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Parameterizing the diffuse pollution in a continental Mediterranean city

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ABSTRACT

Urban surface runoff drags diffuse pollution from entire watersheds in most of the cities with a Mediterranean climate (high rainfall peaks plus lack of rainwater). Pollutants coming from air pollution, road traffic, waste materials, street cleaning, and the contaminants already in place in the sewer network are the main sources. Given a specific rainfall event, understanding, measuring, and predicting pollution is of vital importance when it comes to managing combined sewer overflows into the environment. An exhaustive study of urban runoff pollution for a combined sewer system (CSS) was carried out to promote integrated management of Madrid watershed based on quantity and quality of wastewater that flows along with the CSS and is discharged into the river. Results show that urban runoff pollution peaks are higher than wastewater pollution peaks.

Keywords: Combined sewer overflows; Diffuse pollution; Ecological status; Integrated system; Real-time model

1. Introduction

Madrid combined sewer system is designed based on the concept of dilution, and when the flow exceeds its capacity, combined sewer overflows (CSOs) are discharged into the low flow Manzanares River. Furthermore, climate change effects, which are expected to increase the rainfall event peaks, encourage to take more integral actions for the whole sanitation system [1]. To do this, Madrid is implementing an integrated management protocol that coordinates the entire sanitation system according to urban runoff quality and quantity.

1.1. Sanitation watershed

Madrid region counts on six million inhabitants, its sanitation infrastructure mainly consists of six wastewater treatment plants (WWTP) (Table 1), about 30 stormwater tanks (SWT) (Table 2 shows the main tanks), and more than 15,000 km of combined sewer pipes. These are discharging into two bigger pipes located along both sides of the Manzanares River, which conduct sewage towards the WWTPs. Fig. 1 shows a map of the study area. During severe wet weather periods (WWP), sewage could be discharged into the Manzanares River through several weirs.

1.2. Need for a centralized decision-making protocol

On one hand, during WWP, the WWTP from the upriver zone cannot cope with all the intake flow rate so that exceedance is discharged into a sewer by the riverside. On the other hand, there is a usual tendency to overload one riverside sewer due to the layout of the network and the individual operating protocol for each infrastructure. In order to avoid most of the uncontrolled discharges into the river, sewage exceedance might be conducted towards the downriver WWTP. Despite the fact urban sanitation network is a unique interconnected system when larger hydrographs occur, bypasses are yet not enough to avoid sewage overloads. If there were not for a network of CSO

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tanks along the Manzanares River, uncontrolled discharges into the waterbody may occur more often. Contrary to what could be expected, bypasses could also happen during dry weather periods (DWP).

Table 1
Main wastewater treatment plants in the Madrid region

Name	Design flow rate (m^3/s)	Inhabitants equivalents (millions)
Viveros	2.2	1
La China	3.3	1.5
La Gavia	2	1
Butarque	3.2	1.5
Sur	6	3

Table 2
Stormwater tanks (SWT) in Madrid region

Name	Volume capacity (m^3)
Arroyofresno	400,000
Butarque	360,000
Abroñigales	200,000
La China	130,000
Pozuelo	30,000
Valdemarín	28,000
Secondary SWT's	64,000

Currently, there is an independent operating protocol for each related infrastructure, based on the concept of dilution and quantity of water but not on water quality. There is not yet an integral management protocol for the operation of the entire watershed capable of optimizing the full sanitation system. With a centralized decision-making protocol, the operation will take advantage of the capacity of the full system, being able to control flows and giving the required importance to the water quality along with the quantity [2–4].

This study promotes an integral sanitation watershed management based on the quality and quantity characterization of sewage, so that, when an uncontrolled discharge happens, it will not be harmful to the aquatic ecosystem. Results will rely on a real-time model to support decision-makers in daily management actions, but especially regarding severe rainfall events that could cause failure or malfunctioning of the sewer system.

