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**RESEARCH ON THE EFFECTS OF RAINWATER
RUNOFF TO THE QUALITY OF SAIGON RIVER
SURFACE WATER**

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INTRODUCTION

1. The urgency of PhD research

Saigon River is one of the river basin, and located in the Southeast region of the country. Saigon River water resources are being exploited and used for many different purposes, including clean water for millions people. Increasing urbanization, industrialization, industrial parks, factories, enterprises combine with population growth in the region have increased the pressure on water resources. Urban development on a large scale rise concreting, reduce the permeability of the catchment and limite additional sources of underground water, and cause frequent flooding in the city after heavy rain. Besides, rainwater runoff flow on the catchments, carry the waste and pollutants, and made the river water morepollut in the downstream area, especially the river flows through Ho Chi Minh City to the river mouth. This happening is a threat of resident in Ho Chi Minh City as well as downstream areas for the sustainable development.

Consequently, dissertation: "Research on the effects of rainwater runoff to the quality of Saigon River surface water" was conducted to provide a scientific information for the rain water resource, and support the protection of water resources in the river basin. These things are very necessary in the situation and conditions of the basin because of preventing the decline of river water quality, restoration of river water quality, and ensuring sustainable development.

2. Scientific and practical significance

To establish a scientific basis for investigating the impact of rainwater runoff on water quality of Saigon River.

The characteristics of rainwater runoff, river water quality in this dissertation can be used as a part of environmental impact assessment of the socio-economic projects in the research areas.

The integrated approach of factors affecting the quality of river water in this dissertation can be applied to other river basins in Vietnam and around the world where are the same conditions.

3. Objectives of the research

- To investigate the river water quality, pollution sources in lower Saigon River basin.

- To assess the impact of rainwater runoff on surface water quality in lower Saigon River basin.

- To suggest the solutions to reduce river water environment pollution affected by rainwater runoff.

4. Scope of study

- Location: Saigon River basin (the system of canals, rivers)

- The main objects of this study are rainwater runoff and water quality of Saigon River.

5. Methodology

- Inherited Methods and Properties;

- Methods of Investigation and monitoring;

- Statistical analysis methods;

- Methods of mathematical modeling.

6. List of new scientific contributions

- The results of the survey and analysis of the rainwater surface flow have shown the evolution of pollutant load of the flow during the rain event in different watersheds. For a typical rain event, the first flush of the surface runoff of the rain (about one third of the total volume

of the flow) on residential and industrial clusters carries more than 50% of the cumulative load of pollutants (TSS, BOD₅ and P-PO₄³⁻). Meanwhile, surface runoff on agricultural land accounts for only about 30% of the cumulative load of pollutants.

- The simulation results from the model show the effect of rain water overflow on the quality of Sai Gon river water. For the early rain (R=36 mm; from 20-21/05/2014) and mid-season rain (R=43,3mm; from 18-19/08/2014), the concentrations of pollutants in the river at the confluences have increased starting from the beginning of the rain and reached the peak (C_{max}) in between 240 and 270 minutes (about 4 – 4 hours 30 minutes). After that, the pollutants of river water continue to diffuse and gradually decrease from the minutes of 240 and afterwards. Under the effects of tide, the maximum exposure time (C_{max}) of pollutants does not depend on the delay or early phase compared to the maximum flow (Q_{max}) of river water.

7. The dissertation outline

The dissertation includes the Introduction and four chapters:

Chapter 1: A literature review about rainwater runoff and river water quality.

Chapter 2: The method of studies

Chapter 3: Analysis and assessment of the characteristics of rainwater runoff, watersheds and model simulation of Saigon River water quality during raining time. Then, the solutions to reduce river water environment pollution affected by rainwater runoff were suggested.

Conclusions and recommendations

Chapter 1. OVERVIEW OF RAINWATER RUNOFF AND THE INFLUENCE OF RAINWATER RUNOFF TO RIVER WATER QUALITY

1.1 Rainwater runoff on the catchment surface

A negative relationship between water resource and urbanization has existed for many years. Most catchment surface was built by the urban works, and pollution sources on the upstream region influence the water quality in the downstream region. Recently, increasing population density in urban areas has led to the demand for using clean water and discharged huge wastewater. Source of pollution from waste by the socio-economic activities in urban areas (urban wastewater and industrial wastewater without treatment) have a negative impact on water quality of the rivers downstream in large cities.

