



e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: [www.http://op.niscair.res.in/index/php/JIAEM/index](http://op.niscair.res.in/index/php/JIAEM/index)



Assessment of Water Quality Contamination under Municipal Wastewater in the Northwest Urban Canals, Ho Chi Minh City

Nguyen Thi Thanh Huong¹, Pham Anh Duc^{1*}, Bui Tat Hiep^{2,3}

¹Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam

²University of Science, Ho Chi Minh City, Vietnam

³Vietnam National University Ho Chi Minh City, Vietnam

*Corresponding author: phamanhduc@tdtu.edu.vn

Submitted: 13 July 2024

Revised: 11 September 2024

Accepted: 13 September 2024

Abstract: Anthropogenic pollution is a critical factor in the degradation of water quality in rivers, especially in urban and metropolitan regions of Asia and Africa, where water quality monitoring remains severely constrained by limited testing facilities and capacity. The systematic and scientific assessments on water quality contamination under municipal wastewater were extremely necessary to protecting the urban river eco-environment. In this study, surface water was monitored at five sites along from the Tham Luong-Ben Cat-Vam Thuat Canal system in six monitoring times of March and September from 2020 to 2022. Each surface sample was analysed for 3 physiochemical parameters (TSS, DO, BOD₅) and 9 heavy metals (Fe, Mn, Cr, Zn, Cu, Pb, Cd, Ni, As). Among all parameters examined in the study area, the concentrations of TSS (116 – 271 mg/L), DO (0 – 1.2 mg/L), BOD₅ (130 – 678 mg/L), and Fe (1.59 – 6.72 mg/L) were higher than these of permissible thresholds of the discharge limit standard of Vietnam on water quality for irrigation purposes. The results also revealed the contents of heavy metals as Fe, Mn, Cr, Zn, Cu, Pb, and Ni which were significant exceedances of the water quality standards of United State Environmental Protection Agency for posing severe risks to both aquatic ecosystems and agricultural production. This assessment provides a valuable foundation for policymakers and environmental managers in crafting targeted strategies for environmental protection and sustainable management of the northwest urban canals, Ho Chi Minh City.

Keywords: Water quality, Contamination, Municipal Wastewater, Monitoring, Environmental Protection

I. INTRODUCTION

Accounting for more than 10% of the world's population, megacities have been attracting people and increasing densities themselves. Rapid urbanization growth coupled with the lack of investment in environmental protection in the megacities of developing countries threatens the safety of water resources (Nguyen et al., 2021; Ali & Le, 2019). In the 21st century, the issue of water pollution from megacities has become a pressing concern in Southeast Asia (Ali & Le, 2019; Tran et al. 2016). Heavy metals are a pressing concern in terms of their pollution in aquatic ecosystems because of environmental contamination, persistent chemicals, bioaccumulation, and biological magnification (Jaishankar et al., 2014). The untreated or inadequate treated wastes containing toxic metals as well as metal chelates from different industries resulted in deterioration of water quality and posing

threats on human beings and aquatic biodiversity (Kar et. Al, 2008). Studies across different regions underscored the scale and impact of this problem. For instance, Kannel et al. (2007) reported rising phosphorus levels in the urban areas of the Bagmati River catchment in Nepal from 1999 to 2003, highlighting the link between urban expansion and nutrient pollution. Similarly, Groppo et al. (2008) identified rapid population growth and the consequent increase in untreated sewage as primary drivers of water quality decline in rivers within the state of Sao Paulo, Brazil. An assessment revealed that the Ismailia Canal in Egypt, which is a crucial water source for drinking and fisheries where an assessment revealed severe contamination with heavy metals, was heavily polluted with toxic metals such as Pb, Cd, and Hg (Groppo et al., 2008).

Typically, Goher et al. (2014) conducted a detailed analysis of the water quality in the Narai Canal and Balu River within

Dhaka City, both of which were critical water bodies within the city. The study revealed alarming levels of pollution, with several key parameters (TDS, DO, and NH_4^+ , coliform) exceeding the standard limits set for various uses including domestic water supply, irrigation, and fish cultivation. In Lebanon, Jamilah et al. (2019) investigated the water quality in and around the Deir Kanoun Ras El Ain Dump, an area heavily affected by waste disposal activities. A detailed assessment of water quality in Alur Ilmu, a concrete-cement drainage canal at Universiti Kebangsaan Malaysia, was conducted, focusing on both general water quality parameters (DO, BOD, COD, NH_4^+ , TSS, pH) and heavy metal concentrations (Zn, Ca, Cu, Pb, Mn, Fe, Cr, Ni). The concentration means of heavy metals analysed were below the recommendation of Standard for Water and Packaged Drinking Water (Food Act 1985) for Malaysia except for Fe (>0.30 mg/L) and Mn (>0.001 mg/L). However, the mean concentration of Fe and Mn in Alur Ilmu were still acceptable by USEPA; Mn).