2. Materials and methods

2.1. Sewage characterization

The first stage of this project was based on sewage characterization campaigns to study real pollutants evolution for dry and wet weather conditions in order to obtain hydrographs and pollutographs. Sewage pollutants' parameters were selected according to the usual recommendations for wastewater quality assessment according to Butler [5] and Jiménez [6]:

- chemical oxygen demand (COD)
- biochemical oxygen demand (BOD_5)

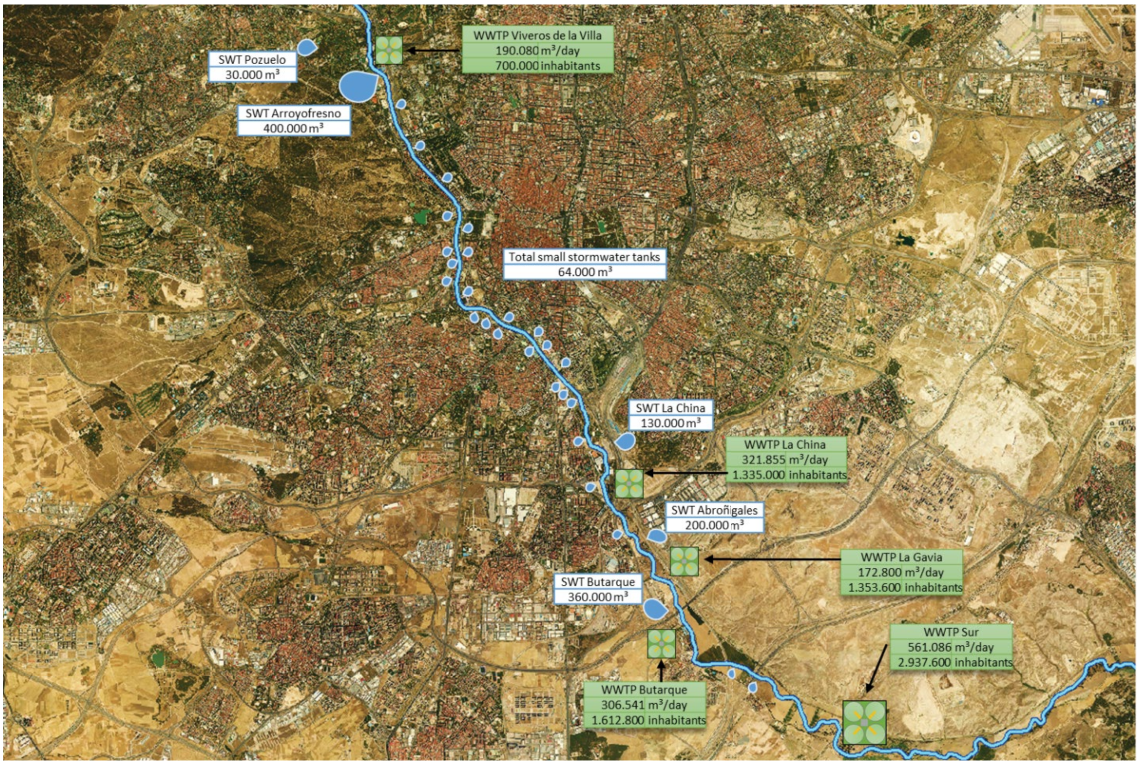


Fig. 1. Map of the Madrid watershed.

- suspended solids (SS), volatile suspended solids (VSS), total suspended solids (TSS)
- TN, NH_4^+
- TP
- conductivity
- pH
- turbidity

The study compared how sewage water quality parameters vary between dry weather flow (DWF) and wet weather flow (WWF) in the most significant control sections.

2.2. Dry weather flow characterization

DWF's characterization was carried out in sewer pipes and at the WWTPs entrances. Data-collection campaigns were performed in 24 bottles of sewage sampler for an entire day. Working and a bank holiday was characterized.

2.3. Wet weather flow characterization

Apart from characterizing the control sections mentioned above, samples at the inlet and outlet of the SWT were taken. A minimum of three campaigns was developed during WWP. The first one after a minimum of 10 d dry period. The aim was to capture the higher pollutants' concentrations that regularly happen in the sub-basin. The other two campaigns are related to two severe rainfall events after several rainy days when the street cleaning has occurred. These campaigns were designed with the aim of quantifying the change in sewage pollution between DWF and WWF.

Sewage characterization campaigns at the SWT were also analyzed after storage time. A semi-automatic system was devised to put into operation the measuring instruments once a specific volume was collected.

Hydrographs were obtained by flowmeters, water level gauges, or hydraulic equations while samples were analyzed in laboratories. The main characteristics of the sensors used to measure pollutant parameters are:

- *Water level gauges*: watertight, ±2 mm accuracy.
- *Data loggers*: IP68 waterproof, 15,000 reading capacity.
- *Samplers*: 24 bottles of sewage sampler, with peristaltic sample pump capable of 60 ml/s at 0.91 m vertical lift.

