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Impacts of Combined Sewer Overflows on surface water bodies. The case study of the Ebro River in Zaragoza city

Lucía Soriano [a, *], José Rubió [b]

[a] Chemical and Environmental Engineering Dpt, University of Zaragoza, Spain
[b] Department of Civil Engineering: Hydraulic, Energy and Environment, Universidad Politécnica de Madrid, Spain

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ABSTRACT

Combined Sewer Overflows (CSOs) are the most important source of diffuse contamination in urban environments. Cleaner production in cities necessarily involves the reduction of both frequency and contamination linked to overflows in rain events as well as the control and minimization of its impacts in aquatic ecosystems. That would additionally lead to an increase in waste water treatment plant energy efficiency. However, there is an extended belief among sanitation managers at municipal level that impacts of CSOs in large rivers are not perceptible due to dilution effect. To dismantle this myth, the present article analyses the impacts of CSOs in the Spanish widest river, the Ebro River. The results suggest that the Ebro tends to worsen in dry season during intense rainfall, inviting to perform proper interventions to reduce CSOs along its urban stretch.

1. Introduction

World is becoming increasingly urbanized (UN – DESA, 2015). In a context of climate change (IPCC, 2015) the vulnerability of cities will increase (Mi et al., 2019; Urban Climate Change Research Network, 2011) worsening the current drainage problems (Semadeni-Davies et al., 2008). Therefore, coping with sustainable development requires sustainable cities (World Bank, 2010) what leads to the urgent need of promoting cleaner production in urban environments. In terms of drainage systems this involves preventing the production of wastewater and minimizing its impacts in aquatic ecosystems while increasing the efficiency of sanitation system (Abebe et al., 2018; Rodríguez-Sinobas et al., 2018).

Based on an intensive waterproofing, the current urban development model deeply modifies the natural water cycle in cities (UN–DESA, 2015; Amores et al., 2013). The decrease of soil infiltration capacity turns most of the rainwater into surface runoff (Wang et al., 2018), rapidly leading to heavy peak flows which are highly contaminated due to the flushing of urban surface (Zang et al., 2018; SWITCH Project, 2011; House et al., 1993; Aalderink et al., 1990).

Several studies carried out in the last 25 years underline that the limited control of Combined Sewer Overflows (CSOs) is the main reason for the persistence of low quality in surface waters in urban environments (Lau et al., 2002). In early nineties first researches focused on characterization of the pollution discharged by combined sewer networks (Cherrered and Chocad, 1990; Lee and Jones-Lee, 1993; Field and Pitt, 1990; Desbordes and Hemain, 1990). Recent case studies managed to detail the composition of CSO's organic micro pollutants (Launay et al., 2016) and microbial parameters (Lucas et al., 2014), complementing large existing data on the distribution and concentration of the surface-dependent runoff water (Göbel et al., 2007; Davis et al., 2001).

Additionally, it has been developed several integrated sewer-river-models to represent how CSOs threaten ecological quality of urban rivers (Riechel et al., 2016; Peng et al., 2016; Even et al., 2007) as well as diverse methodologies that compares the impacts of CSOs between combined and separative sewer systems (Thorndahl et al., 2015).

On the other hand, variation of both quantity and quality of wastewater in rainfall not only causes impacts in receiving waters but also worsen the performance of Waste Water Treatment Plants (WWTP) (Li et al., 2017; Jin et al., 2016; Stricker et al., 2003), specifically the ones based on biological processes (Zang et al., 2015; Wilen et al., 2006). Therefore there have been developed WWTP management plans to consider inflow rate variation, both in quality and quantity, due to rainfall (Ma et al., 2014; Mines et al., 2006).

The impacts of CSOs in aquatic ecosystems are complex (Suárez,

* Corresponding author. EPS Carretera de Cuarte, s/n, 22197, Huesca, Spain.
E-mail address: lsoriano@unizar.es (L. Soriano).

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1994). According to the results of several case studies (Wang, 2014; Andrés-Domenech. et al., 2010; Even et al., 2007; Sztruhar et al., 2002; House et al., 1993), most frequent qualitative impacts are the reduction of dissolved oxygen - with a higher impact in small rivers-, the increase of toxics and sediments and the presence of pathogens. On the other hand, contamination phenomena are related to space and time. The decrease of dissolved oxygen is a measure of the acute, deferred and accumulative impacts. Finally, toxic substances like NH_3 are present in acute and deferred impacts (Lijklema et al., 1989).