There are many assessment methods of study about the river water quality publishing on journals. These researches were classified on difference fields, such as investigation and monitoring, water quality analysis, modeling or combining between experiments and modeling, etc. However, these methods are general assessment, comparing pollution parameter of rainwater runoff among regions with different purpose of the land use. In general, the researcher used survey methods, such as sampling and analyzing rainwater runoff to evaluate the pollutant of rainwater runoff on the different catchment surfaces. Therefore, the methods only focused on assessing the quality of rainwater runoff, but lack of the constantly dynamic characteristics and dynamic description of

hydrology factors follow time by time, pollutant sources as well as linking to other pollutant sources (nonpoint sources residential pollution, agriculture, industry...) affecting to surface water quality.

1.2 Assessment of the river water quality

Since the 1960s, scientists and organizations in the world have been beginning to recognize the fact that the source of rainwater runoff in urban areas was one of the main pollutant source impacting on river water quality. Pollutants from the solid waste on the streets or sediment on the catchment surfaces is one of the main reason causing pollution of rainwater runoff. Consequently, in developed countries like the US, Europe, Japan, Singapore are focused on rainwater runoff, especially large cities. Many countries have built the system separately between rainwater collection system and the other urban wastewater collection system, so people can manage wastewater before discharged into rivers. Rainwater runoff in urban areas as Sai Gon basin with incomplete water treatment or without water treatment facilities, non-seperating collection system between rainwater runoff and other urban wastewater, is actually a challenge for the environmental management. Domestic wastewater and rainwater runoff were discharged directly into the sewer collection system, generally forming urban runoff and discharge to pond, lake and then to rivers.

In Vietnam, there are many studies related to Sai Gon basin, however, these research only focused assessment and river water quality analysis due to impact of pollutants sources from domestic sewage, industrial and agriculture wastewater. The results mainly analyzed the factors of rain, tide, and the effect of these two factors to flooding situation. However, the results focus on assessment,

analyze and simulation correlation between rain and runoff overflow flooded without showing quality rainwater runoff, or characteristics rainwater runoff results. Some studies mainly discussed about quantity rather than quality of rainwater runoff. Therefore, this dissertation will focus on the characteristic of rain water runoff and river water quality.

1.3 Overview of modeling methods to be applied in river quality assessment

Currently, there are many research results beside the research of water quality by traditional methods as surveying and water quality analysis in the laboratory that combine between monitoring, investigating and modern modelling methods. A quality modelling system can simulate the pollutants source on the river water.

These studies have used the method of collecting, water sample analysis, using GIS and rainfall runoff modelling (PRMS) and meteorology, hydrology, hydraulic and water quality modelling (MIKE, HEC-HMS, SWMM&HSPE, QUAL2E, QUAL2K, WASP, WQ97, SAL, MIKE...etc), combined the database and processed by the statistical method for assessing the water quality in the basin.

Based on the overview of references as well as the existence of the data, documents related to water resources of the Saigon River, this dissertation will chose directly to approach traditional methods and modern modelling methods to assess the impact of rainwater runoff by the MIKE modelling. The modelling are used include: Hydraulic module, load diffusion and water quality module.

Chapter 2. RESEARCH METHODOLOGY FOR RAINWATER RUNOFF AND RIVER WATER QUALITY

2.1 Overview of the basin

Saigon River is a sub-basin in the basin of the Dong Nai river system. Saigon River originates from Cham Tonle streams, Cham canal (Loc Ninh hill and along the frontier Vietnam – Cambodia), around 100-150m above sea level, which flows into Dau Tieng reservoir. This river creates a natural boundary among Tay Ninh province, Binh Duong province, and Ho Chi Minh City. Then, it is confluent with Dong Nai River at Den Do intersection, and pour into Nha Be River.

Non-agriculture land use mainly concentrate in a large area from Thu Dau Mot city to Den Do cape, especially in Ho Chi Minh City. Based on the many researches about rain-water runoff in urban areas, residential areas which have been published in the world and in Vietnam, this dissertation focuses on assessment of canal system, rivers in this region as research objectives.

2.2 Hydrometeorological data used in the research

In this dissertation, many documents, data base were synthesized, selected to serve for the water resource and rainwater calculations, accreditation, assessment in river basin case study. Although there is very few meteorological, hydrological stations in basin area, some stations have very good monitoring data over 30 years. These data were used for calculating, for assessment of rainwater resource, rainwater runoff, surface water resources, specific at Tan Son Hoa and Cu Chi meteorological stations having the continual data with rainfall and the other main climate factors since 1980 – 2014. Other stations, such as Vung Tau station, Thu Dau Mot station and Phu An station, have had monitoring data H, Q from 1981 to 2015.