2.4. Parameterizing the diffuse pollution in Madrid catchment

Parameterizing consists of calculating several representative rainfall indicators (parameters, ratios, balances, etc) with the aim of valuing mass balances and calculating statistical variables [7–9]. The statistical variables and indexes resulting are characterizing the watershed behavior and allow an analysis of likely behavioral patterns of mobilized pollution. These patterns are basic information for designing management strategies in urban areas. Furthermore, having patterned rainfall events allows integrating results at a watershed level and a comparison between different watersheds.

For the scope of this study, it is worth mentioning that the calculated parameters were event mean concentration (EMC), event minimum and maximum concentration, mass flow, and total mass of each event, resulting from the obtained pollutographs. EMC is considered the most representative parameter thus indicates what would be the concentration if the pollution flow would have had a uniform concentration. Furthermore, if EMC is multiplied by the total volume of water, the result is the total mobilized mass. EMC is more insensitive to punctual hydrograph peaks and punctual analytical studies.

Hydrograph shape during WWP, flowrate distribution, and pollution balance during DWP enable us to discern pollutants' mass related to dry and WWP.

Currently, the system can display real-time pollutographs during DWF and WWF in the inlet, outlet of the different STW, and at significant control sections. Different rainfall events on every sub-basin have been characterized. These pollutographs are obtained in situ by permanent sensors that measure pollution parameters (pH, turbidity, and conductivity).

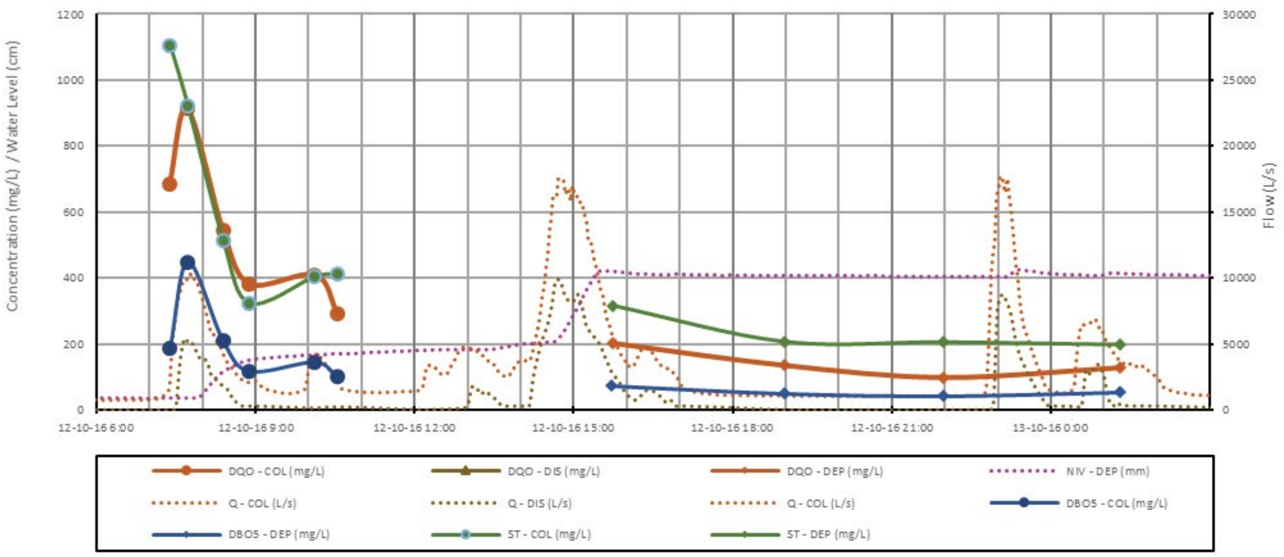


Fig. 2. Pollutograph in Madrid watershed during WWF, pollution generated in the upriver zone.