In Vietnam, concentrations of heavy metals in water of the Nhue River (a suburban waterway), and the To Lich River (an urban tributary), in Hanoi have been the focus of extensive monitoring to understand the spatial and seasonal variations since the early 2000s. This investigation showed that heavy metal concentrations in water of Nhue River and To Lich River were generally lower than these of the discharge limit standard of Vietnam on water quality for domestic water supply purposes but must be applied suitable processing technology (QCVN 08: 2008/BTNMT), except for Mn in several sites, but they were higher than the median values in freshwater of the US EPA by 0.42 – 43 times in Nhue and 0.13 – 32 times in To Lich [12]. Another research evaluated the water quality of main rivers and canals in Ho Chi Minh City (HCMC) with industrial planning and residential development by MIKE 11 Ecolab. The result showed that, when planning industrial park projects, combined with residential area development, the concentrations of BOD and COD have a tendency of increasing in 5 canal systems as Nhieu Loc – Thi Nghe, Tan Hoa – Lo Gom, Doi – Te, Tau Hu – Ben Nghe, Tham Luong – Ben Cat – Vam Thuat. Meanwhile, the concentrations of BOD and COD tend to increase slightly in the rivers such as Sai Gon, Dong Nai and Nha Be (Tran et al., 2020). Up to 2022, In their 2022 study, Vu et al. (2022) examined the surface water quality of selected tributaries flowing through Go Vap District and 12th District in HCMC. Their investigation revealed significant pollution, particularly concerning the concentration of ammonium nitrogen ($\text{NH}_4^+\text{-N}$). Vu et al. discussed the surface water quality of selected tributaries flowing through Go Vap District and 12th District, Ho Chi Minh City (HCMC). Their investigation revealed significant pollution, particularly concerning the $\text{NH}_4^+\text{-N}$ concentration. According to the finding of Linh-Thy Le et al (2024), the canal water systems at HCMC exceeded the permissible thresholds of Vietnam's discharge limit standards of total coliforms and *E. coli*. Almost residents were interviewed that the polluted canal environment affected their lives. The causes of water pollution in canals are people's low awareness, inadequate infrastructure, and the ineffective management of surface water resources.

The investigation into physiochemical parameters and heavy metals in the Tham Luong-Ben Cat-Vam Thuat Canal system, was critical for comprehending the multifaceted environmental issues facing urban waterways. This understanding was essential for guiding effective policy decisions that could lead to sustainable water management and the protection of both public health and ecological systems.

II. MATERIALS AND METHODS

Study area

The Tham Luong-Ben Cat-Vam Thuat waterway is an integral part of HCMC's water infrastructure. Spanning about 30 km, with widths between 30 – 100 m and depths ranging from 3 – 10 m, this waterway plays crucial roles in the city's drainage, irrigation, waterway traffic, and ecological restoration efforts (SCFC, 2015). Given this system's exposure to untreated or inadequately treated wastewater from various sources, understanding its pollution status, influencing factors, ecological risks, and potential sources of contamination is crucial.

Sample collection

Data from about 60 Km² with a length of 13,2 Km was used as a representative example for study areas. Water samples of total suspended solid (TSS), dissolved oxygen (DO), biological oxygen demand (BOD_5) and heavy metals (Fe, Mn, Cr, Zn, Cu, Pb, Cd, Ni, and As) were collected from five designated sites (Figure 1; Tables 1) over six monitoring times spanning of March and September from 2020 to 2022. All water samples were collected in two clean polyethylene bottles, 2.0-Liter. The bottles were immersed to about 30 cm below the water surface to prevent contamination of heavy metals from air (VEA, 2010). The water samples for TSS and BOD_5 analysis were transported to the laboratory in ice boxes, maintained at 2°C until analysis (UNEP, 1992; APHA, 2017).

For samples of heavy metal analysis were acidified with 2 mL concentrated Nitric acid to prevent precipitation of metals, reduce adsorption of the analytes onto the walls of containers and to avoid microbial activity, then samples were stored at 2°C and immediately transported to the laboratory on the same day (UNEP, 1992; APHA, 2017)

Analytical methods

For parameters of physiochemical parameters, DO of surface water was measured directly in the field using a HACH HQ40D meter. TSS referred to the nonfilterable residue retained by a standard filter disk and dried 103 – 105°C (VEA, 2008); and, the *standard BOD₅* was determined at a given temperature, 20°C, to obtain reproducible results (VEA, 2008).

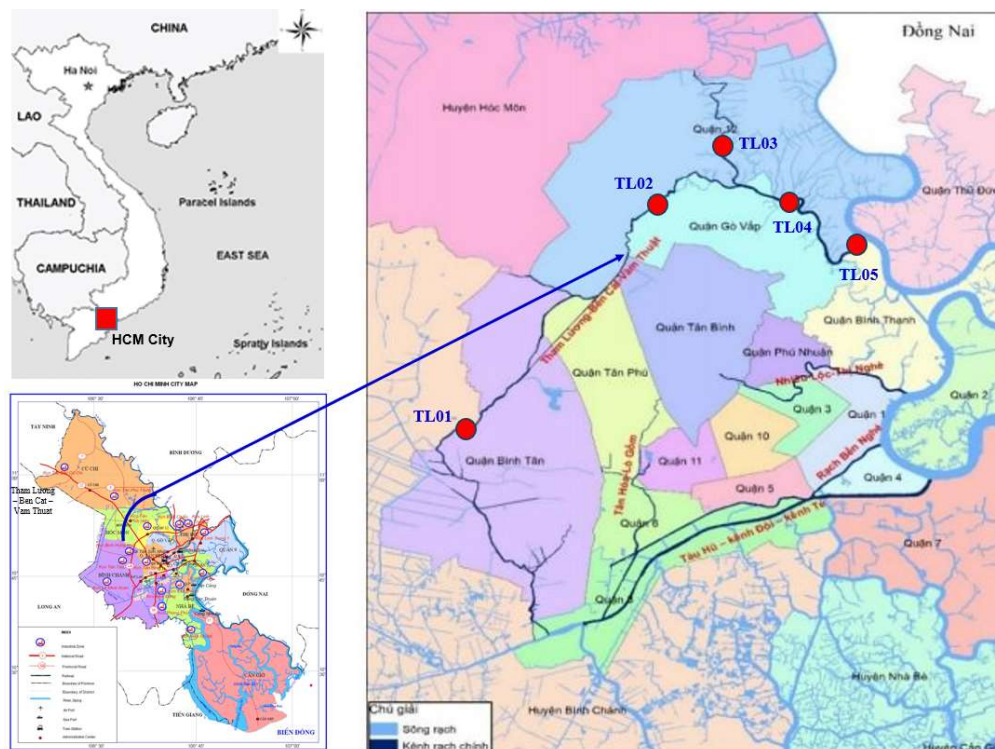


Figure 1: The map of Tham Luong-Ben Cat-Vam Thuat Canal system with 05 sites of sample collection

TABLE 1
Coordinates and locations of the sampling sites (TL01-TL05).