2.3. Monitoring and sample analysis methods

Based on the results of the characteristics rainfall, runoff and the quality of water in Sai Gon river, the study has been arranged, selected representative locations, time and sample space, parameter analyzing rainwater runoff to assess water quality in study region.

2.3.1. The characteristics of rainwater runoff

To study the characteristics of rainwater runoff, rainwater runoff samples were collected at four different catchment surfaces: High density of housing and commerce (DCTM), high density of resident housing and industrial cluster (DCCN), industrial Zone (CN) and agricultural area (NN). Four locations belong to DCCN are No.2 Binh Phuoc Highway, No. 9 Binh Phuoc Road, Nguyen Van Ba Street, Dang Van Bi Street; Two locations belong to DCTM are D1 Truong Sa, D2 Truong Sa; NN located at Ben Than; Two locations belong to CN are Binh Chieu Industrial Zone, Song Than Industrial Zone.

A total of 99 samples of rainwater runoff was sampled to assess the current status of the quality of rainwater runoff at 09 locations on 04 different catchment surfaces as above. Sampling rainwater runoff method was guided by the guidance manual of the US rainwater monitoring Protocols. The monitoring parameters for assessment of the quality of rainwater runoff are: pH, total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD_5), ammonium ($N-NH_4^+$), Total nitrogen (T-N), $N-NO_3^-$, T-P and Zn.

2.3.2. The characteristics of runoff of the watershed during rainy periods

To study the characteristics of the runoff of the watershed as well as to find a correlation between the pollutants in runoff during rainy periods, this study was implemented runoff flow volume

monitoring, taken water sampling at 02 locations of 02 different watersheds including: the watershed with high resident density housing and industrial cluster (LV01) and the watershed with agricultural area (LV02). Water sampling and flow volume (Q; l/h) was monitored at 02 positions on the rainy day period of Saturday 21st, September 2013, with pollutant parameters such as TSS, BOD₅, P-PO₄³⁻, N-NH₄⁺, N-NO₃⁻. A total of 56 water samples of runoff were collected in two watershed as LV (28 samples on 21/9/2013) and LV2 (28 samples on 21/9/2013) to assess the current status of the water quality of the flow at two sub-basins before reaching the Saigon River

2.3.3. River water quality

A total of 280 river water samples was collected to assess Saigon River surface water quality. The results of water quality at 14 representative locations from upstream to downstream of the Saigon River (Environmental Laboratory by VILAS 284, Sub-Institute of Hydrometeorology and Climate Change implemented and studied in the 5 years from 2011 to 2015) was used to assess the present condition of surface water quality of the Saigon River. Surface water monitoring was conducted four times a year, in May, July, September, and November. Water quality analysis results were compared and evaluated according to QCVN 08: 2015 / BTNMT.

2.4. Statistical methods

In this study, all data were used for analysis to determine which factors affect to the water quality of the Saigon River. These data were used to make a diagram of Principle Component Analysis (PCA – a factor dimension reduction method), and Agglomerative Hierarchical Clustering based on the distance (AHC) using XLSTAT and SPSS 21.0 software.

2.5. Modeling methods

In this dissertation, the MIKE 11 software was ran to determine which was the most suitable water quality parameters, and then calculation and simulation for this region. The water quality parameters in this research is the physical and biological parameters. Because of limited data and water quality reference so in this dissertation only focused on calculating and simulating some basic parameters. From these data, the water quality value of some interested indicators was calculated by the time and space, corresponding with the hydraulic and pollutant sources boundary conditions. Computing grid in water quality modeling was extracted from the hydraulic modeling of properties on a regular grid, and set up with boundary conditions at two locations on Tri An and Dau Tieng reservoirs, lower border at Nha Be, Rach Tra, Ben Luc, Ong Lon canal. Monitoring water quality data in July 2014 for calibration of water quality modelling and in September 2014 for verification of water quality modelling. To calculate and simulate the pollutants concentration by the impact of rainwater runoff on the Saigon River, in this dissertation simulated two scenarios for two rain events with different rainfall intensity on 20-21, May 2014 (the beginning of rainy season) and 18-19, April 2014 (rainy season).