However, there is a common belief among managers that high flow rivers, such as the Ebro, do not suffer the impacts of CSOs due to their capacity to dilute contamination. Confronting this myth, the objective of the present article is to analyze the impacts of CSOs in the Ebro at Zaragoza city, in order to promote the necessary interventions to enhance the performance of the sanitation system.

2. Brief characterization of Ebro river

At a height of 217 m above sea level in the centre of the Ebro depression, the city of Zaragoza is located in the north-eastern quadrant of the Iberian Peninsula, encircled by four of the most important cities in Spain: Madrid, Bilbao, Barcelona and Valencia, all of them almost equidistant to Zaragoza, at 300–320 km.

As shown in Fig. 1, the city has a powerful natural drainage network, formed by the Ebro and two of its tributaries, the Huerva on the right bank and the Gállego on the left bank. The city is located over the Ebro alluvial aquifer, except for a part of the rural neighborhoods located on the Gállego aquifer.

The natural drainage network is complemented by an artificial one. On one hand, there is a complex network of irrigation canals, notedly the Aragon Imperial Canal, running parallel to the Ebro along the city. On the other hand, the city's sanitation system relies on two Waste Water Treatment Plants: La Almozara, located upstream of the city and covering approximately one third of the total city area, and La Cartuja, downstream of the city, covering two thirds of the urban area.

The adoption of the Water Framework Directive 2000/60/EC (WFD), which main objective is the achievement of good status of all water bodies, marked a turning point for the Member States of the European Union. River basin Authorities have made a major effort to implement control networks for characterization of the status of all water bodies. This characterization, based on standardized and calibrated indicators at European level, serves as a baseline for the definition of a program of measures that allows the achievement of the main objective, as well as for the follow-up and monitoring of the efficiency and effectiveness of the proposed measures.

The status of a body of water is defined as the degree of disorder that presents with respect to its natural conditions and is determined by the poorer of its ecological and chemical status. The chemical status is an expression of the degree of compliance with environmental quality standards, established regulations for contaminants in a surface water body. The ecological status is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface water and evaluated by a series of biological indicators (benthic invertebrate fauna, flora and phytoplankton), physicochemical and hydromorphological natural conditions in the absence of pressures (reference conditions).

Converging with the water framework directive 2000/60/EC following table lists surface water bodies in the urban basin of Zaragoza, the risks of unfulfillment of the WFD objectives and its status.

The Ebro is the largest stream in Iberian Peninsula. Keeping it in good condition would bring several economic, social and cultural benefits. But, as shown in Table 1, the final status of the Ebro in its urban stretch is moderate and with a medium to high risk of failing to fulfill the objectives of the Water Framework Directive (Cherrered and Chocad, 1990).