Sites	Local Names	Longitude (N)	Latitude (S)
TL01	Tham Luong Canal – 300 m downstream of Tham Luong Bridge	10°49'41.97"N	106°37'49.56"E
TL02	Tham Luong Canal - 300 m upstream of Tham Luong Canal Mouth	10°51'27.53"N	106°39'31.26"E
TL03	Ben Cat Canal – 200 m upstream of Ben Cat 2 Bridge	10°51'51.78"N	106°39'43.59"E
TL04	Vam Thuat River – 200 m downstream of An Loc Bridge	10°51'4.72"N	106°41'3.56"E
TL05	Vam Thuat River – 300 m upstream of Vam Thuat River Mouth	10°50'0.42"N	106°41'51.80"E

All water samples of heavy metal analysis were filtered through Whatman No.41 (0.45 µm pore size) filter paper. The filtrate was diluted by deionized water to a final volume of 50 mL (UNEP, 1992; APHA, 2017). These samples were measured in the Inductively Coupled Plasma Optical Emission Spectrometer. If the concentrations exceeded the calibration curve, the samples were appropriately diluted and acid was added to measure samples (PerkinElmer, 2018).

Data treatment

Basic descriptive statistics of the water quality data were calculated including the number of samples collected, range, mean, median and standard deviation. These values were measures of central tendency and dispersion, respectively, used to summarize and analyse the data by Excel 2019. The Pearson correlation among all the environmental variables were run using R-statistical software. Moreover, the ANOVA was employed, after the normality was passed (Shapiro-Wilk test),

for the organic pollutants and heavy metal concentrations. Significant difference was obtained when the P value was < 0.05.

III. RESULTS AND DISCUSSION

Concentrations of physiochemical parameters and heavy metals

The concentrations of TSS, DO, BOD₅, Fe, Mn, Cu, Ni, Zn, Pb, Cr, Cd and As at all five different sites over 6 periods during 2020, 2021, and 2022 in the Tham Luong-Ben Cat-Vam Thuat Canal system were recorded in Table 2. The concentrations of Fe were higher than these of the discharge limit standards (QCVN 08-MT: 2015/BTNMT – Column B1). While the remaining heavy metals were within the acceptable limits of this technical regulation (MONRE, 2015). However, the mean concentrations of Fe, Mn, Cu, Zn, Ni, Cr, and Pb did not meet the permissible limits of the water quality criteria for aquatic

life of US EPA (US EPA, 2021). This showed that the aquatic environment by heavy metal contamination was a critical concern due to their potential toxicity and accumulation in aquatic habitats (Kumar et al., 2019). Similar to the monitoring results measured in Alur Ilmu canal (Malaysia), the concentration means of heavy metals were below the

recommendation of standard for water and packaged drinking water (Food Act 1985) for Malaysia except for Fe (>0.30 mg/L) and Mn (>0.001 mg/L). However, the mean concentration of Fe and Mn in Alur Ilmu were still acceptable by USEPA; Mn (<0.50 mg/L) and Fe (<1.0 mg/L) (Ruslan et al., 2021).

TABLE 2
Concentrations of physicochemical parameters and heavy metals in the surface water of the Tham Luong-Ben Cat-Vam Thuat Canal system (TL01-TL05)

Parameters	Sampling Sites				
	TL01	TL02	TL03	TL04	TL05
TSS (mg l ⁻¹)					
Range	194 – 271	176 – 220	181 – 203	141 – 163	118 – 131
Mean	236	199	193	152	123
DO (mg l ⁻¹)					
Range	0	0 – 0.1	0 – 0.1	0.2 – 0.9	0.4 – 1.2
Mean	0	0.1	0.1	0.5	0.8
BOD ₅ (mg l ⁻¹)					
Range	431 – 678	301 – 467	290 – 446	231 – 329	126 – 173
Mean	551	380	359	280	149
Fe (mg l ⁻¹)					
Range	4.80 – 6.72	3.34 – 4.31	3.29 – 4.01	2.58 – 2.93	1.59 – 1.74
Mean	5.68	3.97	3.69	2.74	1.65
Mn (mg l ⁻¹)					
Range	0.16 – 0.17	0.22 – 0.25	0.18 – 0.20	0.17 – 0.21	0.15 – 0.18
Mean	0.17	0.24	0.19	0.19	0.16
Cu (mg l ⁻¹)					
Range	0.039 – 0.048	0.037 – 0.043	0.038 – 0.045	0.032 – 0.041	0.028 – 0.037
Mean	0.044	0.040	0.042	0.036	0.031
Zn (mg l ⁻¹)					
Range	0.036 – 0.041	0.032 – 0.041	0.033 – 0.041	0.034 – 0.041	0.031 – 0.035
Mean	0.038	0.036	0.036	0.038	0.033
Ni (mg l ⁻¹)					
Range	0.035 – 0.039	0.034 – 0.037	0.034 – 0.037	0.031 – 0.034	0.028 – 0.033
Mean	0.037	0.035	0.36	0.032	0.029
Cr (mg l ⁻¹)					
Range	0.016 – 0.018	0.014 – 0.016	0.012 – 0.016	0.012 – 0.016	0.012 – 0.014
Mean	0.017	0.015	0.014	0.013	0.013
Pb (mg l ⁻¹)					
Range	0.010 – 0.014	0.010 – 0.012	0.010 – 0.012	0.008 – 0.018	0.010 – 0.012
Mean	0.012	0.011	0.011	0.011	0.011
As (mg l ⁻¹)					
Range	0.005	0.005	0.005	0.005	0.005
Mean	0.005	0.005	0.005	0.005	0.005
Cd (mg l ⁻¹)					
Range	0.002	0.002	0.002	0.002	0.002
Mean	0.002	0.002	0.002	0.002	0.002

