# Monitoring urban storm water: facing climate changes in a Mediterranean coastal city

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## Abstract

In the actual global climate change scenario, Mediterranean cities are particularly vulnerable to floods and droughts, destabilizing the urban water cycle. During the intense precipitation events, more than in normal rainfall scenarios, the resulting diffuse pollution can be a major threat to the natural ecosystems and human health. Therefore, the characterization of the urban storm water runoff is considered of the utmost importance to the region, and was the main objective of this work. With this purpose, a monitoring plan for urban storm water of Faro (Portugal) was developed. Representative sampling locations, frequency of sampling and analytical parameters were defined. A major storm of the 2014–2015 wet season was monitored. The analytical parameters were TSS, BOD, COD, pH, Conductivity, TN, TP, Ni, Cd, Pb, Total Hydrocarbons and *E. coli*. Results showed that, mainly during the first 45 min of the precipitation event, some levels of pollutants (e.g. Pb), can be high enough to cause serial disturbances in the Ria Formosa ecosystem and thus in human health.
*Keywords: urban storm water, Mediterranean coastal city, climate change, EMC, urban pollutants.*

## 1 Introduction

Ecosystems sustain societies that create economies. But although human beings are a product of the natural world, we have become the dominant force that shapes ecological and biophysical systems. Societies developed infrastructure projects,


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for instance, building large industrial and urban areas, particularly in coastal zones to have access to sea ports (ADB [1]). High concentration of people, infrastructures and economic activity mean that urban centres are highly exposed to natural hazards and climate change risks (WWF [2]). Sustainable urban water management is a great challenge to coastal cities, in the current scenario. This study was performed in Faro (Figure 1), which is a Mediterranean coastal city located at south of Portugal in Algarve region, near Ria Formosa.


Figure 1: Location of Faro.

This coastal lagoon is a Natural Park with a relevant socio-economic role, associated to several activities, such as recreation, fisheries, salt extraction, and aquaculture, namely shellfish production. The city has a population of 44,119, and the land use is mainly urban (INE [3]). The urban perimeter catchment has 4.7 $km^2$, with an impervious surface of 96%. The mean annual precipitation is 509.1 mm with a monthly variation between 1.9 mm (in July) and 115.6 mm (in December). The wet period is between October and April. The Köppen climate classification is Csa – a Mediterranean climate with rain being mostly regulated by frontal systems (Miranda [4]). The hydrological response of the basin is dominated by long dry periods followed by the wet season, in which rain events are usually short and intense. As presented in Figure 2, there are seven sub-catchments linked to seven discharge points within the urban perimeter catchment.

There are no previous studies concerning urban storm water in Faro, therefore a methodology for all the different phases was developed following a multi-discipline effort.

# 2 Methodology

## 2.1 Precipitation monitoring and meteorological forecast

The precipitation was monitored by one rain gauge located at no longer than 5000 m from the farthest point of the catchment and it is characterised by a 0.1 mm tipping bucket and a temporal resolution of 1 minute. Meteorological

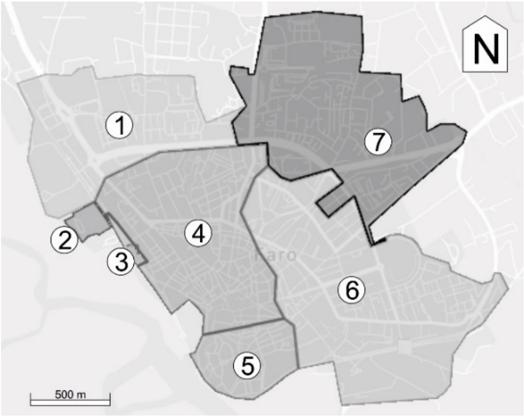


Figure 2: Urban perimeter SC (from 1 to 7).

forecast was made using the Global Forecast System – GFS numerical model with a resolution of 50 km (Kanamitsu *et al.* [5]), and the Weather Research and Forecast – WRF numerical model with a resolution of 9 km (Michalakes *et al.* [6]). It is not the intent of this study to detail these numerical models.