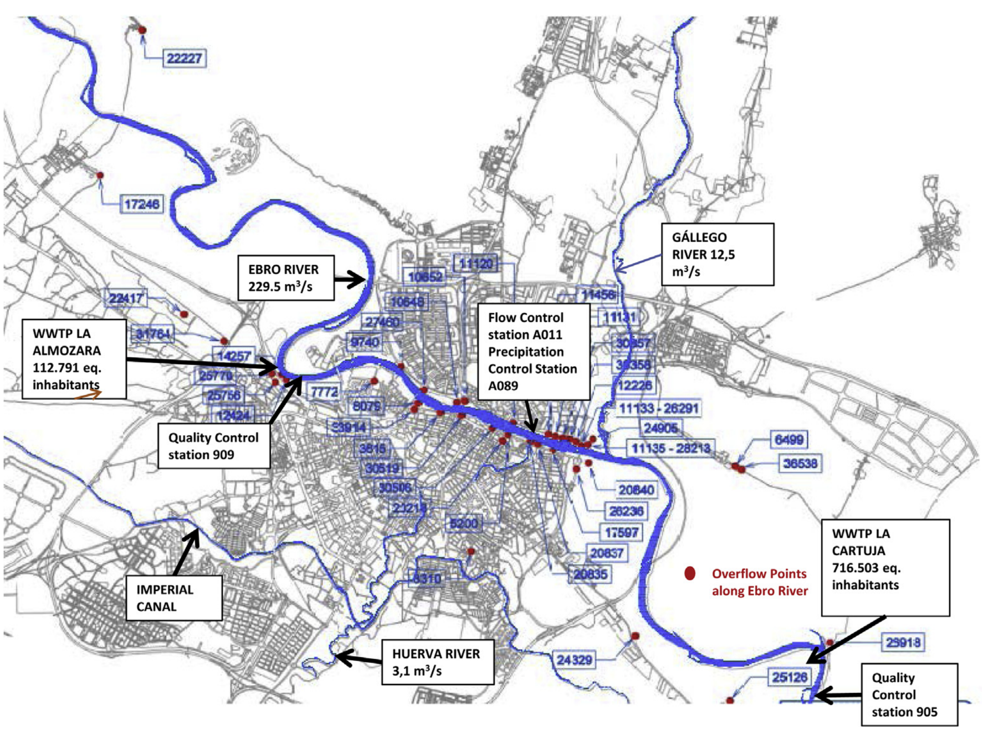

Fig. 1. Natural and artificial drainage networks of Zaragoza.

Table 1
Water bodies in urban basin of Zaragoza.

Water Body Code	Risk of Unfulfilment of WFD	Ecologycal Status			Final Status
		Biological	Physical-chemical	Hydromorphologycal	
452	Medium	Moderate	Moderate	Good	Moderate
453	High	Moderate	Moderate	Good	Moderate

3. Brief characterization of Zaragoza sanitation system

86.5% of Zaragoza's sanitation system is unitary, so discharges in rainfall are a mix of wastewater and highly contaminated runoff. 75% of the sewer network has a slope under 5 m/Km, facilitating the sedimentation process. Therefore, wash up of sediments during rainfall raises contamination rates in overflows. In addition, the sanitation system has a low hydraulic capacity: 55% of the main collectors are under 180 cm width and there are only three stormwater tanks, with a total capacity of 32,200 m^3, insufficient to face intense rains (Entralgo, 2011).

During rainfall and because of the limited hydraulic capacity of the system, peak flows are discharged to Ebro, Gállego and Huerva rivers through 142 overflow points along the sanitation system. 20 of them are located in the right bank of Ebro River and 15 in left bank, making a total of 35 overflow points located along the Ebro. Considering that many of them counts with two to four discharge points there are a total of 72 overflow points. Fig. 1 shows CSOs along the Ebro River.

70% of the CSOs along the Ebro lack any mechanism to retain suspended solids or to prevent highly contaminated first flush flows. These facts allow anticipating a high frequency of highly contaminated flows discharge.

4. Methods

The initial hypothesis is that there is a positive relation between precipitation and a worsening of the quality indicators upstream and downstream of the city. The selected indicators are the concentration of ammonium and of dissolved oxygen.

Concentration of dissolved oxygen (DO) is a parameter that detects acute, differed and cumulative impacts in river water bodies. Oxygen is one of the essential elements for aquatic ecosystems and its decrease below certain values deeply modifies them. Nevertheless, DO is a global parameter resulting from complex interrelations of ecological, chemical and physical processes that take place in water bodies, hindering the restoration of such interactions.

In regards to ammonium concentration, its acute toxicity causes hyper excitability and even death to fishes. Its toxicity is determined by parameters as DO, temperature, pH, salinity or presence of other toxic substances (Passera et al., 2011).

Spanish water quality legal frame do not incorporate Intermittent Emission Standards, which are the most suitable thresholds for CSO impacts measuring. Therefore reference values used in this article are continuous thresholds established by Water Framework Directive for “Very Good status”, “Good status” and “moderate status” for each water body, shown in Table 2.

Table 2
Water status thresholds.

Analysis	Parameter (mg/l)	Very good - Good	Good - Moderate	Bad
1	NH4 (905–909)		<0,40	>0,40
	OD (909–905)		<0,83	>0,83
2	Maximum NH4	<0,25	0,25–0,4	>0,4
	Minimum DO	>7	5–7	>5

Given the fact that Ebro River is highly regulated, there is a low relation between precipitation and circulating flow. Therefore, to detect the variation of parameters the analysis is delimited to dry season (from July to September).

