Contributions of Natural and Human Activities to Urban Surface Runoff with Different Hydrological Scenarios (Orléans, France)

Mohammed Al-Juhaishi, Mikael Motelica-Heino, Fabrice Muller, Audrey Guirimand-Dufour, Christian Défarge

***Abstract*—**This study aims at improving the urban hydrological cycle of the Orléans agglomeration (France) and understanding the relationship between physical and chemical parameters of urban surface runoff and the hydrological conditions. In particular water quality parameters such as pH, conductivity, total dissolved solids, major dissolved cations and anions, and chemical and biological oxygen demands were monitored for three types of urban water discharges (wastewater treatment plant output (WWTP), storm overflow and stormwater outfall) under two hydrologic scenarios (dry and wet weather). The first results were obtained over a period of five months. Each investigated (Ormes, l'Egoutier and La Corne) outfall represents an urban runoff source that receives water from runoff roads, gutters, the irrigation of gardens and other sources of flow over the Earth's surface that drains in its catchments and carries it to the Loire River. In wet weather conditions there is rain water runoff and an additional input from the roof gutters that have entered the stormwater system during rainfall. For the comparison the results La Chilesse is a storm overflow that was selected in our study as a potential source of waste water which is located before the (WWTP).

The comparison of the physical-chemical parameters (total dissolved solids, turbidity, pH, conductivity, dissolved organic carbon (DOC), concentration of major cations and anions) together with the chemical oxygen demand (COD) and biological oxygen demand (BOD) helped to characterize sources of runoff waters in the different watersheds. It also helped to highlight the infiltration of wastewater in some stormwater systems that reject directly in the Loire River. The values of the conductivity measured in the outflow of Ormes were always higher than those measured in the other two outlets. The results showed a temporal variation for the Ormes outfall of conductivity from 1465 µS cm^{-1} in the dry weather flow to 650 µS cm^{-1} in the wet weather flow and also a spatial variation in the wet weather flow from 650 µS cm^{-1} in the Ormes outfall to 281 µS cm^{-1} in L'Egouttier outfall. The ultimate BOD (BOD_{28}) showed a significant decrease in La Corne outfall from 181 mg L^{-1} in the wet weather flow to 95 mg L^{-1} in the dry weather flow because of the nutrient load that was transported by the runoff.

***Keywords*—**BOD, COD, the Loire River, urban hydrology, urban dry and wet weather discharges, macronutrients.

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I. Introduction

THE understanding of the physical and physical-chemical parameters of urban runoff water and associated behavior of both dissolved and suspended organic and mineral matter and their variations within the urban water cycle and temporal and spatial distribution is an important subject for the management of urban drainage systems. Storm water drains collect rainwater that runs off roads, roofs and gutters, and discharges it into nearby rivers. Human activities such as industries, agriculture and domestic inputs represent an important part of the dissolved load of the urban runoff. Generally the dissolved load comes from the chemical weathering while the solid load comes from mechanical erosion. The environmental factors control the weathering, transportation and deposition processes. Previous studies on the Orléans city watershed focused only on the Loire River itself.

Reference [1] presented a study about the temporal distribution of chemical species in the dissolved load and suspended particulate matter (SPM) and bed sediments (BS) of the Loire River basin. They indicated that the concentration of quartz and K-feldspar increased during the periods of high flow together with an increase in calcite concentrations during periods of low flow. The mechanical erosion rate was estimated about 10 t km^{-2} y^{-1}. Reference [2] presented a study of the hysical-chemical parameters and major and trace elements for the Loire River near the city of Orléans with 2 days to 1 week intervals according to the river flow. This study showed that the ratio of total dissolved salts (TDS) to SPM ranged from 1.6 and 17.4 which was attributed to the increase of dissolved anthropogenic inputs. Reference [3] investigated the spatial and temporal distributions of major elements in the dissolved and the suspended matter load in the upper Loire basin between 1995 and 1998. This study also showed that the dissolved load resulted from a process of mixing rainwater inputs, weathering processes of carbonate and silicate bedrock and agricultural urban inputs. This study indicated that as the discharge increased the concentration of major oxides (Al_2O_3, Fe_2O_3, K_2O, MgO and SiO_2) and the percentage of silicate minerals (mostly quartz and feldspars) increased logarithmically. The CaO concentrations decreased sharply from 40% to 5% when the discharge increased up to 300 m^3 s^{-1}.

The main thrust of our study is to highlight the relation between the physical and physical-chemical urban runoff water parameters for the agglomeration of Orléans and the urban hydrological cycles together with its impact on the Loire River.