Chapter 3. ANALYSIS AND ASSESSMENT OF CHARACTERISTICS OF RAINWATER RUNOFF AND WATER QUALITY OF SAIGON RIVER

3.1 Precipitation characteristics, hydrological regime and water quality

The study region located in the climate of tropical monsoon in the Southern region. There are two seasons in this region: dry season (with Northeast wind) and rainy season (with Southwest wind). The rainfall in rainy season averages 1300-1950 mm, occupy 93.6-96.8% of annual rainfall. Also, the study region is influenced by the East Sea tide which belongs to irregular semidiurnal tide with up and down two times a day, with 2 highest peaks approximately the same and 2 lowest peaks quite difference. Every month there are two period of the high-tide and two period of the low-tide.

The study areas were divided by the water quality, so there were three zones in the basin area. In upstream part of river from Tha La bridge to Dau Tieng lake, water quality in is better and stability between the rainy season and dry season. In middle part of river from Ben Suc bridge to Thu Dau Mot, water quality began organic pollution (BOD₅ and COD). In downstream of the Saigon River from Phu Long bridge to Tan Thuan port, water quality highly contaminated nutrients (ammonium, nitrite), and the river this area started to flow into the inner river of Thu Dau Mot city and Ho Chi Minh City.

3.2. Characteristic of rainwater runoff

The results demonstrated that the BOD₅, COD, TSS, turbidity and T-P parameter related to catchment surface in which areas were high resident density housing and commerce (DCTM) – D1 Truong Sa, and less impacted on catchment surface with high resident density housing and industrial cluster (DCCN) (Route 9 Phuoc Binh and Phuoc Binh Boulevard II) or catchment surface with agricultural

area (NN) (Ben Than). Thus, in catchment surface in agricultural area, the vegetation covers on soil preventing the rainwater runoff substance, so the rainwater runoff does not wash the organic materials when it is rainy. However, in industrial Zone (CN) with a impervious catchment surface, the result reported that the rainwater runoff washed away the organic substances easily, especially Zn and $N-NO_3^-$ (Song Than Industrial Zone and Binh Chieu) (Figure 3-2).



Fig. 3-1: Rainwater runoff sampling sites

Sampling rainwater runoff sites and parameters of pollution are highly correlated with each other, it is clearly in catchment surface with high resident density housing, catchment surface with industrial Zone. The reason is that the impervious catchment surface density is high over (76%) which makes rainwater runoff easy to wash away the pollutants, sediment and organic pollutants as well as heavy metals in an impervious catchment surface.

3.3. The characteristics of runoff during rainy periods

Characteristics of the watershed 1 (LV1): The total catchment surface area received rainwater runoff is about 240 ha. Monitoring site of the watershed 1 has Phuoc Long industrial zone, district 9, and area along Binh Tho canal which connected to the discharge

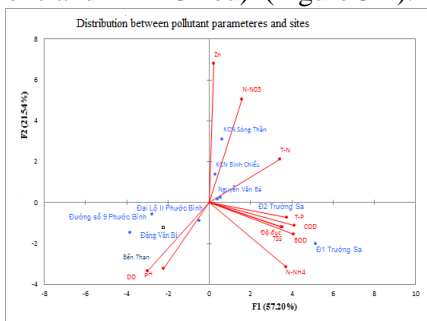


Fig. 3-2: Distribution between pollutant parameters and sites

sewer system of Phuoc Long clusters and then connected to Rach Chiec river, Thu Duc District, Ho Chi Minh City (Figure 3-3).

Characteristics of the watershed 2 (LV2): The total surface area of the buffer received the rain-water is about 30 ha. Sub-basin received rainwater runoff (LV3) flows into the trench, natural canals and rain-water is given Rach Ba Bep, Saigon. The basin is mainly grown rice cultivation and farm produce. Sub-basin has a canal, small ditch, housing with low density and the main roads surrounding sub-basin research with very low traffic density (Figure 3-3).



Fig 3-3: The Catchment surfaces of watershed 1 (LV1) and watershed 2 (LV2)

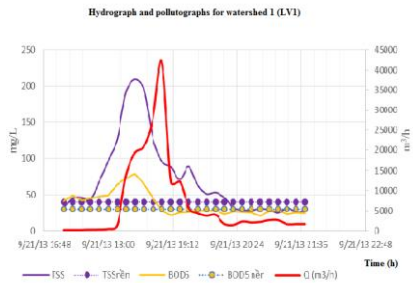


Fig 3-4: Hydrograph and pollutographs for watershed 1 (LV1)

Based on the variable pollutants concentrations and runoff flow volume at LV1 on 21st September 2013 (Fig 3-4), showed that pollutants concentration in the runoff increases quickly after rain event at the time about 20-30 minutes. Pollutant concentrations may reach the maximum value (C_{max}) earlier than the runoff flow volume rate (Q_{max}) in the period time from 20-60 minutes when it starts rain. However, runoff flow volume and runoff pollutant concentrations reduced when it is rain from the 60's onwards.

