

Calculation of pollution loadings and preliminary estimation of alcohol consumption in Hanoi

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Abstract: Alcohol consumption is a cultural practice in many countries around the world, including Vietnam. Estimating alcohol consumption is essential for making public health recommendations. Wastewater-based epidemiology (WBE) is a tool that can help estimate alcohol consumption within a community based on information such as the concentration of the alcohol biomarker ethyl sulfate (EtS) in wastewater, the population residing in the area, and the wastewater flow rate. This study determined the flow rate of the Kim Nguu River and analyzed its water quality in November 2023. The results indicate that the water quality of the Kim Nguu River is poor, with daily loads of approximately 21.3 tons of COD, 9.6 tons of BOD₅, 17.59 tons of TSS, 5.35 tons of TN, and 0.96 tons of TP. Based on EtS concentrations referenced from another study, the estimated alcohol consumption in Hanoi is approximately 2.61±0.33 mL/person/day. These findings contribute to the recommendations for wastewater treatment and environmental pollution reduction in Hanoi, while also providing a preliminary estimate of alcohol consumption among the city's residents, which can inform public health recommendations.

Keywords: Alcohol, wastewater, pollution, loads, Hanoi.

1. Introduction

Alcohol consumption is a deeply rooted sociocultural practice in Vietnam (Ngoc et al., 2012). Despite the well-established risks associated with alcohol, including its addictive nature and the negative impacts on public health, social order, and safety, Vietnam has experienced a troubling increase in alcohol consumption. According to data from the World Health Organization, per capita alcohol consumption rose significantly from 4.7 liters in 2010 to 8.3 liters in 2016, positioning Vietnam as the third highest among Western Pacific nations (WHO, 2018). Supporting this trend, a national survey found that 60% of respondents reported current alcohol use, with rates of 86.8% in males and 31.6% in females (Ngoc & Thieng, 2018).

Wastewater-based epidemiology (WBE) is an emerging method for estimating alcohol consumption at the community level. This method allows for the assessment of alcohol intake by all individuals whose households are connected to the sewer systems (Reid et al., 2011). It involves analyzing ethyl sulfate (EtS), a biomarker of alcohol, in wastewater, which can be used to back-calculate alcohol consumption (Gao et al., 2023). However, it is important to note that EtS is prone to degradation within sewer systems, necessitating a correction factor that accounts for both the excretion rate and in-sewer degradation (Thai et al., 2021). Other essential data for estimating community

alcohol consumption include wastewater flow rate and the population size within the catchment areas. This method offers a rapid, cost-effective alternative to traditional approaches, making it especially useful in situations where survey-based data are sparse or incomplete (Reid et al., 2011).

The Kim Nguu River, along with the Set and Lu Rivers, is a tributary of the To Lich River, playing an essential role in Hanoi's drainage system. The river stretches approximately 3.5 km and is currently facing severe pollution, primarily due to the direct discharge of untreated wastewater (Ha, 2021). Several studies have analyzed water samples from the Kim Nguu River, examining biomarkers to estimate the consumption of illicit drugs (Hue et al., 2022) and artificial sweeteners (Li et al., 2023) among Hanoi's population. Through wastewater analysis, these studies provide important information on the shifting trend of the illicit drug market, which helps to formulate drug control policies (Hue et al., 2022) as well as the habitual consumption of artificial sweeteners (Li et al., 2023).

The objectives of this study were to estimate the pollution loading from the Kim Nguu River and provide a preliminary assessment of alcohol consumption using WBE. We measured the river's flow rate and analyzed its water quality to calculate pollution loading. Alcohol consumption was back-calculated from ethyl sulfate concentrations in the river water (as referenced from previous research), taking into account the river flow rate and the population within the drainage area.