The Tham Luong-Ben Cat-Vam Thuat Canal system has been experiencing a significant rise in physiochemical parameters contamination, which poses serious risks to human health and aquatic life (Tran et al., 2020). Key indicators such as TSS, DO, and BOD₅ have been found to exceed the permissible limits set by the discharge limit standards (QCVN 08-MT: 2015/BTNMT – Column B1 Level). River water having DO < 2.0 mg/L and BOD > 15 mg/L was considered severely polluted, making the survival of aquatic organisms difficult (Giri et al., 2022). The DO was found to increase where water turbulence was high, even though those increments in the DO level were not sufficient to support most of the aquatic life (Omid & Hugo, 2021). Water was considered hypoxic when DO levels were between 0.3 and 2.0 mg/L; anoxic with very little or no oxygen, 0 to 0.2 mg/L. Large areas of hypoxic and/or anoxic water were often called “dead zones”, where fish and macroinvertebrates could not live here because they depended on higher DO levels (Omid & Hugo, 2021). A research assessing the contaminations of water quality applied Metal index (MI) and pollution index (PI) at the Ismailia Canal also indicated the these problem. Of which, Goher et al (2014) used these values to denote the dangerous pollution of the canal water, that was described as seriously at most sites along, in particular for drinking and fisheries utilizations. It may be attributed to the effluents of different industrial wastes arriving

at the canal water. The results indicated a need for more stringent management and remediation efforts to ensure the health and safety of aquatic ecosystems in the Tham Luong-Ben Cat-Vam Thuat Canal system.

Spatial distribution in physiochemical parameters and heavy metals

The concentrations of TSS and BOD₅ tended to decrease from the inside canal to the river mouth, while the concentrations of DO had a tendency the opposite changes (Figure 2). Similar to physiochemical parameters, the concentrations of heavy metals in the Tham Luong-Ben Cat-Vam Thuat Canal system tended to reduce pollution levels from the in-field canal to farther away from the concentrated waste source (Figure 3). The mean contents of heavy metals were in decreasing order of Fe > Mn > Cu > Zn > Ni > Cr > Pb > As > Cd. This was also true for the density of industrial enterprises gradually decreasing from the Tan Binh and Go Vap districts to the Binh Thanh district. Pollution sources from wastes from industrial plants along this canal system being discharged directly into the stream have caused serious pollution to this system (Nguyen et al., 2003; Tran et al., 2020; NOAA, 2022). These patterns reflected the influence of pollution sources, particularly industrial discharges

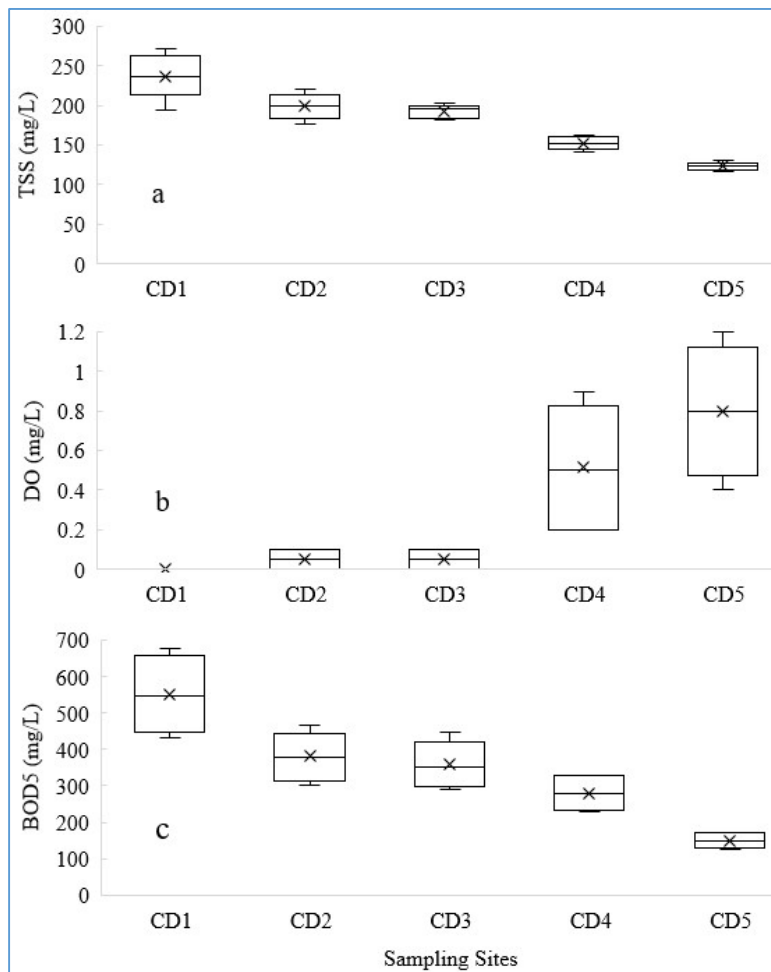


Figure 2: The concentrations of physiochemical parameters measured in the 5 sampling sites in the study area: TSS (a); DO (b); and, BOD₅ (c)