Monitoring, analysis of runoff of rain event (21st September, 2013) in two watersheds, runoff of the first flush (about 1/3 total

volume of runoff) of the watershed with land use for resident and industry carries out more than 50% pollutant load accumulations (TSS, BOD₅ và P-PO₄³⁻). However, runoff of the first flush of watershed with land use for agriculture carries out only 30% pollutant load accumulations (Fig 3-5). The result again shows runoff of the first flush has a strong influence to the water quality of receiving waterbody. Runoff of the first flush flow on the catchment surface and wash pollutants source that it are accumulated on the surface and run away with the surface flow into the receiving waterbody.

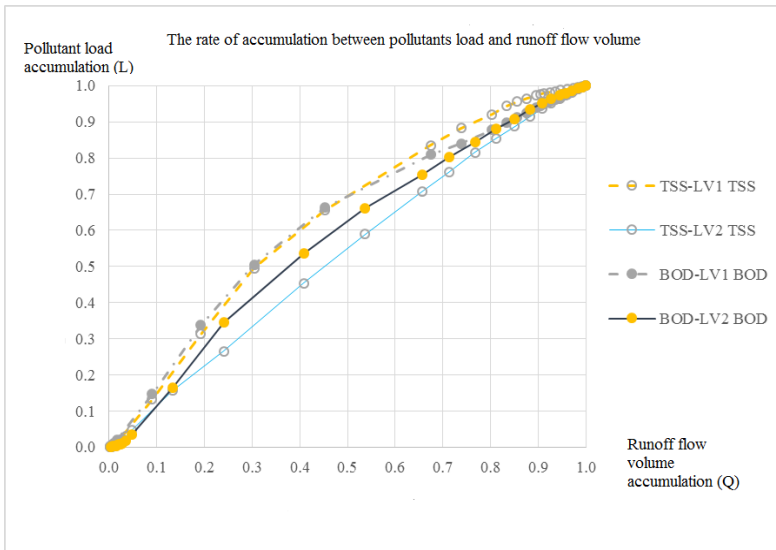


Figure 3-5: The rate of accumulations of LV1 and LV2

3.4. Assessment of the effects of rainwater runoff to the river water quality.

3.4.1. Calculation of rainwater runoff flow

Based on monitoring data at Tan Son Hoa station with 36 mm rainfall on 20-21st May, 2014 and the rainfall with the rainfall of

43.3mm on 18-19th April, 2014, the results of runoff flow volume calculation as shown in Table 3-1

Table 3-1: Calculation of Runoff flow volume on watersheds

Watershed	Areas (ha)	Runoff Coefficient	Q with R = 36 mm (Q, m3/s)	Q with R = 43,3 mm (Q, m3/s)
Cu Chi	43500	0.53	1153	1387
Hoc mon	11500	0.75	431	519
District 12	4700	0.75	176	212
Go Vap Dis	2000	0.75	75	90
Binh Thanh Dis	25300	0.75	949	1141
Q1, Q3, Phu Nhuan Dis	1800	0.75	68	81
Q4 Dis	400	0.75	15	18
Thu Đức Dis	4800	0.75	180	217
District 2	5000	0.75	188	226

3.4.2. Hydraulic simulation.

As a result of hydraulic simulation on August 2014. The average water level at Thu Dau Mot, Phú An and Nha Be stations are 0.130879, -0.05592 and -0.12443 m. In this time, Saigon River water levels can be up to 1.39 m at Thu Dau Mot station, 1.36 m at Phu An and Nha Be stations. Minimum water level on August at the Saigon River can be down to -2.34 m at Nha Be station, -2.05 m at Phu An station and -1.52 m at Thu Dau Mot station.

3.4.3. Water quality simulation

The status and trends of water quality based on the modelling has been calibrated and verification of water quality modelling, so the pollutants source scenario into Saigon River system without rainwater runoff include: wastewater from urban areas, densely housing areas, wastewater from industrial parks, agricultural areas. There are scenarios:

The baseline: The present condition scenario of pollution sources without rainwater runoff.

Scenario with rainfall 36 mm: Pollutants sources with rainfall $R = 36$ mm (scenario rainfall 36 mm, on 20th – 21st May 2014).