### 2.2 Site selection

The site selection was done using three criteria: accessibility, representativeness, and safety. Accessibility to the discharge points is a compulsory condition at all times, and is not possible at SC 2 because it's located on private property. Sub-catchments 1, 3, 4, 6 and 7 can be accessed by paved roads. Sub-catchment 5 can only be accessed by water. Faro is considered a city with homogeneous land use, so representativeness was measured considering the relative area of the SC to the total area of the urban catchment. The relative areas were measured: SC 1 (17.0%); SC 2 (0.9%); SC 3 (0.5%); SC 4 (20.0%); SC 5 (5.6%); SC 6 (30.7%); and SC 7 (25.3%). Concerning safety, and given the sloped access, SC 1, SC 2 and SC 7 have low risk of accident, SC 3, SC 4 and SC 6 have medium risk, and SC 5 has high risk, in this case depending on tides. The main sampling SC was chosen using the criteria mentioned above, in a three step exclusion scheme. The first exclusion step was the accessibility to sampling site, with SC 2 and SC 5 being excluded. On the second step, the combination of representativeness and safety was evaluated, and showed that SC 1, SC 3 and SC 4 should be excluded. On the third step all mentioned criteria were used. The two remaining sub-catchments, SC 6 and SC 7 have good accessibility and similar representativeness, but SC 7 has safer conditions, and was therefore chosen as the main sampling SC.

### 2.3 Sampling

A major storm of the 2014–2015 wet season was monitored on the 15 of January, 2015. Samples were collected every 15 min during the first hour after the rainfall event start, and then every 30 min until the end of the event.

### 2.4 Parameters

The selected parameters were Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), pH, Conductivity, Nickel (Ni), Cadmium (Cd), Lead (Pb), Total Hydrocarbons (TH) and *Escherichia coli* (*E. coli*) All analysis were performed by the Sanitary Engineering Laboratory of the University of the Algarve, accredited for water analysis (national code L0306), and analytical methods are presented in Table 1.

Table 1: Analytical methodology.

| Parameter | Unit | Method | Reference |
|---|---|---|---|
| **TN SMEWW** | mg/L N | Persulfate digestion and Ultraviolet Spectrophotometric Screening Method | Eaton *et al.* [7] |
| **Cd** | mg/L Cd | Flame Atomic Absorption: Air-Acetylene Flame method | Eaton *et al.* [7] |
| **$BOD_5$, 20°C** | mg/L $O_2$ | Respirometric method | Eaton *et al.* [7] |
| **COD** | mg/L $O_2$ | Colorimetric method | Eaton *et al.* [7] |
| **Pb** | mg/L Pb | Flame Atomic Absorption: Air-Acetylene Flame method | Eaton *et al.* [7] |
| **Conductivity at 20°C in situ** | µS/cm | Electrometric method | Eaton *et al.* [7] |
| ***Escherichia coli*** | N/100 mL | Membrane filtration | ISO [8] |
| **TP** | mg/L P | Flame Molecular Absorption: Ascorbic Acid Method | Eaton *et al.* [7] |
| **Ni** | mg/L Ni | Flame Atomic Absorption: Air-Acetylene Flame method | Eaton *et al.* [7] |
| **pH *in situ*** | Sorenson scale | Electrometric method | Eaton *et al.* [7] |
| **TSS** | mg/L | Gravimetric method | Eaton *et al.* [7] |
| **TH** | mg/L | Gas Chromatography: Flame Ionization Detector | -- |

### 2.5 Calculations

Event Mean Concentration (EMC), determines pollutant loads from a site and is representative of average pollutant concentrations over an entire runoff event (Heart *et al.* [9]). The EMC is an important factor in predicting the total pollutant load, and therefore a critical parameter for estimating the contribution of runoff to the ecosystem (Maniquiz *et al.* [10]). EMC was determined using eqn. (1):

$$EMC = \frac{M}{R} \tag{1}$$

where:
*EMC* = event mean concentration (mg/L);
*M* = total discharged mass of pollutant (mg);
*R* = total runoff volume (L).

Total discharged mass of pollutant (Load) was determined using a runoff-weighted trapezoidal rule for numerical integration with a non-uniform grid (Atkinson [11]), as shown in eqn. (2):

$$\int_{Ri}^{Rf} f(R).dR \approx \frac{1}{2}\sum_{k=1}^{N} |(R_{k+1} - R_k)\big(f(R_{k+1}) + f(R_k)\big)| = \frac{1}{2}\sum_{k=1}^{N} |(R_{k+1} - R_k)(C_{k+1} + C_k)| \tag{2}$$

where:
*Ri* = initial runoff (L);
*Rf* = final runoff (L);
*R* = accumulated runoff (L);
*N* = number of samples;
*k* = sample number;
*C* = pollutant concentration (units according to pollutant).