II. Material and Methods

A. Studied Area

Orléans is located on the river Loire in the central part of France. The length of the Loire River is about 1012 km and its drain basin is about 120,000 km^2, with a mean annual discharge of 850 m^3 s^{-1}. Mechanical erosion rate was estimated *ca* 10 t km^{-2} y $^{-1}$[3]. Orléans city represents 34% of the total Loire River basin. Three types of urban water discharges (wastewater treatment plant output (WWTP), storm overflow and stormwater outfall) were investigated for the four major watersheds of the Orleans agglomeration (Saran 15,496 inhabitants, Ingré 8147, Ormes 3616 and Saint-Jean-de-Braye, 19623) Table I, [4] and Fig. 1.

Water samples were taken in stormwater outfalls: L'Egouttier et la Corne are streams that were built underground in which runoff is carried while Ormes is the output of a storm water network of three urban catchments (Saran, Ingré and Ormes).

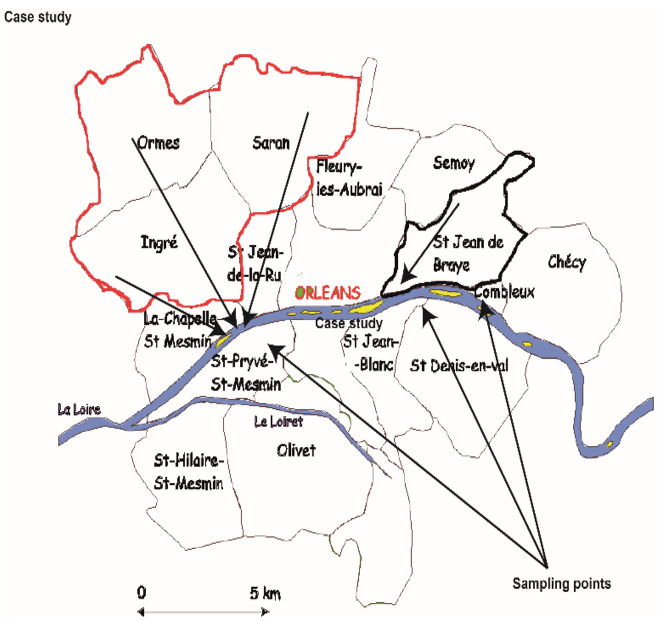

Fig. 1 Location of the studied urban watersheds with the sampling points

TABLE I
Watershed Area and Population

Town	Area, km^2	Hab.	Network length, m
Saran	19.65	15,496	34495
Ingré	20.82	8147	21681
Ormes	18.15	3616	24423

B. Sampling

1. Rain Water Sampling

A device of rain water sampling of type ARG100 (funnel diameter 254 mm, funnel rim height 340 mm) installed at the ISTO laboratory (GPS coordinates 47.833197, 1.941443), south of the river Loire, located at 15 km south of Orléans center was used to collect rain water. The sampling device has been operated since March 2015. The rain water of the 2015/05/06 was of 1.5 mm depth.

2. Dry and Wet Weather Flow Urban Run-Off Sampling

The water samples were taken from the three outfalls that are located beside the right bank of the Loire River (Fig. 1). The sampling dates were 2015/04/23 and 2015/05/06 for the dry weather flow and wet weather flow respectively. Four liters of water were sampled from each outfall for each campaign.

C. *Water Analysis*

1. Sampling Procedures

Except for the in-situ parameters (pH, conductivity, dissolved oxygen, turbidity) that were directly measured in the field, successive water samples were taken using 4 liter plastic tubes. All samples were stored at 4°C.

2. Physical and Physical-Chemical Parameters

Several analyses of the drain waters were performed in-situ by using a WTW 1970i multimeter device for measuring the pH, dissolved oxygen concentration and conductivity at a reference temperature of 20°C. A Smart3 LaMotte spectrophotometer was used for measuring turbidity of the drain water.

3. Total Suspended Solids

The analyses of the Total Suspended Solids (TSS) were performed on 500-mL samples of undisturbed water using 47-mm diameter cellulose nitrate membrane filters with a 0.2-µm pore-size

4. Dissolved Organic Carbon

The measurements of the dissolved organic carbon (DOC) concentrations were performed using a Shimadzu (total organic carbon analyzer) DOC analyzer on the filtered water samples.

5. Dissolved Salts

The analyses of major cations (Na^+, Mg^+, K^+, Ca^{2+}) and anions (Cl^-, NO_2^-, NO_3^-, SO_4^{2-}) were performed by Dionex ICS 900 and 1100 ion chromatographies on the filtered water samples.