Scenario with rainfall 43,3 mm: Pollution sources with rainfall $R = 43,3$ mm (scenario rainfall 43,3 mm, on 18th -19th August 2014).

3.4.3.1. Simulation with rainfall $R = 36$ mm, on 20th – 21st May 2014

In this dissertation, the rainfall data was used with rainfall on 20th – 21st May, 2014 at Tan Son Hoa meteorological station to simulation. The event has high volume rainfall at the beginning of the rainy season with many non-rainy day periods before rainy events, so rainwater runoff should be able to wash pollutants source of the dry season into rivers. Time simulation starts at 18:00h, on 20th May 2014 to at 18:00h on 21st May 2014 (The start simulation set up at 0 minute). The time of modelling simulation are continuously in 1440 minutes periods.

Before rainy event, the BOD_5 concentration with peak tide at the maximum water level at Lang The canal, Tra canal, Vam Thuat River, Thanh Da, Nhieu Loc Thi Nghe canal , Giong Ong To canal

is following: 9.885 mg/l, 10.905 mg/l, 13.288 mg/l, 11.171 mg/l, 6.862 mg/l, 11.34 mg/l and 5.187 mg/l.

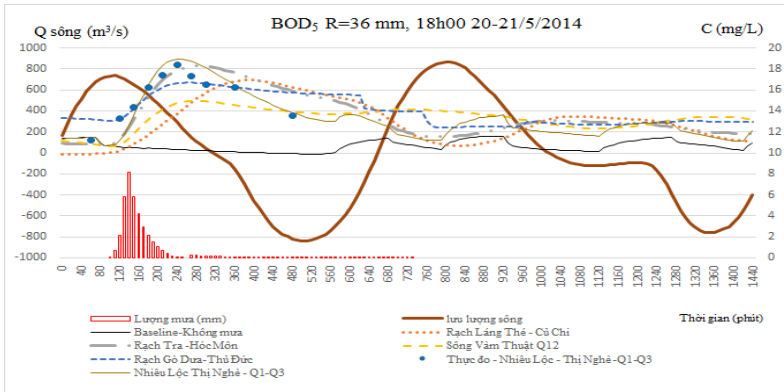


Figure 3-6: Concentration of BOD₅ of rainfall 36mm

At rainy event time, the BOD₅ concentration in rivers proportionally rises with the flow volume of river water due to tidal up in this time (slopes up). The flow volume reaches the maximum value at the minute of 150 (Q_{max}), concentration level of BOD₅ reaches the maximum value at the minute of 240, mean values BOD₅ reaches the maximum value after the flow volume reaches the maximum value at the minute of 90. During this 90 minutes, concentration level of BOD₅ in rivers inversely increases with the flow volume of river water due to tidal up (slopes down). Then concentration level of BOD₅ trends to decrease, the time of decreasing is longer than the time of rising (Fig.3 - 6).

It can be seen the contribution of pollutant source from rainwater runoff, concentration of BOD₅ value in Nhiêu Loc Thi Nghe canal highest increasing level, with approximately 5-7 mg/l (from 27% to 38%) and affects to the river water quality with its concentration get over the standards under QCVN08: 2015/ BTNMT B2. Therefore, with heavy rain of the early rainy season we should

avoid the use of river water for different purposes at time of 3-4 hours after the rain events, means at the minutes of 180 onwards.

Water quality simulations of watersheds of Go Dua canal, Tra canal, Vam Thuat River, although the concentration of BOD₅ value lower than the other watersheds above after rainy event, about 2-3 mg/l (from 14% to 20%). With the concentration baseline of BOD₅ value (without rainy events) was high at 11mg/l, combined with pollutants source from rainwater runoff so the river water quality for BOD₅ indicators was overcame the standards for surface water use QCVN: 08/2015 B1.

Particularly on Nhieu Loc - Thi Nghe canal, concentration baseline of BOD₅ value was lower than the other canals. However after rainy event, concentration of BOD₅ value of river water has increased rapidly and more unusual than the other watersheds. This proves that rainwater runoff wash away a large amount of organic pollutants, and push the accumulation of organic matter of the dry season from the collecting sewer system to river body. And other reasons:

- + Flow rate of Nhieu Loc Thi Nghe canal is lower than the other canals such as Thanh Da, Giong Ong To canals because these rivers are interconnected and lead the Saigon River.

- + Moreover, flow rate of Nhieu Loc - Thi Nghe river is extremely slow. Thus capable of transporting as well as the exchange of oxygen concentrations between transient surface and inside water is poor, leading to concentration of DO level is low and pollutants concentration of parameters in river water suddenly rise which makes the water quality of Nhieu Loc Thi Nghe river seriously polluted at the beginning of the rainy season.