Fig. 1 shows the control stations upstream and downstream Zaragoza city. Finally, Table 3 shows the parameters used for the analysis obtained from the Automatic Hydrological Information System and the Automatic Water Quality Information System from the Ebro River Basin Authority.

The data analysis is limited to historical series from 2002, first year of available data, to 2012, since when control station 909 is out of order. Table 4 resumes basic characteristics of the sample used in frequency analysis.

As shown in Table 4 it is considered as the variable of analysis the variation of selected parameters from control points upstream and downstream the city of Zaragoza. Therefore non attributable discharges outside urban stretch of the river are eliminated.

For conducting the frequency analysis it is first established the typology of rain event shown in Table 5.

5. Results

The objective of the first analysis is to seek the frequency of rain events in which the difference between upstream and downstream concentration of the selected parameters is higher than the one in dry season, considering the status thresholds shown in Table 2. Table 6 shows frequency analysis results.

As shown in Table 6, in dry season (July to September), when Ebro River average flow is below 50 m^3/s, the percentage of variation of both concentration of ammonium and concentration of dissolved oxygen increases gradually as rain intensity increases. Percentage grows significantly when cumulative daily precipitations are over 15 l/m^2. Therefore, in intense rain events in dry season it is detected a tendency to increase the relative concentration of total ammonium and to decrease the relative concentration of dissolved oxygen.

A second frequency analysis was conducted to study the frequency of not fulfillment of “good quality status” thresholds in downstream control station 905 obtaining the results shown in Table 7.

In regards to the fulfillment of concentration thresholds of both ammonium and dissolved oxygen, as rain intensity increases ecological status tends to worsen, being this tendency stronger when precipitation is higher than 15 l/m^2.

It stands out that not rainy events also shows a high percentage of “Bad status” what emphasize the need to display measures to enhance the health of aquatic ecosystems in Ebro River beyond the ones related to CSOs control.

6. Analysis limitations

It should be noted two main limitations along the analysis. On one hand, there has not been conducted a sample analysis on site to characterize contamination of urban runoff and CSOs. Therefore for the definition of the river pressures in rain events the present article has referenced the results of literature review and global

Table 3
Parameters for the frequency analysis.

Parameter	Unit	Description	Source	Control Point
Precipitation	l/m^2	Cumulative daily precipitation	SAIH	A089
Flow	m^3/s	Minimum daily flow	SAIH	A011
Amonium	mg/l	Difference between upstream and downstream concentration	SAICA	909 905
Dissolved Oxygen	mg/l	Difference between upstream and downstream concentration	SAICA	909 905

Table 4
Sample description.

Along the study timeframe	Units	Average	Maximun Value	Minimum Value	Standard deviation
Qmed	m^3/s	49,19	687,75	14	32,83
NH4 max medio 909	mg/l	0,08	0,98	0	0,08
NH4 max medio 905	mg/l	0,50	6,81	0,06	0,48
NH4 905–909 media	mg/l	0,42	6,76	−0,25	0,47
OD min 909	mg/l	5,13	10	2,4	1,19
OD min 905	mg/l	4,25	12,2	0,1	1,80
OD 909-905 media	mg/l	0,89	5,8	−7,5	1,82
Not rainy days		**Average**	**Maximun Value**	**Minimum Value**	**Standard deviation**
Qmed	m^3/s	48,24	687,75	14	32,39
NH4 max medio 909	mg/l	0,08	0,98	0,04	0,08
NH4 max medio 905	mg/l	0,49	6,81	0,06	0,47
NH4 905–909 media	mg/l	0,40	6,76	−0,25	0,46
OD min 909	mg/l	5,16	9,7	2,4	1,17
OD min 905	mg/l	4,34	12,2	0,1	1,76
OD 909-905 media	mg/l	0,83	5,6	−7,5	1,79
Rainy days		**Average**	**Maximun Value**	**Minimum Value**	**Standard deviation**
Qmed	m^3/s	54,99	317	16,2	34,96
NH4 max medio 909	mg/l	0,07	0,23	0,02	0,04
NH4 max medio 905	mg/l	0,56	4,79	0,07	0,54
NH4 905–909 media	mg/l	0,49	4,72	0	0,54
OD min medio 909	mg/l	4,94	10	2,6	1,26
OD min medio 905	mg/l	3,70	10,6	0,1	1,91
OD 909-905 media	mg/l	1,24	5,8	−5,9	1,93

Table 5
Typology of rain event.

