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Fecal Microbial Inputs To Coastal Waters From An Urbanized Basin

**Marlène Rio ⁽¹⁾, Christian Salles ⁽¹⁾, Patricia Licznar-Fajardo ⁽¹⁾,
Pierre Marchand ⁽¹⁾, Mylène Toubiana ⁽¹⁾, Claire Rodier ⁽¹⁾, Flavie
Cernesson ⁽²⁾, Patrick Monfort ⁽¹⁾ and Marie-George
Tournoud ⁽¹⁾**

⁽¹⁾ HydroSciences Montpellier (HSM), UMR 5569 CNRS, IRD, Université de Montpellier, 34093 Montpellier Cedex 05, France

Tel: + 33-467-144-269 Fax: + 33-467-144-774

E-mail: christian.salles@umontpellier.fr

⁽²⁾ Territoires, Environnement, Télédétection et Information Spatiale (TETIS), UMR IRSTEA, CIRAD, AgroParisTech, 34093 Montpellier Cedex 5, France

Abstract

Continental human activities are mainly responsible for the contamination of coastal waters. Anthropogenic pressures and more specifically urban activities represent diffuse and point sources of pollution that release contaminants on impervious surfaces and into drainage and sewage networks. Surface leaching, land runoff and floods are the key factors driven by rain events causing the transfer of contaminants from the points of emission to receiving waters. The sharp characteristics of Mediterranean rainfall patterns, long dry periods cut by short rainfall events, strengthen the river dynamics and contaminant transfer. Since fast changes in urbanized areas are observed around the Mediterranean Sea, the contaminant inputs and the apportionment of the sources to coastal pollution are key issues for integrated coastal water management. This study deals with fecal pollution of surface waters through the use of two indicators of anthropogenic and land storage contamination. The fecal indicators bacteria (FIB) are Thermo-Tolerant Coliforms (TTC) and Intestinal Enterococci (IE). The study site is the Gulf of Aigues-Mortes, a very attractive site for summer seaside tourism and winter retirement in southern France.

Simulations were performed at the basin outlets and measurements were conducted downstream of anthropogenic activities such as a hospital zone, a densely populated area, a waste disposal landfill and a peri-urban area. River discharge measurements and water samplings were concurrently processed. The river discharge was measured in-situ with a Doppler current profiler and water samples were characterized for TTC and IE concentrations. Current FIB inputs from the basin to the sea were simulated using a statistical linear regression models that consider the antecedent hydrometeorological conditions. The apportionment of the FIB loads from the selected spots of anthropogenic activities is discussed and compared to the simulated load at the basin outlet.

Introduction

Within urbanised areas, anthropogenic activities generate a wide range and increasing levels of contaminants. Human and animals disseminate fecal bacteria on land surfaces and into inland waters. Surface leaching and land runoff drive contaminants to the drainage network (Jeong et al., 2005) and dysfunctions of sewage network represent the main point source load of fecal pollution to the river network (Anh et al., 2005). Fecal Indicator Bacteria (FIB), such as thermo-tolerant coliforms (TTC) and intestinal enterococci (IE) are indicators of the hygienic status of an aquatic environment (Cho et al., 2016) and are commonly used across the world to assess the threat of pathogen contamination in coastal and surface waters (Gronewold et al., 2008).

Rainfall events are the triggering events for the transfer of inland contaminants to the catchment outlet. Mediterranean rainfall patterns, short and intense rainfall events cutting long dry periods, strengthen contaminant dynamics in the hydrographic network. During those events, the abrupt contaminant load from the catchment can severely affect the quality of the receiving waters such as lagoons, estuaries or coastal waters. To face fecal contamination issues that affect fishing and recreational activities, the active management of coastal waters needs an accurate quantification of bacterial loadings and a detailed identification of the main inland activities contributing to contamination.

This study aims at assessing the FIB inputs from Mediterranean coastal urbanised catchments and provide a picture of the apportionment of FIB contaminant sources. The study site is the Lez basin, which is one of the watersheds of the Gulf of Aigues-Mortes, a very attractive site for summer seaside tourism and winter retirement in southern France. From measurements conducted at the catchment outlets, a statistical model provides daily TTC and IE loadings from the basin. Downstream of spots of anthropogenic activities, monitored sites for river discharge and water quality give insights into the apportionment of bacterial loads from the anthropogenic activities. The considered activities are a hospital zone, a densely populated area, a waste disposal landfill and a peri-urban area.

Materials and methods

Description of the study area

The Gulf of Aigues-Mortes (hereafter GAM), located in southern France, is a well-known seaside spot for recreational activities. Its sunny and mild climate is very attractive for summer seaside tourism and winter retirement. The average annual rainfall is 672 mm. The climate is semi-arid with the majority of rainfall observed in autumn. A

high inter-annual variability of rainfall is characteristic of the Mediterranean climate, along with the occurrence of extreme rainstorms. Consequently, the hydrological regime is extremely variable and leads to flood events that yield contaminant loads. In this context, the major rainfall events can represent more than 98% of the annual bacterial load (Reeves et al., 2004 ; Chu et al. 2011).