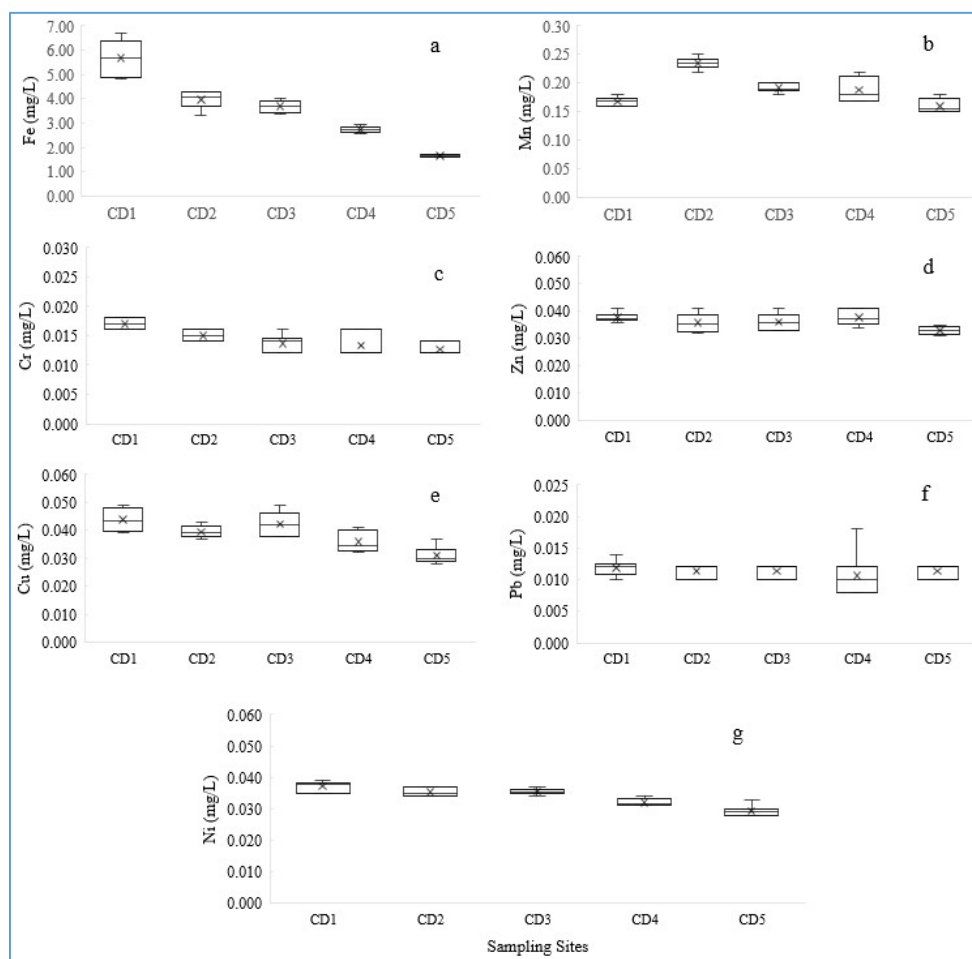


Figure 3: The concentrations of heavy metals measured in the 5 sampling sites in the study area: Fe (a); Mn (b); Cr (c); Zn (d); Cu (e); Pb (f); and, Ni (g)

The spatial change of physiochemical parameters and heavy metals in this waterway was significant with the pollution level gradually decreasing towards the river mouth. Tran et al. (2020) also figured that the total metal concentrations in surface water of the estuary of Dong Nai River System were higher in the rainy season than those during the dry season. The increase in rainfall in the Dong Nai River Basin during the transition time from the dry season to the wet season transferred both dissolved and particulate metals (Fe, Zn, Li, Ba, Ag, Cr, Ni, Cu, and Pb) from the sediments to the water environment (Nguyen et al., 2020; Nguyen et al., 2023). While, Edokpayi et al. (2017) claimed that higher concentrations of Fe, Mn, Pb, Cu and Zn were determined in the dry season in the water of Nzhelele River, South Africa whereas in the sediments higher levels were recorded for Al, Fe, Cd, Cr, Cu and Zn in the wet season. The study of surface water quality and monitoring in southern Vietnam using multicriteria statistical approaches showed that the WQI classified water quality from bad to very good (WQI = 42–100) due to the impact of hydrological conditions, navigation, wastewater from industrial zones, and fishing ports. Locations with medium and bad water quality are concentrated in Dong Nai, HCMC and Long An, which requires finding effective solutions to improve the water quality. By integrating these findings with ongoing monitoring efforts, decision-making leaders could develop comprehensive strategies to

address the challenges of physiochemical parameters and heavy metal contamination in this canal system (Nguyen & Huynh, 2022).

Correlation analysis

The correlation analysis was evaluated for the association among water environment parameters and heavy metals to understand the significance of these variables in the samples. Figure 4 showed that there was a strong negative correlation among DO with TSS, BOD₅, Fe, Cu, and Ni (-0.73 – -0.76). While, TSS and BOD₅ were also strong positive correlated with Fe, Cr, Cu, and Ni. Besides, strong positive correlations were observed between Fe with other heavy metals. The results showed that there was a relationship between pollutants and the discharge of industrial waste that has impacted this canal system. The water quality as described above could not be used for drinking purposes and irrigation as well due to the the high contents of organic matters and heavy metals (Kar et al., 2008; Shafiuddin et al., 2021; Tong et al., 2021). By addressing the complex interplay between water quality parameters and heavy metals, stakeholders could work towards restoring and maintaining the ecological integrity of the the Tham Luong-Ben Cat-Vam Thuat Canal system while ensuring the availability of safe water resources for communities and ecosystems alike.