Typology	Precipitation (l/m^2)	Number of samples
Not rainy	$p = 0$	869
light	$P < 2$	95
moderate	$2 < P < 15$	41
heavy	$15 < P < 30$	5
very heavy	$P > 30$	2
	Total:	1012

Table 6
Results of frequency analysis 1.

Parameter (mg/l)	Typology of event				
	Not rainy	Light	Moderate	Heavy	Very heavy
NH4 (905–909)<0,40	64,0	54,7	53,7	40	0
NH4 (905–909)>0,40	36,0	45,3	46,3	60	100
OD (909–905)<0,83	43,6	41,1	29,3	0	0
OD (909–905)>0,83	56,4	58,9	70,7	100	100

reports of the river authority.

On the other hand, given the fact that one of the control stations is out of order since 2012, only few samples of intense and very intense rainfall were analyzed hindering the significance of the analysis. Nevertheless, the results of this analysis are considered of relevance as a first approach to set down future researches in this area.

Table 7
Results of frequency analysis 2.

Parameter (mg/l)	Typology of event				
	Not rainy	Light	Moderate	Heavy	Very heavy
NH4<0,25	206	22	5	0	0
0,25 < NH4<0,4	250	25	12	2	0
NH4>0,4	413	48	24	3	2
Total	869	95	41	5	2
OD > 7	55	5	2	0	0
5 < OD < 7	206	15	5	0	0
OD < 5	608	75	34	5	2
Total	869	95	41	5	2

7. Conclusions

Rainwater management in urban environments faces challenges not only in terms of quantity (peak flow management) but also qualitative ones. Runoff pollution overlaps spatially and temporally with residual water pollution, both domestic and industrial ones. Therefore, Combined Sewer Overflows (CSOs) has become one of the main pressures over surface waters in urban areas what hinders the fulfillment of Water Framework Directive.

The first step to approach this challenge is to characterize those impacts through the analysis of basic data. The present article reviews most appropriate parameters to identify impacts of CSOs in surface waters and analyze available data in the case study of Ebro River in Zaragoza city.

The results show that in dry season, with a base flow lower than 50 m^3/s and a daily accumulate precipitation higher than 15 l/m^2 it exists a tendency of increasing the concentration of ammonium and decreasing the concentration of dissolved oxygen among upstream and downstream control points. Those impacts are foreseeable produced by CSOs what may explain changes of river quality in city stretch during rainfall. Moreover, concentration of both ammonium and dissolved oxygen exceed the "good status" thresholds.

Therefore, there is an urgent need to minimize frequency and pollution of CSOs in order to reach good status of Ebro River.

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References

Aalderink, R.H., Lijklema, L., Ellis, J.B., 1990. Urban storm water quality and ecological effects upon receiving waters. In: IAWPRC Conference on Urban Storm Water Quality and Ecological Effects upon Receiving Waters. Wageningen: Pergamon.

Abebe, Y., Kabir, G., Tesfamariam, S., 2018. Assessing urban areas vulnerability to pluvial flooding using GIS applications and Bayesian Belief Network model. J. Clean. Prod. 174, 1629–1641, 10 February 2018. https://doi.org/10.1016/j.jclepro.2017.11.066.

Amores, M.J., Meneses, M., Pasqualino, J., Antón, A., Castells, F., 2013. Environmental assessment of urban water cycle on Mediterranean conditions by LCA approach, 2013 J. Clean. Prod. 43, 84–92. ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2012.12.033.

Andrés-Domenech, I., Múnera, J.C., Francés, F., Marco, J.B., 2010. Coupling urban event-based and catchment continuous modeling for combined sewer overflow river impact assessment. Hidrol. Earth Syst. Sci. 14. https://www.hydrol-earth-syst-sci.net/14/2057/2010/.

Cherrered, M., Chocad, B., 1990. Development of a methodology to determine the pollution discharged by a combined sewer network. Water Sci. Technol. 22, 15–22. https://doi.org/10.2166/wst.1990.0283.

Davis, A., Shokouhian, M., Ni, S., 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 44, 997–1009, 2001. https://doi.org/10.1016/S0045-6535(00)00561-0.

