population, economic and production activities are trivial. Thereby, the main pollutant loads come from runoff source. The content of TSS, turbidity, Coliform raised in rainy season is the cause making local water quality decline.

The 3rd segment of Dong Nai river and its tributaries (flowing through Bien Hoa city): receiving almost wastewater from urban and industrial activities of Bien Hoa city via rivers, streams and sewers, etc. Besides rainwater runoff, Bien Hoa city also contributed significant pollutant loads from household and industrial activities (average loads were 40 % of the total loads of 2 sources in Dong Nai). This is the main cause making concentrations of nutrients and microorganisms appear in the whole year.

The 4th segment of Dong Nai River and its tributaries (flowing through Long Thanh – Nhon Trach district): The reasons that made concentrations of TSS, microorganisms and nutrients arise in water were local wastewater and nearby localities' influence, such as household and industry sources in Nhon Trach, Long Thanh, Bien Hoa (in which, total loads of industrial wastewater accounted for nearly 80 % of total loads of industrial activities in Dong Nai); livestock wastewater in this segment and Trang Bom, Cam My districts were the areas which had loads of livestock source contributed approximately 30 % of the total loads of Dong Nai province, respectively.

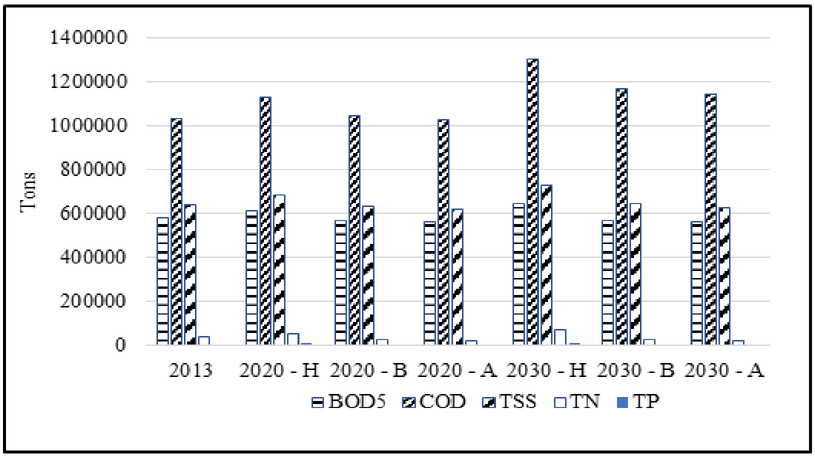

Fig. 4. The pollutant loads of Dong Nai Province in the period 2013 – 2020 – 2030

CONCLUSION

The quality of surface water in the main rivers of Dong Nai province in the period 2010 – 2014 improved significantly during the dry season but tends to decline during the rainy season with presence mainly of TSS, turbidity and coliform, etc. The 2nd segment of Dong Nai river had the highest water quality, conversely, the 3rd segment and its tributaries in Bien Hoa city have the worst quality, especially in San Mau stream - Cai river and Linh stream - Cai river.

Regarding pollutant loads, besides natural sources (rainwater runoff), household, livestock and aquaculture are various artificial sources contributing most loads. In 2013, pollutant loads from industrial and household activities in Bien Hoa city accounted for a large proportion (40 % each source); livestock activities developed in Xuan Loc district (nearly 20 %); aquaculture activities in Nhon Trach district contributed more than 75 % of the corresponding total loads in Dong Nai. In the period 2020 - 2030, pollutant loads of household, aquaculture and livestock will increase and create pressure on the quality of the local environment, particularly the 3rd and 4th segments of Dong Nai river, requiring appropriate management and attention.

Đánh giá diễn biến chất lượng nước mặt và tải lượng ô nhiễm tại tỉnh Đồng Nai

- **Bùi Thị Diễm Hương**

Viện Khí tượng Thủy văn Hải văn và Môi trường

- **Lê Ngọc Tuấn**

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TÓM TẮT

Nghiên cứu nhằm mục tiêu đánh giá diễn biến chất lượng nước mặt tỉnh Đồng Nai giai đoạn 2010 – 2014. Bên cạnh đó, tải lượng ô nhiễm từ các nguồn thải được tính toán đến năm 2020, 2030 với 03 kịch bản xử lý nước thải khác nhau - phục vụ kiện toàn công tác quản lý môi trường tại địa phương. Kết quả đánh giá theo chỉ số chất lượng nước (WQI) cho thấy, trong 5 năm gần đây, chất lượng nước mặt ở tỉnh Đồng Nai dần được cải thiện vào mùa khô nhưng suy giảm đáng kể vào mùa mưa do hàm lượng cao các chất rắn lơ lửng, sắt và vi sinh – nhất là đoạn sông Đồng Nai 3 chảy qua thành phố Biên Hòa. Hiện trạng này liên quan nhất định đến tải lượng ô nhiễm từ các nguồn thải trên địa bàn. Tải lượng ô nhiễm từ hai nguồn sinh hoạt và công nghiệp của TP Biên Hòa hiện chiếm tỷ trọng lớn (40 % mỗi nguồn); hoạt động chăn nuôi phát triển nhất tại huyện Xuân Lộc - chiếm khoảng 20 %; hoạt động nuôi trồng thủy sản tại huyện Nhơn Trạch đóng góp hơn 75 % tổng tải lượng tương ứng của toàn tỉnh... trong đó, tải lượng BOD5, COD và TSS rất lớn -tương ứng 581.570 tấn, 1.035.403 tấn và 639.153 tấn/năm, có chiều hướng gia tăng trong tương lai - đòi hỏi phải có biện pháp quản lý thích hợp.

Từ khóa*: tải lượng ô nhiễm, nước mặt, chất lượng nước, chỉ số chất lượng nước*

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