Runoff volume was determined using an adaptation of the Simple Method (McCarthy [12], Schueler [13]) with eqn. (3):

$$R = P * Rv \tag{3}$$

where:
*R* = runoff (L);
*P* = precipitation (L);
*Rv* = runoff coefficient.

Runoff coefficient was determined with eqn. (4):

$$Rv = 0{,}05 + 0{,}9Ia \tag{4}$$

where:
*Rv* = runoff coefficient;
*Ia* = percent impervious area draining to the sub-catchment in decimal form.

# 3 Results and discussion

## 3.1 Characterization of the event

The rainfall event lasted for 174 min, having its maximum intensity peak of 20.4 mm/h at 115 min, and total accumulated rainfall of 12.7 mm (Figure 3).

## 3.2 Evolution of pollutants during the event

In general, there was a clear peak in pollutant concentrations in the first 31 min (16 min after runoff start) for all parameters except *E. coli*, which had the maximum peak later. These results indicate a typical first flush effect. The concentration of pollutants at the beginning of the event is substantially higher than during later periods (Lee *et al.* [14]). Runoff began 15 min after the rainfall

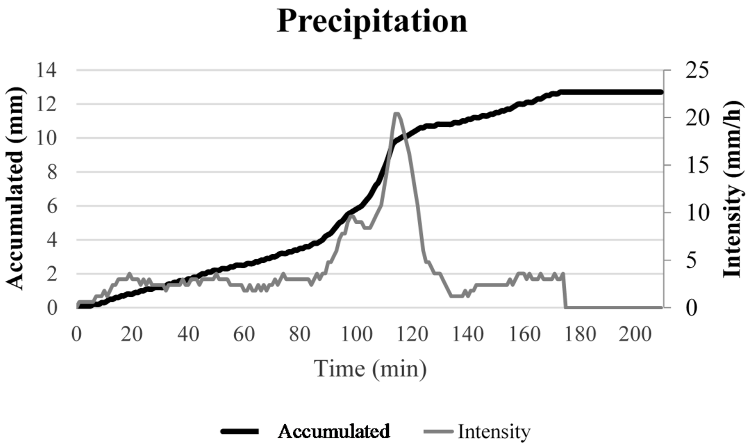


Figure 3: Hydrograph.

start. The results of the TSS, BOD and COD analysis are shown in Figure 4. According to previous studies in other urban areas (e.g. Lee *et al.* [15]), similar temporal evolutions of the TSS, BOD and COD were observed. Maximum concentration of TSS was 2507 mg/L at 31 min and minimum 50 mg/L at 209 min. Concentrations of BOD and COD were maximum at 31 min with 500 mg/L. Minimum values were obtained at 209 min, 22 mg/L for BOD and 40 mg/L for COD. Total suspended solids can be related to multiple sources, such as, pavement wear, construction sites, waste and atmospheric deposition, among others (Lee *et al.* [15], Barbosa *et al.* [16]), and can therefore be associated to BOD and COD values in different ways, according to the respective origins. Organic matter present in storm water is mainly of vegetal origin, but animal waste or dead organisms can also contribute to the BOD and COD values (Lee *et al.* [15], Barbosa *et al.* [16]).

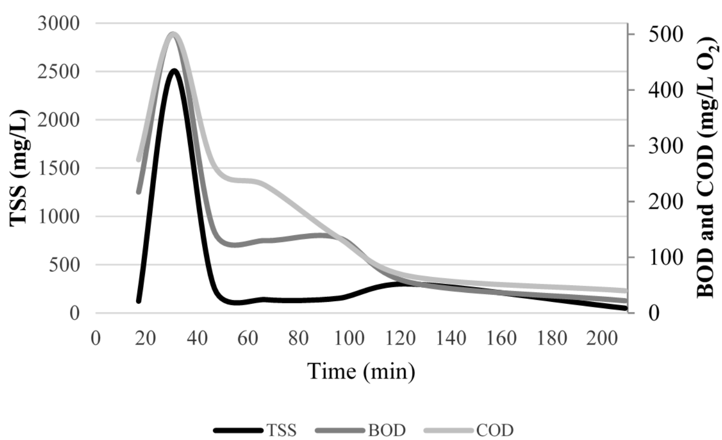


Figure 4: Evolution of TSS, BOD and COD.