6. Chemical Oxygen Demand (COD)

The COD expresses the amount of oxidizable organic compounds and inorganic reducing agents in waters. It was measured on the filtered samples using WTW C3/25 and C4/25 Cell Tests corresponding to ISO 15705:2002 sealed tube method.

7. Biological Oxygen Demand (BOD)

Biochemical oxygen demand is a measure of the quantity of dissolved oxygen consumed by microorganisms during the oxidation of reduced substances in a water sample, during 5 (BOD_5) to 28 days (BOD_{28}) of incubation at 20 ± 0.5°C in the dark. BOD_{28} is named Ultimate BOD (UBOD) [5]. It was measured on the raw samples by the manometric respirometric method, using VELP scientifica BOD devices.

III. Results and Discussion

The values of the TSS, turbidity, conductivity, DOC, ion concentrations, and oxygen demands for the dry weather flow are generally higher than for those the wet weather flow in all outlets (Figs. 2-4 and 7-12), indicating that the dilution effect by the rainfall predominates on possible erosion or weathering effects.

In La Corne outfall, however, the values of the turbidity for the dry weather flow is lower than for the wet weather flow (Fig. 3), which could be explained by higher fine particle erosion in the latter conditions.

The values of the conductivity for the Ormes outfall are always higher than those for L'Egouttier and La Corne because urban runoff at Ormes is mixed with wastewaters (Fig. 4).

This mixture may also explain why the values of the pH of the wet weather flow is higher than those of the dry weather flow at Ormes, whereas it is the contrary at L'Egouttier and La Corne (Fig. 5).

The values of the dissolved oxygen concentration for the wet weather flow are always higher than those for the dry weather flow (Fig. 6), which is coherent with storm inputs.

The value of UBOD for the dry weather flow of Ormes outfall is higher than those for L'Egouttier and La Corne (Fig. 11), which may be also due to the mixture with wastewater. At La Corne, as in the case of turbidity, the UBOD value of the wet weather flow is higher than those of the dry weather flow (Figs. 11, 12); this higher UBOD might thus be attributed to a higher load of fine organic particles. The value of UBOD for La Chilesse indicates a source of waste water (Fig. 12).

Fig. 13 presents the values for COD/BOD_5 ratio *vs.* DOC. For the dry weather flow this ratio is higher than 1 for all outlets and this ratio is less than 1 for the La Corne. COD/BOD_5 ratios lesser than 1 indicate that the COD is underestimated because it has been measured on filtered samples; further analyses will have to be done on decanted samples, in order to estimate COD content of the particulate fraction.

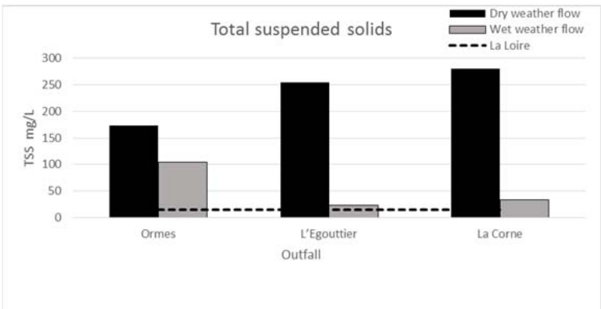

Fig. 2 Total suspended solids in the different runoff outfalls with two-hydrological scenarios

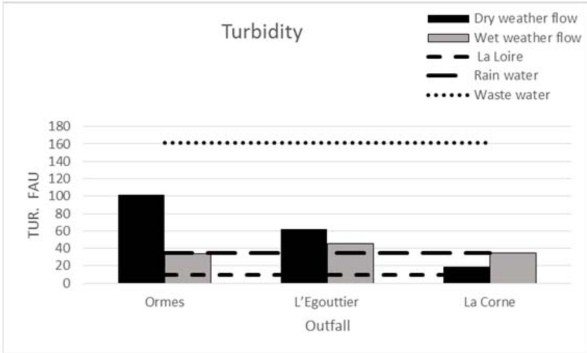

Fig. 3 Turbidity in the different runoff outfalls with two-hydrological scenarios