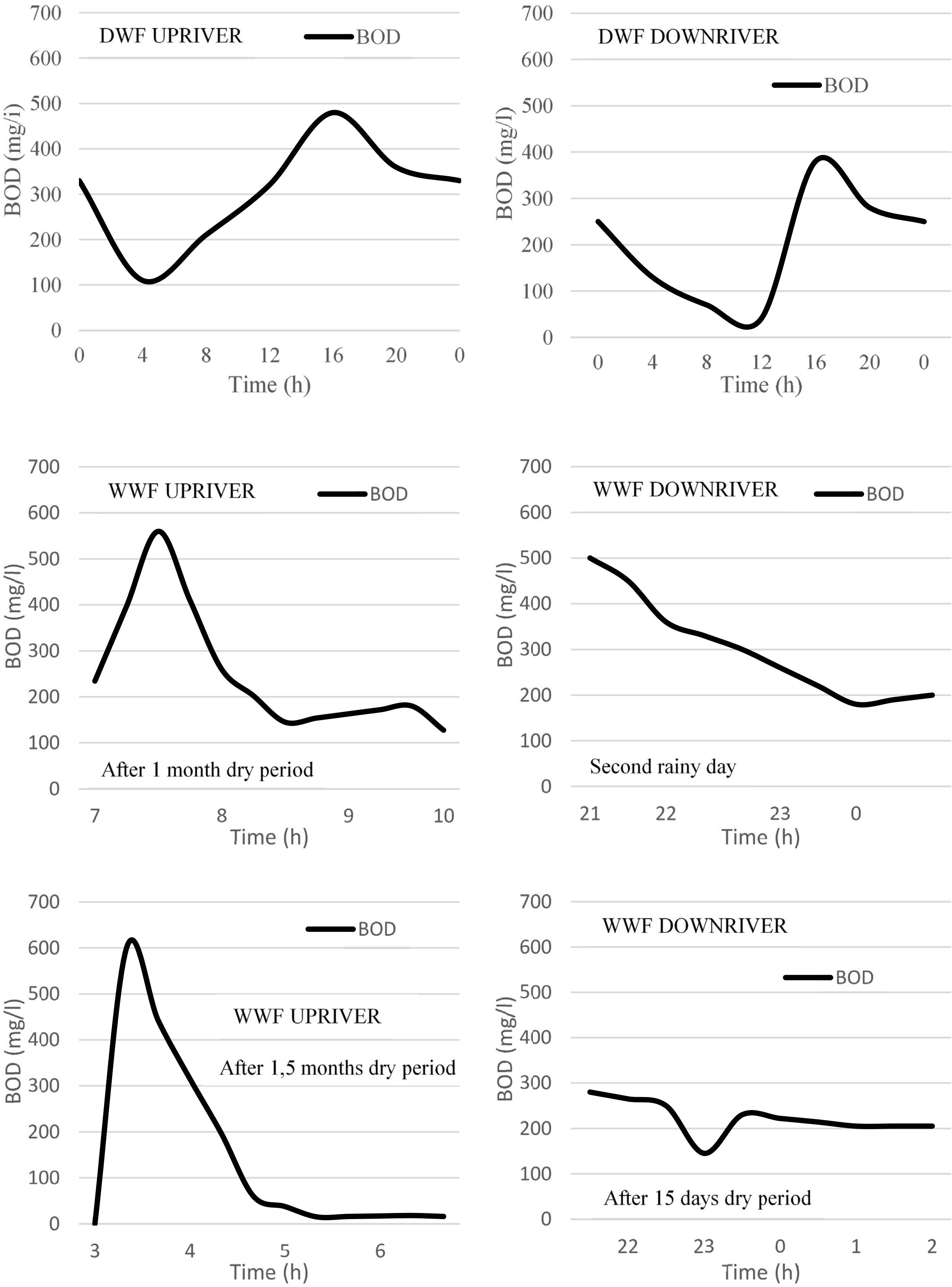


Fig. 3. Characterization of BOD during DWF in comparison with BOD during WWF in the upriver and downriver zones.