- + In addition, upstream Nhieu Loc - Thi Nghe canal is a place which connected to the sewer drainage system of Tan Binh district without of wastewater treatment plan, this wastewater resource was

not treated and pumped into the Nguyen Huu Canh collection system and discharged to the Saigon River. Low concentration of DO levels makes aquatic organisms stress, especially the phenomenon of mass fish death due to less exchanging oxygen in water body.

Water quality simulation for Thanh Da and Giong Ong To canal (Fig.3-6), concentration of BOD₅ values has the lowest value compare with other canals in the range of 6-8 mg/l. A large amounts of rain runoff volume flow to the Saigon River, and these canal are connect to the main Saigon River at downstream so the flow of the river are high volume ($Q = 2000 - 2700 \text{ m}^3/\text{s}$), the ability of transported and exchanged oxygen between airy water surface and water body are so high, to leads to high DO values in water body and effected ecosystem of river water.

3.4.3.2. Simulation with rainfall R= 43.3 mm on 18th -19th, August, 2014

In this dissertation, the rainfall data was used with rainfall on 18th – 19th August, 2014 at Tan Son Hoa meteorological station to simulation. The event has high volume rainfall at main rainy season with short dry day before rainy events, this time is representative characteristic of wet season time with high river water volume. Time simulation starts at 23:00h, on 18th August 2014 to at 23:00h on 19th August 2014 (The start simulation set up at 0 minute), The time of modelling simulation are continuously in 1440 minutes periods.

The distribution of river volume in space and time at the first 0 to minutes of 100 are at the time without raining, at the intersection between Saigon River and Lang The canal, river water volume $Q = 365.25 \text{ m}^3/\text{s}$, Tra canal with $Q = 580,713 \text{ m}^3/\text{s}$, Go Dua canal $Q = 489,826 \text{ m}^3/\text{s}$, Vam Thuat river with $727,296 \text{ m}^3/\text{s}$, Thanh Da canal with $Q = 772,955 \text{ m}^3/\text{s}$, Nhieu Loc Thi Nghe canal with $Q = 787.24 \text{ m}^3/\text{s}$ and Giong Ong To with $Q = 855,923 \text{ m}^3/\text{s}$. During this time

with the hydraulic regime of Saigon River, water volume down (slope down), river volume decreases from upstream to downstream.

The concentrations of BOD₅ values at peak water level before rainy event of Lang The canal, Tra canal, Vam Thuat River, Thanh Da, Nheu Loc Thi Nghe, Giong Ong To is 7.53 mg/l, 7.75 mg/l, 13.288 mg/l, 7.17 mg/l, 7.81 mg/l, 8.691 mg/l, 7.487 mg/l and 7.775 mg/l.

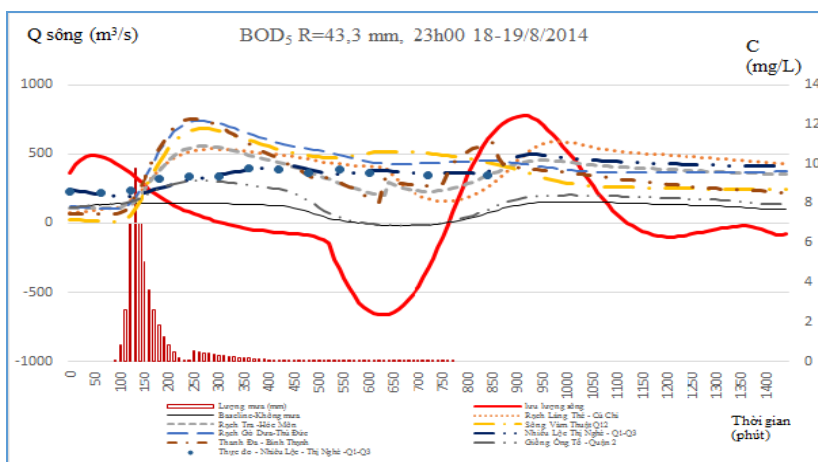


Figure 3-7: Changes in the value of BOD₅ for 43.3 mm rainfall

The concentrations of BOD₅ values at time of raining increased and the river water volume went down. The river volume reached the maximum value at the minutes of 50th then the river volume was at a maximum value (Q_{max}), concentrations of BOD₅ reached the maximum value at about the minutes of 240th, so concentraion of BOD₅ value got the maximum value after the flow volume rate reaches a maximum value at 190 minutes. Then concentrations of BOD₅ tends to decrease, the time decreased was slower than the

rised time. It can be seen clearly that the contribution of pollutants of rainwater runoff with concentration of BOD₅ value in Tra canal, The Lang canal gained the highest value, approximately concentration of BOD₅ value are from 7 mg/l to 8 mg/l and effected the river water quality get over the limit allowed Vietnam standards QCVN08: 2015 / BTNMT B2. Also in Go Dua canal and Vam Thuat River increased lower than these other watersheds.