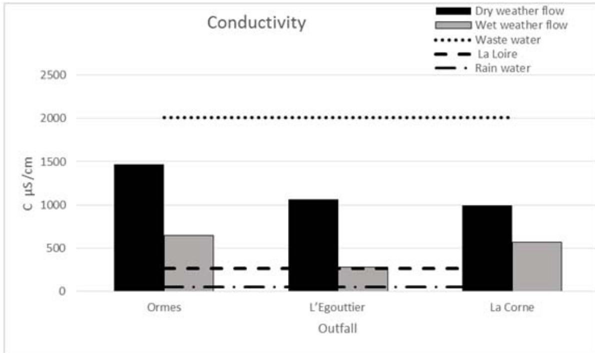

Fig. 4 Conductivity with two-hydrological scenarios

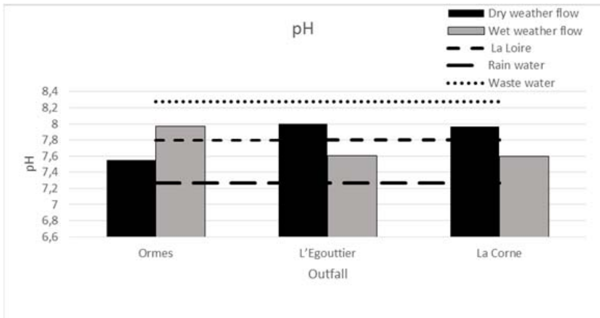

Fig. 5 pH in the different runoff outfalls with two-hydrological scenarios

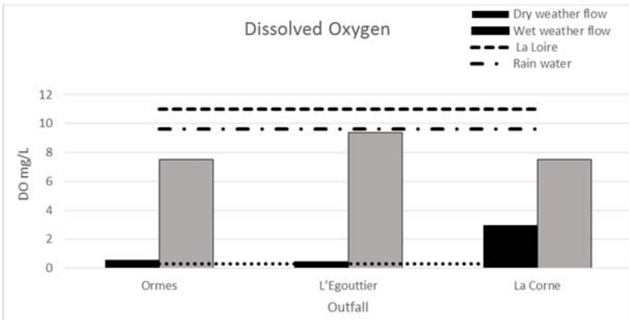

Fig. 6 Dissolved Oxygen in the different runoff outfalls for different hydrological scenarios

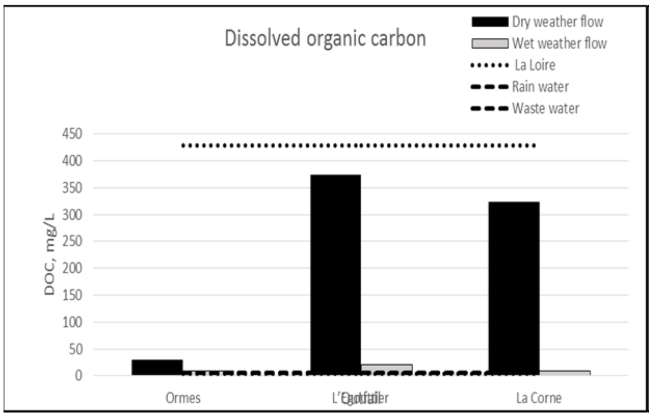

Fig. 7 Dissolved Organic Carbon values in the different runoff outfalls for different hydrological scenarios

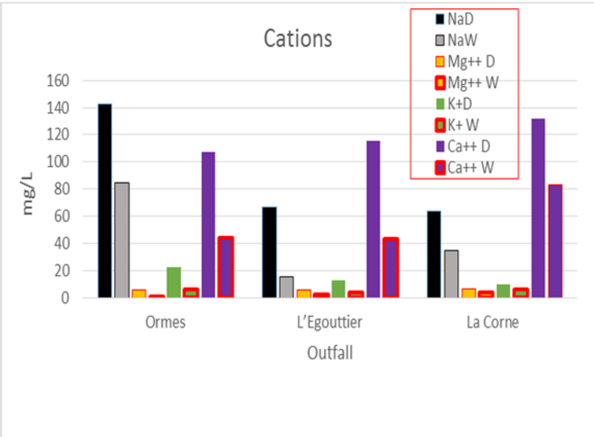

Fig. 8 Major cations concentrations in the different runoff outfalls for different hydrological scenarios

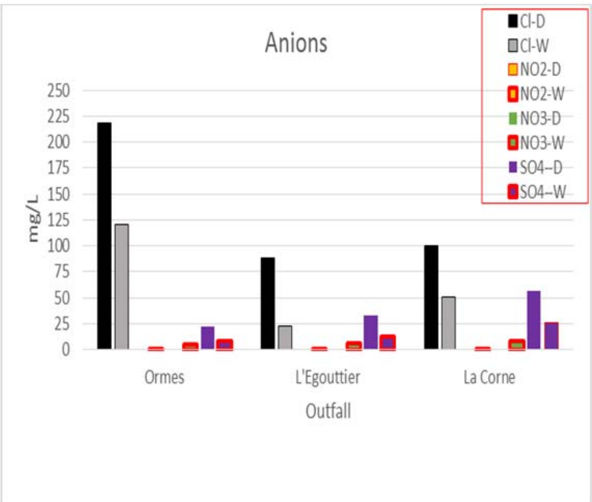

Fig. 9 Major anions concentrations for different runoff outfalls for different hydrological scenarios