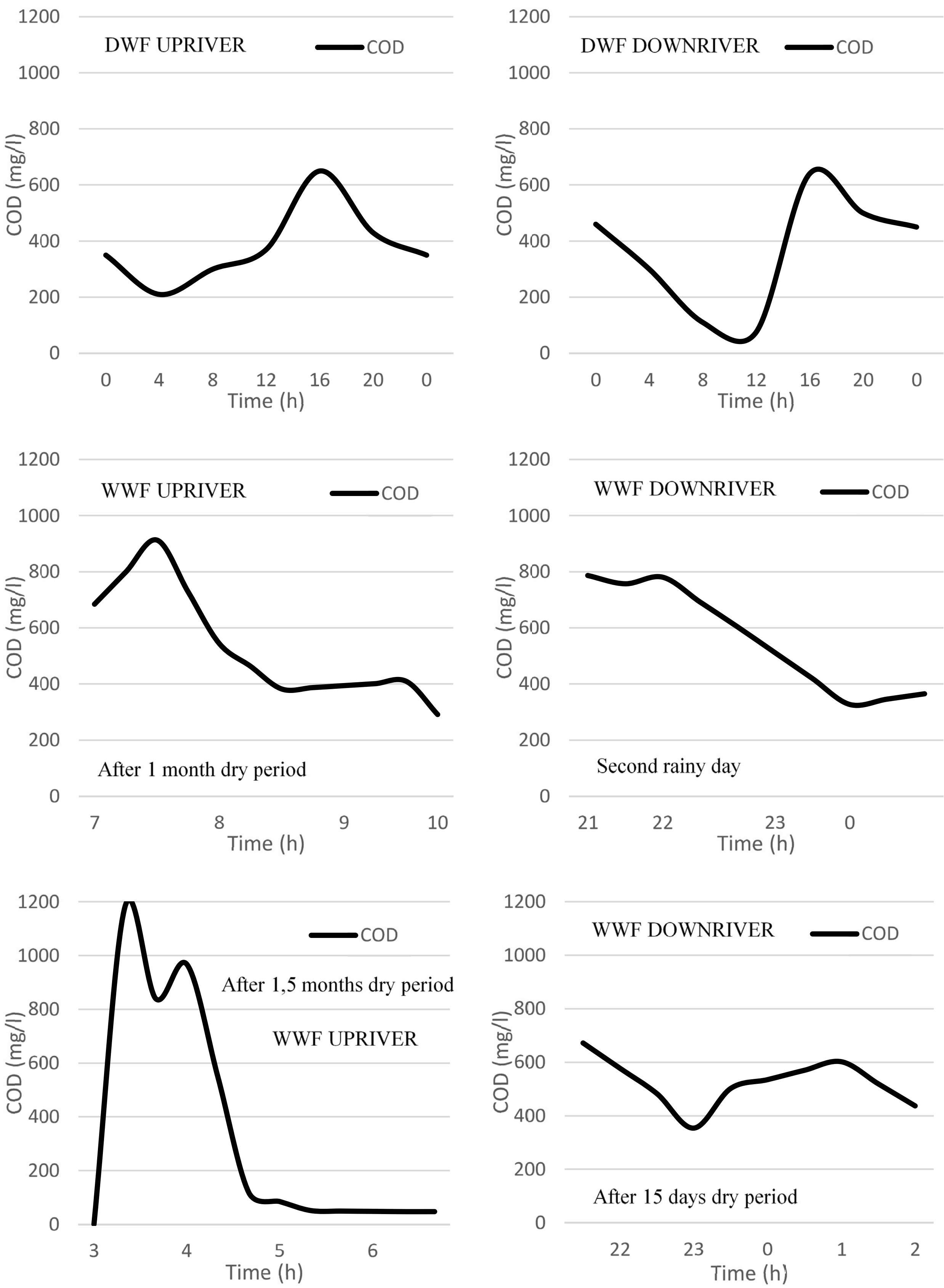


Fig. 4. Characterization of COD during DWF in comparison with COD during WWF in the upriver and downriver zones.