As previously demonstrated, e.g. in the French Mediterranean Coast (Obermann *et al.* [17]), TN and TP had similar behaviours during the event (Figure 5). Maximum concentrations of TN and TP occurred at 31 min, 72 mg/L and 19.2 mg/L respectively, and minimum at 209 min, 3 mg/L and 0.8 mg/L, respectively. In the case of TN at 124 min, another minimum value of 3 mg/L was observed.

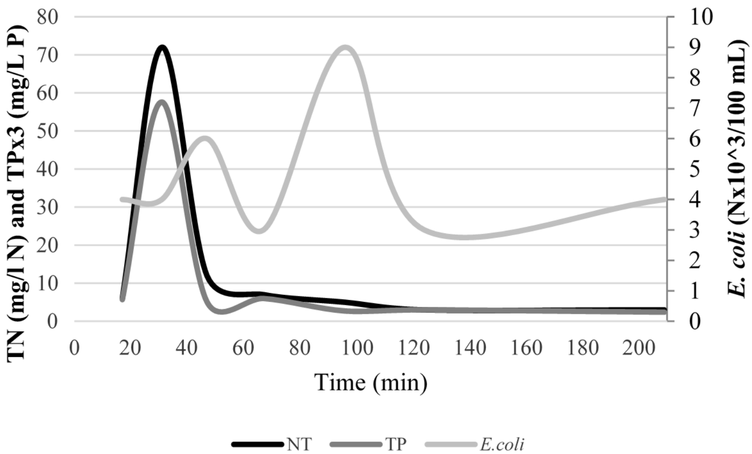


Figure 5: Evolution of TN, TP and *E. coli*.

The most important sources of N and P in urban areas, are atmospheric deposition and fertilizers used in the treatment of urban green areas (Lee *et al.* [15], Barbosa *et al.* [16]). In terms of microbiological results, the first peak of *E. coli* occurred at 47 min, which can be related to the first flush effect, followed by a decreasing to 3 x 103 N/100 mL at 67 min. At 96 min, during a peak of rainfall intensity, a second maximum of *E. coli* (9 x 103 N/100 mL) occurred, perhaps due to a non-authorized wastewater discharge to the storm water system. Wastewater cross connections, leakages and overflows are common origins of *E. coli*, when precipitation intensity peaks exist (McCarthy *et al.* [18]). According to previous studies (House *et al.* [19], D'Arcy *et al.* [20], Moy *et al.* [21], Ellis and Mitchell [22]), *E. coli* in the UK ranges between 400 and 50,000 MPN/100 mL, associated with specific urban land use types and surfaces. The temporal evolution pattern of Conductivity was according to the first flush effect, with a maximum of 430 µS/cm at 31 min, and a minimum of 66 µS/cm at 124 min (Figure 6). Cadmium, Ni and Pb had similar variations during the event, with some particular differences, namely to Pb. The maximum of Pb concentration was 93.42 µg/L at the beginning of the event, followed by a decreasing. A second peak of Pb occurred at 124 min. The minimum concentration of Pb was 7.77 µg/L and was observed at the end of runoff. The first flush effect was clearly noticed also on Ni and Cd concentrations. Maximums were at 31 min, with 21.56 µg/L Ni and 2.32 µg/L Cd. The minimum concentrations occurred from 96 min to Ni (4.96 µg/L) and from 124 min to Cd (0.56 µg/L). In general, Cd, Ni and Pb have the same sources: tire wear, lubricating oils, fuel, and diverse metallic structures such as road signs, roofs or covers

(Barbosa *et al.* [16], Gikas and Tsihrintzis [23]). In this study, according to official data, the main anthropic pressures associated to the presence of heavy metals, are traffic and urbanization.