2. Materials and methods

2.1. River sampling and flowrate estimation

A river water sampling campaign was conducted in November 2023 at a site (20°58'57.5"N

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105°51'49.5"E) located approximately 500 meters upstream of the Yen So wastewater treatment plant on the Kim Nguu River. A one-hour composite river water sample was obtained on five consecutive days. In situ measurements of pH and dissolved oxygen (DO) were performed using calibrated and verified portable devices: pH was measured with a Horiba instrument (Japan), while DO was determined using a HACH device (Germany). Following collection, samples were preserved

and transported to the laboratory for the quantitative analysis of chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP). The analytical methods employed are detailed in Table 1. Sampling and preservation protocols adhered to the guidelines specified in TCVN 6663-14:2018, Water Quality – Sampling – Part 14: Guidance on quality assurance of environmental water sampling and handling.

Table 1. Parameters and analytical methods

No.	Parameters	Analytical method	No.	Parameters	Analytical method
1	pH	Horiba device, Japan	5	TSS	TCVN 6625:2000
2	DO	Hach device, Germany	6	TN	TCVN 6638:2000
3	COD	TCVN 6491:1999	7	TP	TCVN 6202:2008
4	BOD ₅	TCVN 6001-1:2021	8	Total Coliform	TCVN 6187-1:1996

Concurrently, river flow velocity was determined utilizing a flowmeter (AEM213-D). To achieve this, the river's cross-sectional area was partitioned into five discrete sub-sections. At each sub-section, water depth and flow velocity were measured using the aforementioned flowmeter. Subsequently, the river's volumetric flow rate was estimated through the application of Equation (1):

$$F = \sum_{i=1}^5 F_i = \sum_{i=1}^5 v_i \times A_i \times 86400 \quad (1)$$

where F is the flowrate of the river (m³/day). F_i is the flowrate of sub-section i (m³/day), v_i is the flow velocity of sub-section i (m/s), A_i is the area of the sub-section i (m²) which is calculated by the measured depth and width of the river sub-section.

2.2. Pollution loadings estimation

The pollution loading of river water was estimated by Equation 2.

$$L_k = F \times Q_k \times 10^{-6} \quad (2)$$

where L_k is the pollution loadings of parameter k (tons/day); k represents COD, BOD₅, TSS, TN and TP. F is the river flowrate (m³/day); Q_k is river quality in terms of parameter k (g/m³).

2.3. Estimation of alcohol consumption

The alcohol consumption is estimated by Equation (3) from Thai et al. (2021)

$$V_{alcohol} = \frac{C_{EtS} \times F \times f_{alcohol}}{P \times \rho_{alcohol}} \times 10^{-3} \quad (3)$$

where $V_{alcohol}$ is the consumption of alcohol per capita (mL/person/day); C_{EtS} is the concentration of ethyl sulfate (EtS) in the wastewater (μg/L) (Bui et al., 2024); F is the daily wastewater flow of the catchment (m³/day), $f_{alcohol}$ is the correction factor (4000) which incorporates both the excretion rate and sewer degradation of EtS (Thai et al., 2021), P is the population in the catchment, $\rho_{alcohol}$ is the density of alcohol (0.789 g/mL).

3. Results and discussion

3.1. Kim Nguu river water quality

Table 2 presents a comparative analysis of Kim Nguu River water quality, displaying average parameter values of five consecutive days in November 2023, against the standards outlined in QCVN 08:2023/BTNMT – National Technical Regulation on Surface Water Quality. The data show that most parameters align with Level D classification, indicating severely degraded water quality as defined by QCVN 08:2023/BTNMT. Notably, the dissolved oxygen (DO) levels were consistently below the minimum threshold required by the regulation, making it impossible to classify the river under the specified standards.