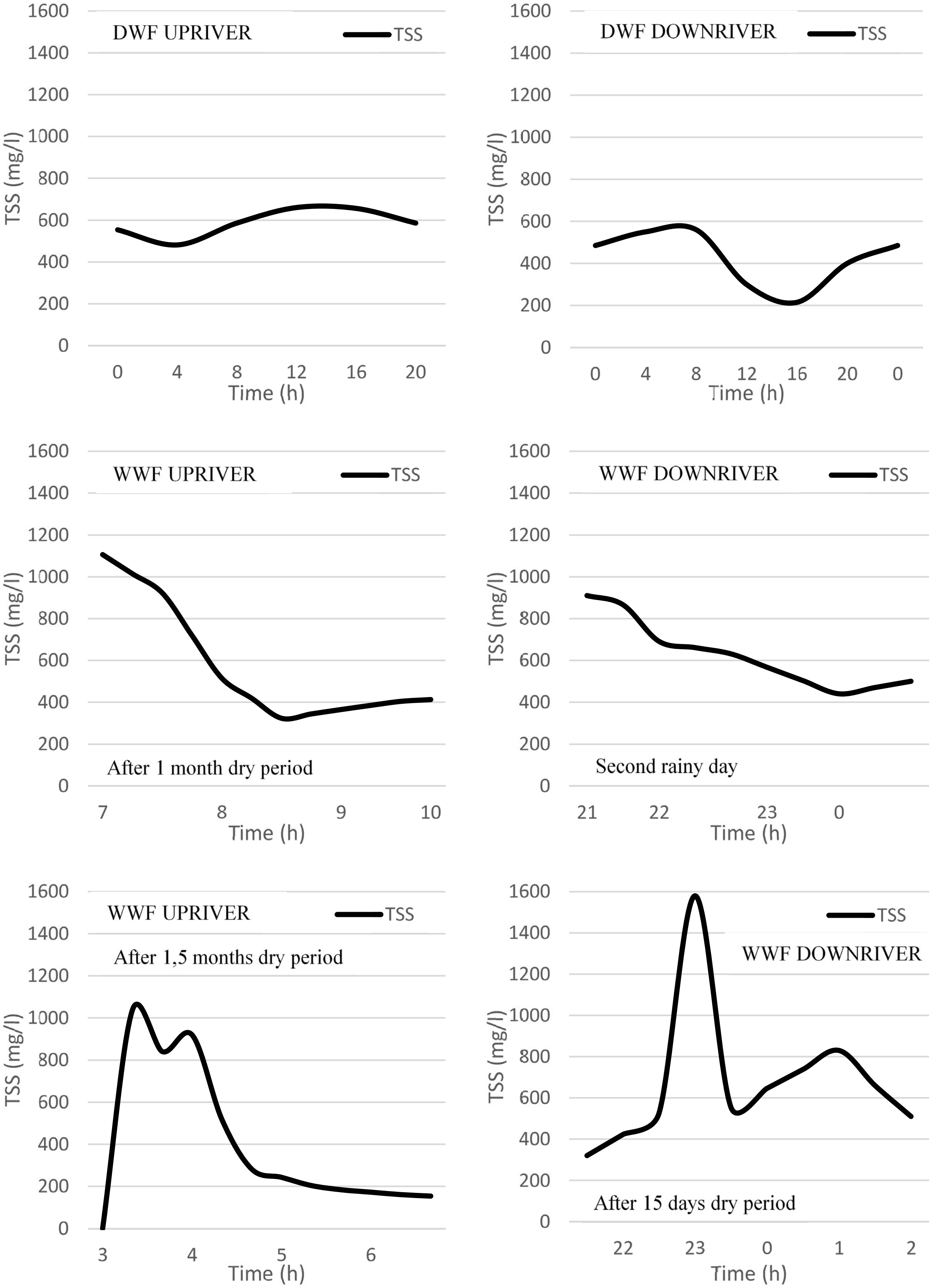


Fig. 5. Characterization of TSS during DWF in comparison with TSS during WWF in the upriver and downriver zones.