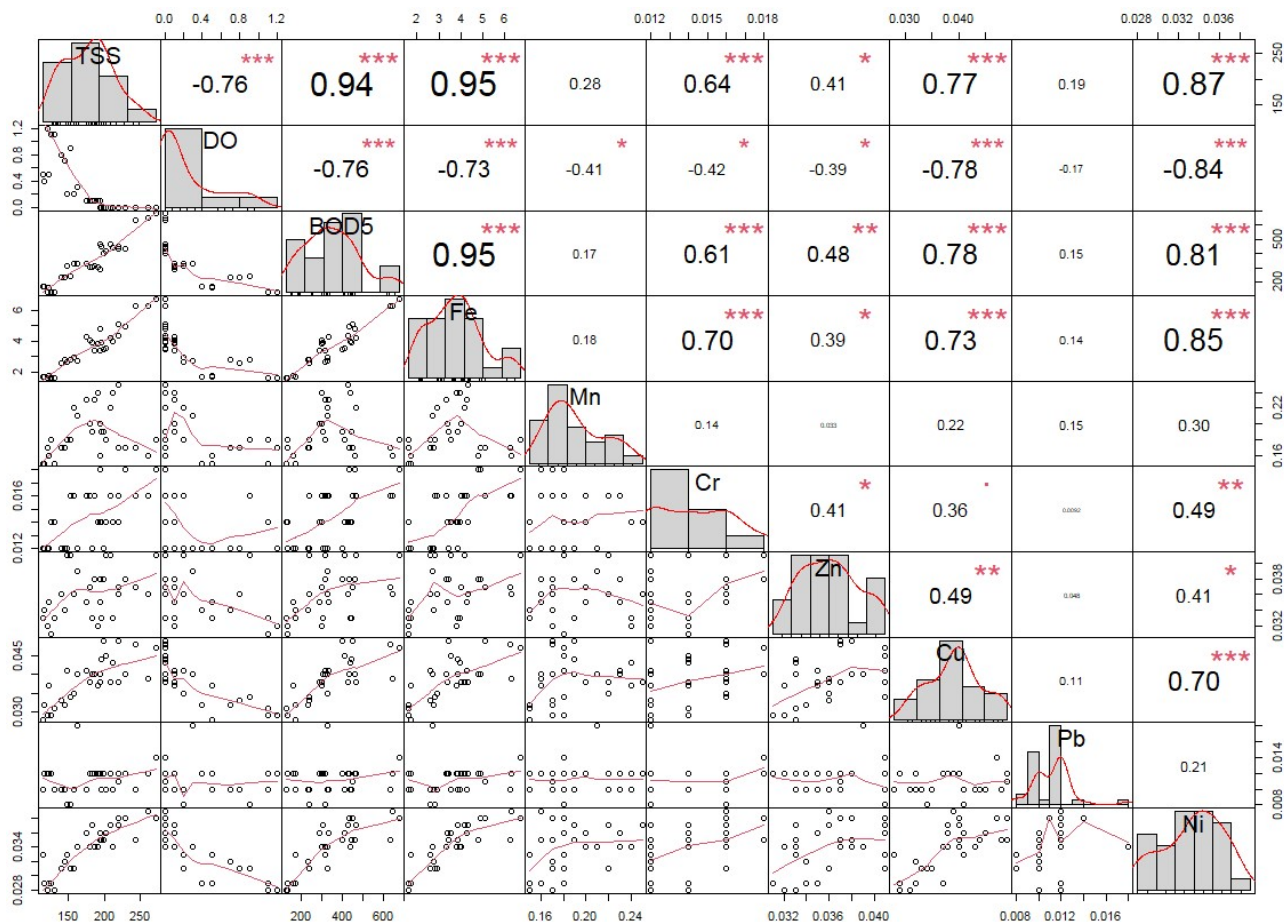


Figure 4. Relationship between physiochemical parameters and heavy metal concentrations in the study area

III. CONCLUSION

From the results of physiochemical parameters and heavy metal pollution measured in the study area, it could be summarized as follows: Fe concentrations exceeded permissible thresholds set by Vietnam's water quality standards for irrigation purposes (QCVN 08-MT: 2015/BTNMT – Column B1), while other heavy metals (Mn, Zn, Cu, Pb, Ni) were within permissible limits. However, all concentrations of heavy metals did not meet the water quality standards for aquatic life as per US EPA standards. Seriously, the concentrations of TSS, DO, and BOD₅ exceeded the allowable limits of the QCVN 08-MT: 2015/BTNMT at the Column B1 by significant margins. The concentrations of water quality pollutants tended to decrease gradually from the Tham Luong Canal to the Vam Thuat River mouth. In addition, concentrations of heavy metals were also observed in descending order Fe > Mn > Cu > Zn > Ni > Cr > Pb > As > Cd. The correlation patterns suggested complex interactions between water quality parameters, highlighting the challenges in managing and maintaining aquatic ecosystems in the study area.