Table 2. Kim Nguu River water quality

No.	Parameters	Unit	Average ± S.D.	Class (QCVN 08:2023/BTNMT)
1	pH	-	7.51 ± 0.06	A
2	DO	mg/L	1.15 ± 0.03	N.C.
3	COD	mg/L	204 ± 27	D
4	BOD ₅	mg/L	92 ± 6	D
5	TSS	mg/L	169 ± 13	B
6	TN	mg/L	51.5 ± 1.2	D
7	TP	mg/L	9.3 ± 0.7	D
8	Total Coliform	CFU/100mL	1.1x10 ⁶ ± 1.0x10 ⁵	D

Note: QCVN 08:2023/BTNMT - National technical regulation on Surface water quality; N.C. means Not Classified.

Such Level D conditions point to poor water quality, which poses significant risks to aquatic life, particularly fish, due to the severe depletion of DO and high pollutant concentrations. The average DO level of 1.15 mg/L, although higher than the 0.5–0.6 mg/L range reported by Huong et al., 2008, was still slightly lower than the 1.6 mg/L observed by Luong et al. (2019) in a 2019 study. The average TSS concentration was recored at 169 mg/L, which is lower than the 200–250 mg/L reported by Huong et al. (2008) and 173 mg/L documented by Luong et al. (2019). Furthermore, the results reveal significant organic pollution, with average COD and BOD₅ concentrations of 204 mg/L and 92 mg/L, respectively, inline with findings by Luong et al. (2019). The river also displayed eutrophic conditions, with TN and TP concentration of 51.5 mg/L and 9.3 mg/L, respectively. Additionally, total coliform levels were high, with an average concentration of 1.1×10^6 CFU/100mL.

3.2. Kim Nguu River flowrate and pollution loadings

The river's width was measured at 19 meters, with each sub-section representing one-fifth of the total width, or 3.8 meters. Depth (H) and water velocity (v) were measured at each sub-section throughout the survey period, and the resultant data were averaged, as presented in Table 2. Using Equation (1), the cross-sectional area and volumetric flow rate for each sub-section were calculated. The total river flow rate, obtained by summing the individual flow rates of all sub-sections, was estimated to be approximately 104,000 m³/day. A previous study by the Hanoi Sewerage Company, as reported by Hà (2021), indicated a daily wastewater discharge of approximately 125,000 m³ into the Kim Nguu River. Considering that our sampling site was located 500 meters upstream of the Yen So Wastewater Treatment Plant (WWTP), the estimated flow rate of 104,000 m³/day aligns well with the findings from this prior investigation.

Table 2. Kim Nguu River flowrate estimation

Items	Unit	Section number				
		1	2	3	4	5
Width (B)	m	3.8	3.8	3.8	3.8	3.8
Depth (H)*	m	0.94	1.19	1.23	1.20	1.04
Area (S)	m ²	3.57	4.52	4.67	4.56	3.95
Water velocity (v)*	m/s	0.05	0.06	0.07	0.05	0.05
Flowrate (F)	m ³ /d	15,422	23,432	28,244	19,699	17,064

Note: * average values of the measurement in 5 days

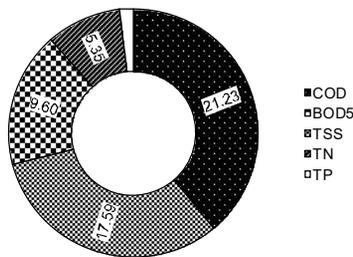


Figure 1. Kim Nguu River pollution loadings

The estimated river water pollution loadings, calculated using Equation (2) and presented in Figure 2, indicates a burden of organic matter. Specifically, the estimated daily loadings were determined to be 21.3 tons of COD, 9.6 tons of BOD₅, 17.59 tons of TSS, 5.35 tons of TN, and 0.96 tons of TP. These findings underscore organic materials, as indicated by COD and BOD₅, as the primary source of pollution in

the river, with significant contributions also coming from suspended solids (TSS) and nutrient loading (TN and TP). In comparison, a study by Lan Hương & Việt Nga (2023) reported daily discharges into the To Lich River of 16,788 tons of BOD₅ and 11,809 tons of TSS. The pollution loads in the Kim Nguu River, therefore, represent approximately 6% and 15% of those observed in the To Lich River, respectively.