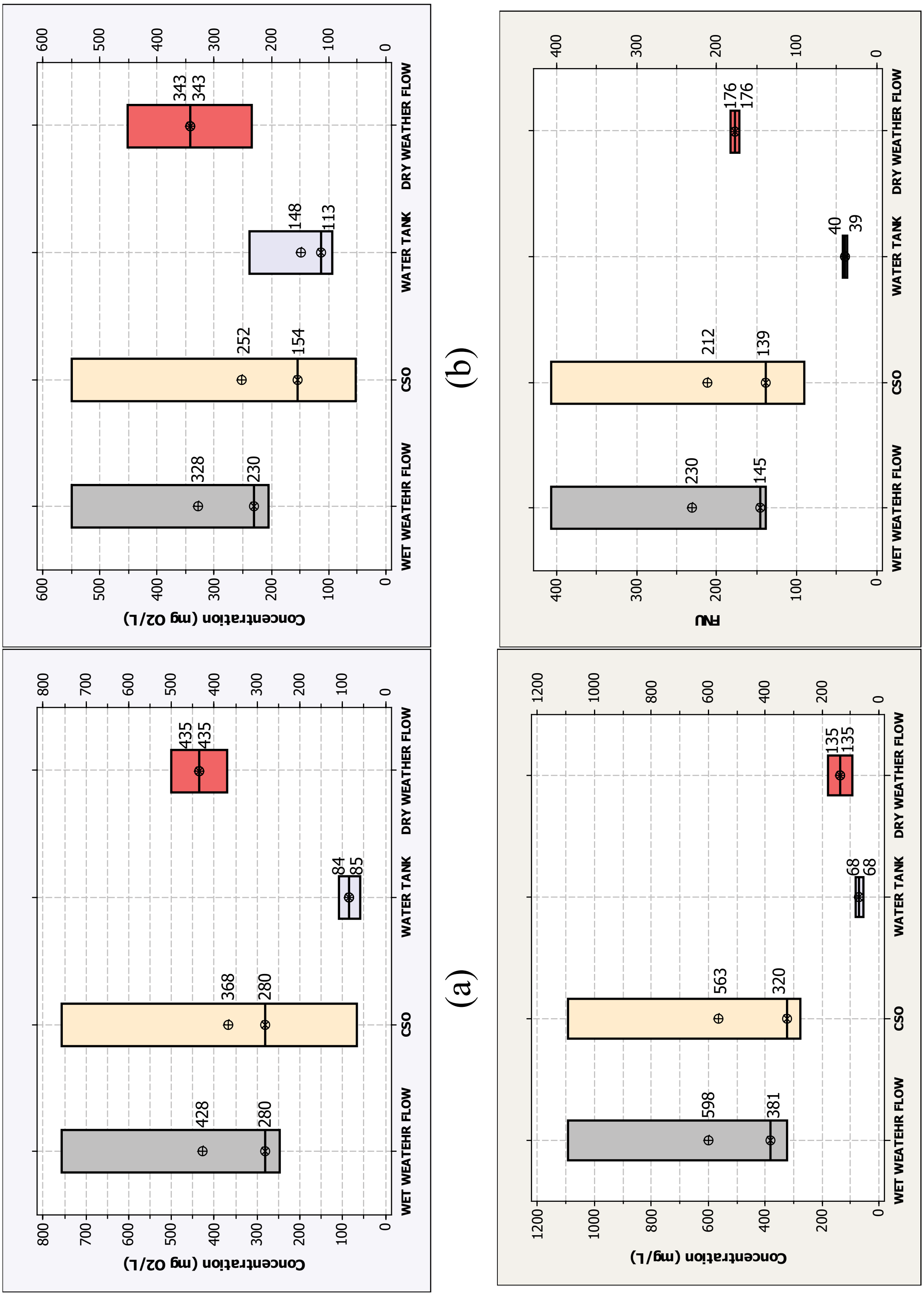
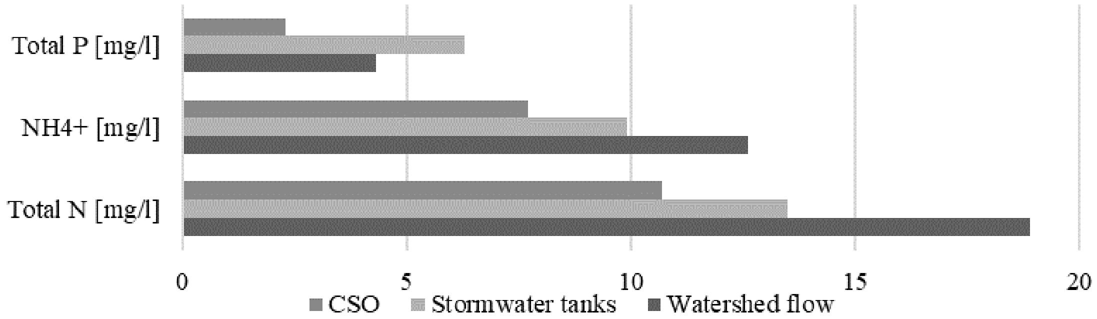
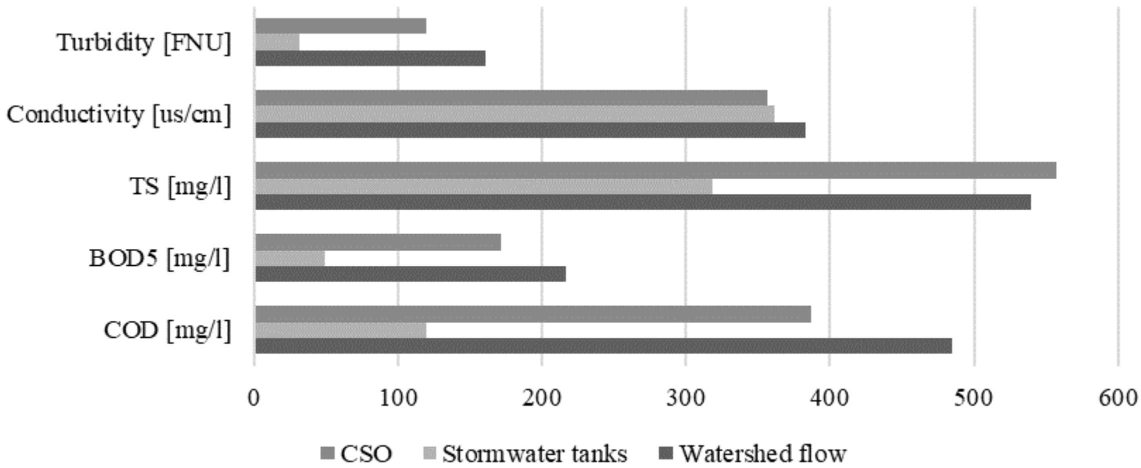


Fig. 6. EMC of (a) BOD_5, (b) COD, (c) SS, and (d) turbidity



(a)



(b)

Fig. 7. Summary of SMC parameters for the entire watershed of Madrid during wet weather period (a) total P, NH_4^+, and total N and (b) turbidity, conductivity, TSS, BOD_5, and COD.