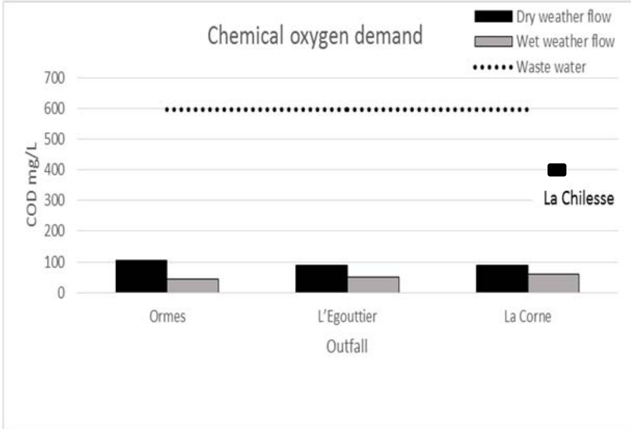

Fig. 10 Chemical Oxygen demand values in the different runoff outfall for different hydrological scenarios. Chilesse is an outfall influenced by wastewater (see BOD discussion)

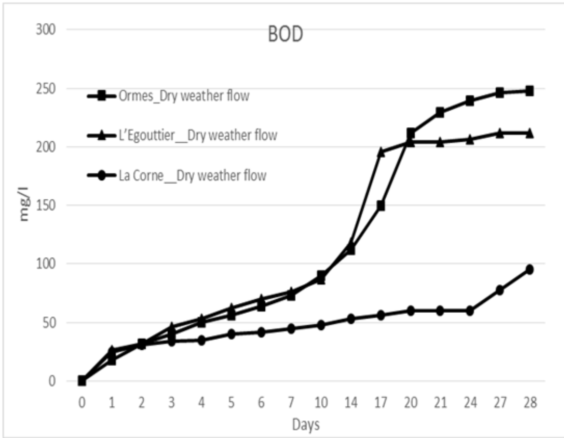

Fig. 11 BOD values in the different runoff outfalls during dry weather hydrological scenario

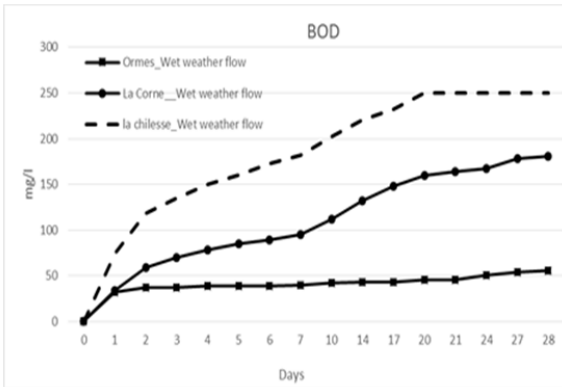

Fig. 12 BOD values in the different runoff outfalls during wet weather hydrological scenario

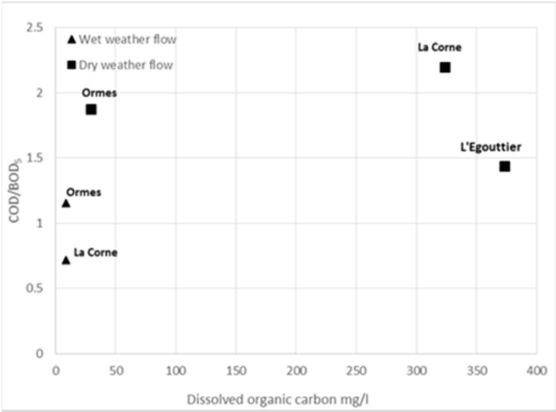

Fig. 13 Relationship between COD/BOD_5 and DOC for different runoff outfalls during different hydrological scenarios

IV. Conclusion

This preliminary study underlines the relationship between physical and chemical parameters of urban surface runoff and the hydrological conditions. It indicates that the variations of physical and chemical parameters in surface water runoff results from the combined effects of several anthropogenic and natural sources and various chemical processes.

The extent of the contamination evaluation would need to be further investigated by the analysis of newly emerging contaminants such as pharmaceutical compounds for tracing the impact of waste waters, studying the effect of different urban surfaces on the polycyclic aromatic hydrocarbons fate, sampling spillways before the water treatment plants during storm events and using integrative sampling with passive samplers (e.g. DGT, SPMD and POCIS) and developing a flow model using geochemical and mineralogical multi-tracers.

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