By integrating these practices into daily routines and community efforts, significant strides can be made in conserving water and protecting water quality. Not only do these actions contribute to environmental sustainability, but

they also help ensure a safe and reliable water supply for everyone. Detailed steps and practices that can be adopted both at home and within the community: proper disposal of fats, oils, and grease; safe disposal of household chemicals; avoid dumping garbage down the drain; install water-efficient fixtures; minimize detergent and bleach use; regular maintenance of drainage systems. Addressing water pollution comprehensively requires a multi-faceted approach combining both macroscopic measures and individual actions. Additionally, to tackle water pollution on a larger scale and ensure comprehensive protection of waterways comprehensively as follows: efficient wastewater collection and centralized treatment for industrial parks; effective stormwater management; reduction in agricultural chemical use; active community participation in clean-up efforts; coordinated pollution control efforts. The more efficient these processes are, the cleaner the river water becomes.

Acknowledgment

The authors would like to express our thanks to Ton Duc Thang University, Vietnam for the technical support for this project.

IV. REFERENCES

- Ali, S. M., & Le, T. P. Q. (2019). Urbanization and Water Pollution in Southeast Asia. *Environmental Research*, 170, 400-410. DOI: <https://doi.org/10.1016/j.envres.2018.12.040>.
- American Public Health Association (APHA) (2017). *Standard methods for the examination of water and wastewater, 21st ed.*. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, D.C.
- Chesapeake Bay Interpretive Buoy System (2022). *Summertime dissolved oxygen levels: what do they mean for fish and fishermen?* NOAA.
- Edokpayi, J. N., Odiyo, J. O., Popoola, E. O., & Msagati, T. A. M. (2017). Evaluation of temporary seasonal variation of heavy metals and their potential ecological risk in Nzhelele River, South Africa, *Open Chemistry*, 15(1), 272-282. DOI: 10.1515/chem-2017-0033.
- Giri I, Ritika, K. C., Udhav, R. K. (2022). Water quality status in Bagmati river of Kathmandu valley, Nepal. Ecological Significance of River Ecosystems. *Elsevier*, 481-502. DOI: 10.1016/B978-0-323-85045-2.00017-0.
- Goher, M. H., Hassan, A. M., Ibrahim, A. A. M., Ayman, H. F., Seliem, M. E. (2014). Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *Egyptian Journal of Aquatic Research*, 40(3), 225-233 DOI:10.1016/j.ejar.2014.09.001.
- Grosso, J. D., Ribeiro, F. L., Pedreira Filho, W. R., Nascimento, C. A., & Camargo, A. P. (2008). Urbanization Impact on Water Quality in the Rivers of the Metropolitan Region of Sao Paulo, Brazil. *Water Science and Technology*, 58(1), 151-157. DOI: <https://doi.org/10.2166/wst.2008.664>.
- HCMC Steering Center of the Urban Flood Control (SCFC) (2015). *Environmental and Social Impact Assessment*, People's Committee of Ho Chi Minh City.
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, Mechanism and Health Effects of Some Heavy Metals. *Interdisciplinary Toxicology*, 7(2), 60-72. DOI: <https://doi.org/10.2478/intox-2014-0009>.
- Jamilah, B., Manal, El. J., Rawan, K., Lobna, Y., & Diane, A. B. (2019). Heavy metals and organic compounds contamination in leachates collected from Deir Kanoun Ras El Ain dump and its adjacent canal in South Lebanon. *Heliyon*, 5(8). DOI: 10.1016/j.heliyon.2019.e02212
- Kannel, P. R., Lee, S., Kanel, S. R., Khan. S. P., & Lee, Y. S. (2007). Spatial-Temporal Variation and Comparative Assessment of Water Qualities of urban River System: A Case Study of the River Bagmati (Nepal). *Environmental Monitoring and Assessment*, 129, 433-459. DOI: <https://doi.org/10.1007/s10661-006-9375-6>.
- Kar, D., Sur, P., Mandal, S. K., Saha, T., & Kole R. (2008). Assessment of heavy metal pollution in surface water. *Int. J. Environ. Sci. Tech.*, 5(1), 119-124. DOI: 10.1007/BF03326004.
- Kikuchi, T., Furuichi, T., Huynh, T. H., & Tanaka, S. (2009). Assessment of heavy metal pollution in river water in Hanoi, Vietnam using multivariate analysis. *Bull Environ Contam Toxicol*, 83, 575-582. DOI: 10.1007/s00128-009-9815-4.
- Kumar, V., Parihar, R. D., Sharma, A., Bakshi, P., Sidhu, G. P. S., Bali, A. S., Karaouzas, I., Bhardwaj, R., Thukral, A. K., Yeboah, G. A., & Jesús, R.C. (2019). Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses. *Chemosphere*, 236, 124364, ISSN 0045-6535. DOI: 10.1016/j.chemosphere.2019.124364.
- Le, L. T., Dao, T. V. H., Nguyen, G. H., Tran, T. M., Nguyen, T., Lam, M. Q., Tran, T. B., Nguyen, V. P. T. Nguyen, Tran P. Y. N., Nguyen, N. T., Lens P. N. L., & Bui, X. T. (2024). Investigation of canal water quality, sanitation, and hygiene amongst residents living along the side of the canals - A cross - Sectional epidemiological survey at Ho Chi Minh city, Vietnam. *Case Studies in Chemical and Environmental Engineering*, 9. DOI: 10.1016/j.cscee.2024.100700.
- Ministry of Natural Resources and Environment (MONRE) (2015). *National Technical Regulation on surface water quality (QCVN 08-MT:2015/BTNMT)*. MONRE, Vietnam.
- Nguyen, A. T., Némery, J., Gratiot, N., Dao, T. S., Thieu, V., Garnier, J. & Laruelle, G. (2021). Evaluating the response of water quality to pollutant loading in the Saigon River system (Vietnam): modelling scenario by C-GEM, an estuarine biogeochemical model. *Water, Megacities and Global Change*, 1-11. (hal-03420862v1).
- Nguyen, K. P. & Nguyen, T. H. (2008). Evaluation of water quality in canals and wastewater treatment in Ho Chi Minh City, *Vietnam Journal of Hydrometeorology*, 46-57. DOI: 10.36335/VNJHM.
- Nguyen, Q. H., T. V. Luyen, T. M. Phe, & N. V. Mai. Toxic elements and heavy metals in sediments in Tham Luong Canal, Ho Chi Minh City, Vietnam. *Environmental Geology*, 2003, 43, 836-841. DOI: 10.1007/s00254-002-0699-4.
- Nguyen, T. B., Do, D. D., Nguyen. T. X., Nguyen, N. V., Nguyen, P. T. D., Nguyen, M. H., Truong, T. T. H., Dong, P. H., Le, H. A., & Bach, Q. V. (2020). Seasonal, spatial variation, and pollution sources of heavy metals in the sediment of the Saigon River, *Vietnam. Environmental Pollution*, 256. DOI: 10.1016/j.envpol.2019.113412.
- Nguyen, T. G. & Huynh, T. H. N. (2022). Assessment of surface water quality and monitoring in southern Vietnam using multicriteria statistical approaches, *Sustainable Environment Research*, 2-12, DOI: 10.1186/s42834-022.