Desbordes, M., Hemain, J.C., 1990. Further research needs for impact estimates of urban storm water pollution. Water Sci. Technol. 22 (10–11), 9–14. https://doi.org/10.2166/wst.1990.0282.

Entralgo, J.R., 2011. Scope and limitations of Zaragoza sanitation system (Alcance y limitaciones de los sistemas urbanos de saneamiento. Situacion de Zaragoza). Infrastructures conservation and exploitation Department. Zaragoza Council.

Even, S., Mouchel, J.M., Servais, P., Flipo, N., Poulin, M., Blan, S., Chabanel, M., Paffonie, C., 2007. Modelling the impacts of combined sewer overflows on the river seine water quality. Sci. Total Environ. 375, 140–151. Issues 1–3, 1 April 2007. https://doi.org/10.1016/j.scitotenv.2006.12.007.

Field, R., Pitt, R.E., 1990. Urban storm-induced discharge impacts: US-EPA Research program review. Water Sci. Technol. 22, 1–7. https://doi.org/10.2166/wst.1990.0281.

Göbel, P., Dierkes, C., Coldewey, W.G., 2007. Storm water runoff concentration matrix for urban areas. J. Contam. Hydrol. 91, 26–42, 2007. https://doi.org/10.1016/j.jconhyd.2006.08.008.

House, M.A., Ellis, J.B., Herricks, E.E., Hvitved-Jacobsen, T., Seager, J., Lijkema, L., Clifforde, I.T., 1993. Urban drainage: impacts on receiving water quality. Water Sci. Technol. 27, 117–158.

IPCC, 2015. Climate Change 2014. Intergovernmental Panel on Climate Change. United Nations Environmental Program and World Meteorological Organization.

Jin, Y., You, X.Y., Ji, M., 2016. Process response of wastewater treatment plant under large rainfall influent flow. Environ. Eng. Manag. J. 15 (11) pp.2357–2365. 9pp.

Lau, J., Butler, D., Schütze, M., 2002. Is combined sewer overflow spill frequency/volume a good indicator of receiving water quality impact? Urban Water 4 (Issue 2), 181–189. June 2002. https://doi.org/10.1016/S1462-0758(02)00013-4.

Launay, M.A., Dittmer, U., Steinmetz, H., 2016. Organic micropollutants discharged by combined sewer overflows - characterisation of pollutant sources and stormwater-related processes. Water Res. 104, 82–92.

Lee, G.F., Jones-Lee, A., 1993. Water quality impacts of stormwater associated contaminants. Focus on real problems. Water Sci. Tech. 28, 231–240. https://doi.org/10.1016/j.watres.2016.07.068.

Li, Y., Hou, X., Zhang, W., Xiong, W., Wang, L., Zhang, S., Wang, P., Wang, C., 2017. Integration of life cycle assessment and statistical analysis to understand the influence of rainfall on WWTPs with combined sewer systems, 2018 J. Clean. Prod. 172, 2521–2530. https://doi.org/10.1016/j.jclepro.2017.11.158.

Lijklema, L., Roijackers, R.M., Cupper, J.G.M., 1989. In: Ellis, J.B. (Ed.), Biological Assessment of Effects of CSOs and Stormwater Discharges. Pergamon Press, Oxford.

Lucas, F.S., Therial, C., Gonçalves, A., et al., 2014. Variation of raw wastewater microbiological quality in dry and wet weather conditions. Environ. Sci. Pollut. Res. 21 (8), 5318–5328. https://doi.org/10.1007/s11356-013-2361-y.

Ma, S., Zeng, S.Y., Dong, X., Chen, J.N., Olsson, G., 2014. Short-term prediction of influent flow rate and ammonia concentration in municipal wastewater treatment plants. Front. Environ. Sci. Eng. 8 (1), 128–136. https://doi.org/10.1007/s11783-013-0598-9.

Mi, Z., Guan, D., Liu, Z., Liu, J., Viguié, V., Fromer, N., Wang, Y., 2019. Cities: the core of climate change mitigation. J. Clean. Prod. 207, 582–589. https://doi.org/10.1016/j.jclepro.2018.10.034.

Mines, R.O., Lackey, L.W., Behrend, G.H., 2006. The impact of rainfall on flows and loadings at Georgia's wastewater treatment plants. Water, Air, Soil Pollution 179 (1–4), 135–157. February 2007.