3. Results and discussion

Sewage pollutants' parameters have been patterned for the sanitation watershed of Madrid. Analyzing the shape of the hydrograph and the distributions of flow and pollutants during the WWF and DWF, masses of pollutants associated with DWF and the registered storm events can be differentiated. In general, pollutants related to the particulate fraction are mobilized to a greater extent during the event, while dissolved ones are more present in the wastewater [10,11]. Fig. 2 shows pressures of organic matter content as well as suspended solids during a CSO.

The following figures compare the characterization campaign during DWF with WWF along the watershed from upriver to the lowest WWTP, down the river. Considering the pollutographs that characterize the DWF, important peaks can be observed during WWF (up to 610 BOD in Fig. 3, 1,200 COD in Fig. 4 and 1,050 TSS mg/L in Fig. 5). High pollutant concentration tends to increase as the DWP previous to the rainfall event grows, indicating the effects of the first flush.

The characterization of the watershed has provided a large dataset, allowing further comparative studies between the significant sections. Fig. 6 shows the EMC of BOD_5, COD, SS, and turbidity in significant control sections in the middle of the watershed.

When comparing WWF with DWF it is observed that SS, BOD_5, and COD are always higher during rainy periods. Wastewater from CSO is at least as polluted as wastewater from the system, and even higher in some cases. This means that urban runoff is dragging a higher concentration of pollutants that end up in the river instead of ending in the WWTP.

Fig. 7 compares site mean concentration (SMC) as a consequence of WWF in the sewer pipes, in the SWT (after a defined storage time) and uncontrolled sewage discharges during the overflowing. It is observed that the attenuation achieved in the tank is particularly significant for pollutants that can be decanted and, to a lesser degree, for NH_4^+.

Given an SWT in the middle of the watershed, (Fig. 8) represents the variations between dry and wet weather flow. The graph summarises the results from all the analyzed rainfall events, showing a clear increase in pollutants due to the dragging of the pollution present in the watershed. This increase is even more clear for rainfall events that occur after a long DWP.

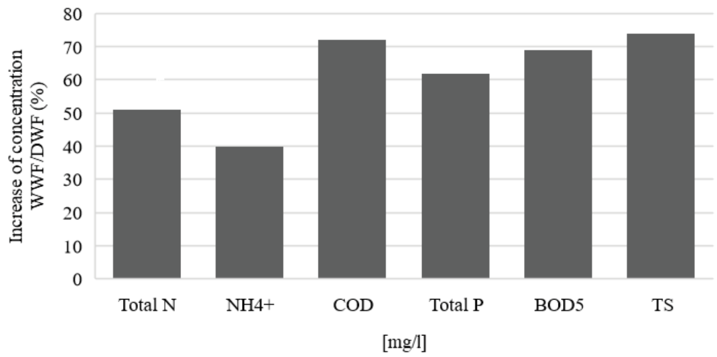


Fig. 8. Pollution increasing during WWF in comparison with DWF.

4. Conclusions and recommendations

In the study case of Madrid city (continental Mediterranean weather), urban runoff pollution peaks are higher than wastewater pollution peaks for rainfall's return period up to 5 y. Furthermore, it is demonstrated that infrastructures built with an average dilution of 1/14 do not work properly in all cases, primarily because urban runoff pollution exceeds the permitted values discharged into the river [12].

It was observed that, during DWF, pollutant concentration is, on average, similar to the scientific literature values for urban areas [5,6] while pollution's exceedance during WWF is dragged from the watershed and overall from the re-suspension caused from the flow in the sewer network.

The first flush effects in the watershed can last more than 2 h (time required for pollutants concentration to decrease under mean values during dry weather), so it should not be a crucial parameter for the management of the wastewater.

Future and more effective strategies to avoid contamination of the water bodies during a rain event must comprise a protocol to anticipate the diffuse pollution existing in the watershed for every kind of rainfall, in order to adapt water management to the pollutograph profile. Future projects will focus on the relations between parameters measured in real-time and those that require laboratory analysis. Finally, it is possible to conclude that in a Mediterranean city like Madrid, the runoff is especially polluted in terms of COD, BOD_5, and SS.

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