- Nguyen, X. T., Pham, T. B. V., Le, H. A. (2023). Assessing the current status and proposing solutions for heavy metal management in the Saigon River Basin sediments, **VNU Journal of Science. Earth and Environmental Sciences**, 39(2). DOI: [10.25073/2588-1094/vnuces.4931](https://doi.org/10.25073/2588-1094/vnuces.4931).
- Olewi, A. S. & Al-Dabbas, M. (2022). Assessment of Contamination along the Tigris River from Tharthar-Tigris Canal to Aziziyah, Middle of Iraq. *Water*, 14. DOI: [10.3390/w14081194](https://doi.org/10.3390/w14081194).
- Omid, B. H. & Hugo, A. L. (2021). *Water quality, hygiene, and health, economical, political, and social Issues in water resources*. Elsevier.
- PerkinElmer (2018). *Perkin Elmer Avio 200 ICP-OES Manual*. PerkinElmer.
- Ruslan, N., Jasni, J, Yusri, N. F. (2021). Assessment of water quality and heavy metals in drainage canal. *International Research Journal of Modernization in Engineering, Technology and Science*, 849-856.
- Shafiuddin, A. S. A., Mohammad, B. H., Omar, S. M. F. B., Moshur, M. R., & Shafiqul, M. I. S. (2021). Human health risk assessment of heavy metals in water from the subtropical river, Gomti, Bangladesh, *Environmental Nanotechnology, Monitoring & Management*, 15. DOI: [10.1016/j.enmm.2020.100416](https://doi.org/10.1016/j.enmm.2020.100416).
- Tong, S., Li, H., Tudi, M., Yuan, X., & Yang, L. (2021) Comparison of characteristics, water quality, and health risk assessment of trace elements in surface water and groundwater in China, *Ecotoxicology and Environmental Safety*, 219. DOI: [10.1016/j.ecoenv.2021.112283](https://doi.org/10.1016/j.ecoenv.2021.112283).
- Tran, N. T. D. et al. (2016). Ho Chi Minh City growing with water-related challenges. Water, megacities and global change: portraits of 15 emblematic cities of the world. UNESCO and IHP,
- Tran, T. K., Phung, T. M. D., T. T. T. An, N. C. Toai, P. Ngoc, & N. T. Bay (2020) Assessment of water quality in the main river Ho Chi Minh City with industrial planning and residential development. *Da Nang Journal of Science and Technology*, 18(9), 11-16. DOI: [10.21272/jnep.14\(3\).03002](https://doi.org/10.21272/jnep.14(3).03002).
- Tran, T. V., Nguyen, P. D., & Strady, E. (2020). Bioaccumulation of trace elements in the hard clam, *Meretrix lyrata*, reared downstream of a developing megacity, the Saigon-Dongnai River Estuary, Vietnam, *Environ Monit Assess*, 492-556. DOI: [10.1007/s10661-020-08502-z](https://doi.org/10.1007/s10661-020-08502-z).
- United Nation Water Program (UNWP) – GEMS/Water (1992). *Operational Guide (3rd Ed.)*. UN Environment Programme, Burlington.
- United State Environmental Protection Agency (US EPA) (2021). *Water quality criteria – National recommended aquatic life criteria table*. US EPA, United State.
- Vietnam Environment Administration (VEA) (2008). *TCVN 6625-2000 (ISO 11923:1997) on Water quality – Determination suspended solids by filtration through glass-fibre filters*. Vietnam.
- Vietnam Environment Administration (VEA) (2008). *TCVN 6001-1:2000 (ISO 5815-1:2003) on Water quality – Determination of biochemical oxygen demand after n days (BOD_n) – Part 1: Dilution and seeding method with allylthiourea addition*. Vietnam.
- Vietnam Environment Administration (VEA) (2010). *TCVN 6663-1:2010 Water quality - Sampling - Part 1: Guidance on the design of sampling programs and sampling techniques*. Vietnam.
- Vu, L. D., M. C. Tuan, D. T. M. Duyen, H. T. L. Anh, Tran, T., & L. Q. Tuong (2022). Surface water quality of selected tributaries flowing through two districts, Ho Chi Minh City, Vietnam. *Journal of Nano- and Electronic Physics*, 14(3), 1-5. DOI: [10.21272/jnep.14\(3\).03002](https://doi.org/10.21272/jnep.14(3).03002).