Passera, J., Ouattara, N.K., Mouchel, J.M., Rocher, V., Servais, P., 2011. Impact of an intense combined sewer overflow event on the microbiological water quality of the Seine River. Water Res. 45, 893–903. https://doi.org/10.1016/j.watres.2010.09.024.

Peng, H.Q., Liu, Y., Wang, H.W., Gao, X.L., Chen, Y., Ma, L.M., 2016. Urban stormwater forecasting model and drainage optimization based on water environmental capacity. Environmental Earth Science 75, 1094. https://doi.org/10.1007/s12665-016-5824-x.

Riechel, M., Matzinger, A., Pawlowsky-Reusing, E., Sonnenberg, H., Uldack, M., Heinzmann, B., Caradot, N., von Seggern, D., Rouault, P., 2016. Impacts of combined sewer overflows on a large urban river - understanding the effect of different management strategies. Water Res. 105, 264–273. https://doi.org/10.1016/j.watres.2016.08.017.

Rodríguez-Sinobas, L.-, Zubelzu, S., Perales-Momparler, S., Canogar, S., 2018. Techniques and criteria for sustainable urban stormwater management. The case study of Valdebebas (Madrid, Spain). J. Clean. Prod. 172, 402–416, 20 January 2018. https://doi.org/10.1016/j.jclepro.2017.10.070.

Semadeni-Davies, A., Hernebrin, C., Svensson, G., Gustafsson, L., 2008. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: combined sewer system. J. Hydrol. 350, 100–113. https://doi.org/10.1016/j.jhydrol.2007.05.028.

Stricker, A.E., Lessard, P., Heduit, A., Chatellier, P., 2003. Observed and simulated effect of rain events on the behaviour of an activated sludge plant removing nitrogen. J. Environ. Eng. Sci. 2 (6), 429–440. https://doi.org/10.1139/s03-045.

Suárez, J., 1994. The Nalón river water quality models: application to the study of the wet dry season (Modelos de calidad del agua del río Nalón: Aplicación al estudio del estiaje húmedo.). Doctoral thesis. University of Cantabria.

SWITCH Project, 2006-2011. Managing Water for the City of the Future. UNESCO-IHE.

Sztruhar, D., Sok, M., Holien, A., Markovi, A., 2002. Comprehensive assessment of combined sewer overflows in Slovakia. Urban Water 4, 237–243, 2002. https://doi.org/10.1016/S1462-0758(02)00008-0.

Thorndahl, S., Schaarup-Jensen, K., Rasmussen, M.R., 2015. On hydraulic and pollution effects of converting combined sewer catchments to separate sewer catchments. Urban Water J. 12 (2), 120–130. https://doi.org/10.1080/1573062X.2013.831915.

UN-DESA, 2015. World Population Prospects. Department of Economic and Social Affairs, United Nations. New York.

Urban Climate Change Research Network, 2011. First Assessment Report. Cambridge University.

Wang, J., 2014. Combined sewer overflows (CSOs) impact on water quality and environmental ecosystem in the harlem river. J. Environ. Prot. 5, 1373–1389. https://doi.org/10.4236/jep.2014.513131.

Wang, S., Wang, H., Deng, Y., 2018. Effect of meteorological conditions on onsite runoff control for reducing the hydrological footprint of green building. J. Clean. Prod. 175 (2018), 333–342. ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2017.12.049.

Wilen, B.M., Lumley, D., Mattsson, A., Mino, T., 2006. Rain events and their effect on effluent quality studied at a full scale activated sludge treatment plant. Water Sci. Technol. 54 (10), 201–208. https://doi.org/10.2166/wst.2006.721.

World Bank, 2010. Cities and Climate Change. An Urgent Agenda. The World Bank, Washington, DC.

Zang, Y.W., Li, Y., Wang, C., Zhang, W.L., Xiong, W., 2015. Towards more accurate life cycle assessment of biological wastewater treatment plants: a review. J. Clean. Prod. 107, 676–692. https://doi.org/10.1016/j.jclepro.2015.05.060.

Zang, P., Cai, Y., Wang, J., 2018. A simulation-based real-time control system for reducing urban runoff pollution through a stormwater storage tank. J. Clean. Prod. 183, 641–652. https://doi.org/10.1016/j.jclepro.2018.02.130.