3.5. Solutions to reduce river water pollution caused by rainwater runoff

These are some suggested solutions base on the fact as well as the news scientific contributions of this dissertation and other reference solutions. There are main solutions following:

- Increasing the system of collecting rainwater in the household. Developing rainwater harvesting system in the apartments, schools, the workplace, the industrial zones (with large catchments). Designing the harvesting rainwater system in the public sector. Planning the construction of ponds, landscape ponds.

- Planning, building a system of collecting rainwater with separated sewer collection system. Base on the fact as well as the news scientific contributions of this dissertation. The rainwater runoff have to treated the 1/3 volume runoff in the first flush of the events.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The quality of water in Sai Gon River have separated into three areas: Upstream area from from Tha La bridge to Dau Tieng lake is good water quality and stability rainy season and dry season; middle area from Ben Suc bridge to Thu Dau Mot, water quality began organic pollution (BOD₅ and COD); downstream area from Phu Long bridge to Tan Thuan port was high contamination nutrients (ammonium, nitrite).

The parameter pollution of rainwater runoff are high correlated with catchment surface land use. It is clearly that pollutant level of BOD₅, COD, T-N, T-P, N-NO₃⁻, N-NH₄⁺ and Zn of rainwater runoff in catchment surface with high density of resident housing, industrial Zone are higher than other catchment surfaces. Specially, the impermeable catchment surfaces ratio is over 76%.

Using the monitoring, observation of hydrographs and pollute-graphs of two watersheds showed that runoff of the first flush (about 1/3 total volume of runoff) of the watershed with land use for resident and industry carried over 50% pollutant load accumulations (TSS, BOD₅ and P-PO₄³⁻). However, runoff of the first flush of watershed with land use for agriculture only carried around 30% pollutant load accumulation.

Modeling and simulating of pollutants transportation in Sai Gon river at the beginning of rainy season and the main rainy season, demonstrated that the water pollutant concentration of river

has increased at the beginning of the rainy, and reached to the maximum water pollutants concentration of river (C_{max}) in minutes from 240-270 (about 4 - 4 hours 30 minutes). The water pollutants concentration continuing diffused in river until 240 minutes, then decreased the pollutant concentration from 240 minutes to 600 minutes (about 4-10 hours). With the impact of the tide, pollutants reach to the maximum water pollutants concentration (C_{max}) without depending on late phase or early phase, comparing with the maximum river flow volume (Q_{max}) of water.

The quality of river water at the beginning of the rainy season is more pollutant than in the middle or late rainy season. Particularly, pollutants of river water at the catchment surfaces with high density of population, poor drainage sewer systems are much higher than other areas when rainy events.

B. Recommendations

It is suggested to continue more research on pollution sources of rainwater runoff in other watersheds, with different intensity and time of each rainy event.

More parameters of rainwater runoff water and river water should be analysed accordingly./.

**LIST OF ARTICLES BY AUTHOR RELATING TO
THE DISSERTATION**

1. **Nguyen Van Hong**, Pham Thanh Long, Phan Thuy Linh (2013), *Study on calculated load of the main source of pollution in the Binh Tho canal - Ho Chi Minh City*, Journal of Hydrometeorology, 2013, No. 630 ISSN0866-8744, page 41-45.
2. **Nguyen Van Hong**, Phan Thuy Linh (2013), *Study on calculation of the load of pollution sources of Saigon River*, Journal of Hydrometeorology, 2013, No. 636 ISSN0866-8744, page 6-11.
3. **Nguyen Van Hong**, Tran Tuan Hoang (2014), *Study on the correlation between rain, flow and water quality in downstream of Saigon River*, Journal of Hydrometeorology, 2014, No. 642 ISSN0866-8744, page 12-14.
4. **Nguyen Van Hong** (2015), *Investigate the effects of rainwater runoff to surface water quality of Saigon River*, Journal of Hydrometeorology, 2015, No. 658 ISSN0866-8744, page 29-34.