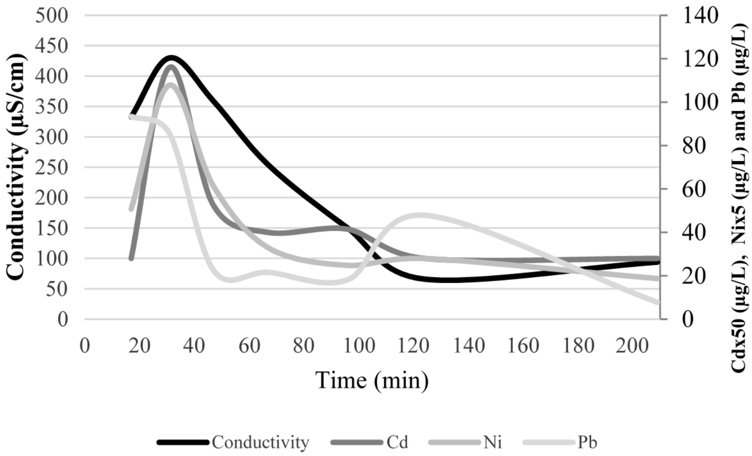


Figure 6: Evolution of Conductivity, Ni, Cd and Pb.

Total Hydrocarbons (C10–C40) were lower than 0.1 mg/L (Limit of Quantification) during all event. Main sources of TH in urban basins are fossil fuel combustion, road and pavement wear, tire wear, and plastic materials from construction, or other temporary structures (Lee *et al.* [15], Barbosa *et al.* [16]). During this event, pH ranged between 7.1 and 8.0, which are common values to surface waters (Smith [24]). Event Mean Concentrations and loads were calculated and are presented in Table 2.

Table 2: Pollutant concentrations and loadings.

| | Sub-catchment 7 | | | Urban perimeter catchment |
|---|---|---|---|---|
| **Parameter** | **EMC (mg/L)** | **Load (kg)** | **Load per unit area ($kg/km^2$)** | **Load (kg)** |
| **TSS** | 316 | 4661 | 3950 | 18565 |
| **TN** | 9 | 126 | 107 | 502 |
| **TP** | 2.1 | 32 | 27.12 | 127 |
| **Ni** | 6.73 x 10^-3 | 0.099 | 0.084 | 0.394 |
| **Cd** | 0.79 x 10^-3 | 0.012 | 0.010 | 0.048 |
| **Pb** | 33.46 x 10^-3 | 0.493 | 0.418 | 2 |
| **TH** | <0.1 | -- | -- | -- |
| ***E. coli*** | 4x10^3 | -- | -- | -- |

### 3.3 Pollutant concentrations and loadings

The EMC's for different parameters monitored during this event, were compared with EMC's from previous studies (McCarthy *et al.* [18], Ellis and Mitchell [22], Brezonik and Stadelmann [25] and Mitchell [26]), despite the different climate classification of the studied cities. Total Suspended Solids, TN and TP had higher EMC's than the UK (Ellis and Mitchell [22]) and the Twin Cities, USA (Brezonik and Stadelmann [25]). Nickel, Cd and Pb presented lower EMC's than those quantified by Mitchell [26], and in case of Pb also by Ellis and Mitchell [22]. The *E. coli* EMC is lower than that described by Ellis and Mitchell [22] and McCarthy *et al.* [18]. The EMC values obtained can be overestimated or underestimated (eqn. (1)), which might lead to considerable variations depending on the event monitored. These variations are reported in several studies (Maniquiz *et al.* [10], Lee *et al.* [15], McCarthy *et al.* [18], Bi *et al.* [27], Maniquiz *et al.* [28] and Ellis and Chatfield [29]).

In an environmental perspective, loads per unit area were calculated for SC 7, and then estimated to the entire urban catchment to access the quantity of pollutants discharged to Ria Formosa. During this event, it was shown that, even parameters with low EMC's can represent risk to natural ecosystems and human health (e.g. Pb).

## 4 Conclusions

Results showed that, mainly during the first 45 min of the precipitation event, some levels of pollutants (e.g. Pb), can be high enough to cause serial disturbances in environment and human health. The risk can be higher in a scenario of climate changes, in which coastal Mediterranean cities like Faro are particularly vulnerable to extreme precipitation phenomena, occurring even more frequently. In the case of Faro, all pollutants are discharged directly to Ria Formosa, which is a Natural Park, considered of main importance to habitats and biodiversity, but also to local economy. An integrated urban water management plan should be developed, with tools and measures, supported by scientific studies to monitor storms. Mediterranean coastal cities should implement technological solutions like first flush treatment to reduce the pollution loads from storm runoff, and to achieve sustainable development.

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