3.3. Alcohol consumption

The determined wastewater flow rate is 104,000 m³/h, which allows an estimate of the population in the area to be approximately 530,000 people. According to a study of Bui et al. (2024), the average 24-hour concentration of Ethylsulfate in the water of the Kim Nguu River is approximately 2.62 ± 0.34 µg/L. Using formula (3), the per capita alcohol consumption within the population of Hanoi is estimated to be around 2.61 ± 0.33 mL/person/day.

Table 3. Alcohol consumption in different cities

No.	Country, City/region	Alcohol consumption (mL/person/day)	Reference
1	Vietnam, Hanoi	2.61 ± 0.33	This study
2	Vietnam, Ho Chi Minh city	1.56 ± 0.23	Quyen et al., 2024
3	China, Southern region	1.40 ± 0.60	Zheng et al., 2022

No.	Country, City/region	Alcohol consumption (mL/person/day)	Reference
4	Maldives, Malé capital	1.30	Fallati et al., 2020
5	Slovakia, 9 cities	7.00-126.00	Brandeburová et al., 2020
6	Australia, South-East Queensland	19.00-30.00	Zheng et al., 2020
7	US, three communities	36.70	Chen et al., 2019

Table 3 presents alcohol consumption estimated this study compared to other cities. A study on alcohol and tobacco consumption among the urban population in Ho Chi Minh City found that individuals aged 15 and above consume alcohol at an average rate of 1.56 ± 0.23 mL/person/day (Quyen et al., 2024). Another study conducted in China analyzed wastewater at a wastewater treatment plant in the southern urban region to assess alcohol consumption levels, revealing a consumption rate of 1.4 ± 0.6 mL/person/day (Zheng et al., 2022). In Malé, the capital city of Maldives, a study collected wastewater samples in a combined sewer at the inlet of 9 pumping stations, from which the wastewater was pumped directly into the sea. Despite the prohibition of alcoholic beverages in Maldives, the study found that the alcohol consumption rate in Malé was 1.3 mL/person/day (Fallati et al., 2020).

In Australia, an analysis of wastewater samples from the South-East Queensland wastewater treatment plant between 2012 and 2017 showed that alcohol consumption among the population aged 15 and above ranged from 19 to 30 mL/person/day (Zheng et al., 2020). Wastewater samples from nine cities in Slovakia collected between 2017 and 2018 also revealed an estimated alcohol consumption rate of 7 to 126 mL/person/day (Brandeburová et al., 2020). In three cities in the United States, raw wastewater samples were collected over an 11-month period, with results indicating an alcohol consumption rate of 13.4 ± 5.6 L/y/person, equivalent to 36.7 mL/person/day (Chen et al., 2019).

Thus, compared to similar studies, alcohol consumption in Hanoi is slightly higher than in Ho Chi Minh City and certain studies in Asia. However, it is significantly lower when compared to consumption rates in Slovakia, Australia, and the United States.

4. Conclusions

This study suggests that, although the water quality of the Kim Nguu River has shown certain improvements compared to previous evaluations, it continues to be significantly degraded, remaining within the poor-quality category. The estimated pollution loadings indicate that the river is receiving a large amount of organic matter, followed by TSS and nutrients. Additionally, based on measured river flow and ethyl sulfate biomarker concentration from previous study, per capita alcohol consumption in Hanoi is calculated to be 2.61 ± 0.33 mL/person/day. This figure is slightly higher than that of Ho Chi Minh City and other studies in Asia but considerably lower

than consumption levels observed in Slovakia, Australia, and the United States. The findings of this study are crucial for wastewater management strategies aimed at mitigating environmental pollution in Hanoi, while also providing a preliminary estimate of alcohol consumption among the city's population, which could help the development of target public health policies.

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