The study area is the Lez-Mosson catchment that covers the urban area of Montpellier (410 000 inhabitants). The Lez river drains a 709 km² basin, the population density is 691 inhabitants/km² and the land use is mixed: 28% of agricultural area, 44% of natural vegetation and forests and 20% of urbanisation. The remainder areas are water courses, lagoons and wetlands. The Lez River is fed by a karstic aquifer and flows for 20 km to the GAM at Palavas-Les-Flots. Its main tributary is the Mosson River that flows directly into the sea during floods through the “Etangs Palavasiens” coastal lagoon system. This lagoon system is connected to the sea by the Prevost “Grau”, Occitan term for a small channel between lagoon and sea. At the south end of Montpellier, a new wastewater treatment plant, MAERA, is operational since 2006 with a capacity of 470,000 population equivalent. The effluents are discharged through a sea outfall 10 km off the coast, 30 m deep.

The spatial observation network is composed by 14 sites selected within the drainage network along the main river and near spot of anthropogenic activities (Fig. 1). The sites L1 to L6 are located along the Lez River. L1, located downstream of the karstic spring gives the baseline status of river water. Then L2 to L6 scattered from the entrance of the city area to the vicinity of the outlet gradually integrate the urban pressures and tributaries flows. Sites along the tributaries are selected for spot activities in the surrounding. Two sites, FA1 and FA2, were located along the Font d’Aurelle tributary that is channelled under the area of the hospital. FA1 is upstream of the hospital and FA2 is at the outlet of the underground channel. Along the Verdanson tributary, 2 sites were selected upstream (V1) and downstream (V2) of a residential area. The site downstream of the Lantissargues tributary (Lant) is representative of a peri-urban catchment with mainly commercial activities. Along the Mosson River, the sites M1 and M2 are respectively downstream of a mainly agricultural and natural area and downstream of a disused landfill area, the Thot area (T). The Thot area was the sanitary landfilling used from 1975 to 2006 to eliminate municipal solid wastes of the City of Montpellier. The landfill leachates are collected and directly transferred to the wastewater treatment plant. The runoff water from the reclaimed area of the landfill area was collected in basins. The site labelled T corresponds to one of these basins. Main characteristics of the drained area for the 14 sampling sites are given in Table 1.

Table 1: Characteristics of the sub-catchments upstream of the monitored sites (based on Corine Land Cover 2012)

Site name	Area (km ²)	Natural area (%)	Agricultural area (%)	Artificial area (%)	Waterbodies (%)
L2	127.8	53.1	32.0	14.9	0
L3	141.2	48.4	30.7	20.9	0
L4	147.6	46.5	29.7	23.8	0
L5	150.9	45.5	29.3	25.2	0
L6	519.8	48.5	30.5	20.9	0.2
FA1	2.1	12.8	0.0	87.2	0

FA2	4.1	6.7	3.2	90.1	0
V1	1.1	3.7	0.9	95.4	0
V2	2.3	1.7	15.0	83.3	0
Lant	15.3	0.0	24.2	75.8	0
M1	322.2	56.8	31.2	12.0	0
M2	337.5	54.2	30.9	14.9	0

Loads simulation and data collection

For the period, Aug 2009 to Sept 2013, daily simulation of thermo-tolerant coliforms (TTC) and intestinal enterococci (IE) loadings are provided at the basin outlet from a statistical linear regressive model. The model, described by Rio *et al.* (submitted), is based on explanatory relationships established between antecedent hydro-meteorological conditions and measured loads of TTC and IE at the outlets of the Lez catchment. The developed model quantifies daily TTC and IE loadings at the catchment outlets in relation to the Antecedent Precipitation Index (API) derived from collected rain data within the catchment. The main hypothesis for model application is temporal stationarity in territorial dynamics and rainfall patterns, avoiding major changes during the modelling period due to land use planning or climate change. Confidence intervals of the model predictions are assessed. From three evenly distributed rain gauge stations, daily rainfall data from Aug-2009 to Sept-2013 were obtained from Météo-France in the study area. The daily rainfall amount over the Lez catchment was assessed applying Thiessen interpolation to the rain gauge network. Monthly records of TTC and IE concentrations at the sea outfall of the wastewater treatment plant were provided by the Montpellier-Méditerranée Métropole from 2009 to 2013. The catchment loadings assessed from the model outputs are compared to the FIB loads measured at the entrance of the sea outfall pipe of the wastewater treatment plant.

A first campaign took place on 9-May-2016 during a rainy day of spring and a second on 12-Dec-2016 during a clear and sunny day of autumn. At each site, river discharges were measured using an Acoustic Doppler Current Profiler (ADCP) for large river section and an electromagnetic current meter for tributaries with section not suited for ADCP measurements. Concurrently to discharge measurement water grab samples were collected in the river section and stored in suited bottles packaging for analysis. Water samples were processed at the laboratory using the reference methods ISO 9308-1 and ISO 7899-2 mentioned in the European bathing water directive 2006/7/EC to enumerate thermo-tolerant coliforms (TTC) and intestinal enterococci (IE), respectively (European Parliament. Council of the European Union, 2006). Water volumes (0.1, 1, 10 and 100 mL) were filtered in duplicate on cellulose nitrate membrane (Whatman filters). TTC were quantified on Triphenyl Tetrazolium Chloride Tergitol agar incubated for 24h at 44.5°C, and intestinal enterococci were enumerated on Slanetz medium incubated for 48h at 37°C. The results are expressed as colony forming units per 100 mL (CFU/100mL).

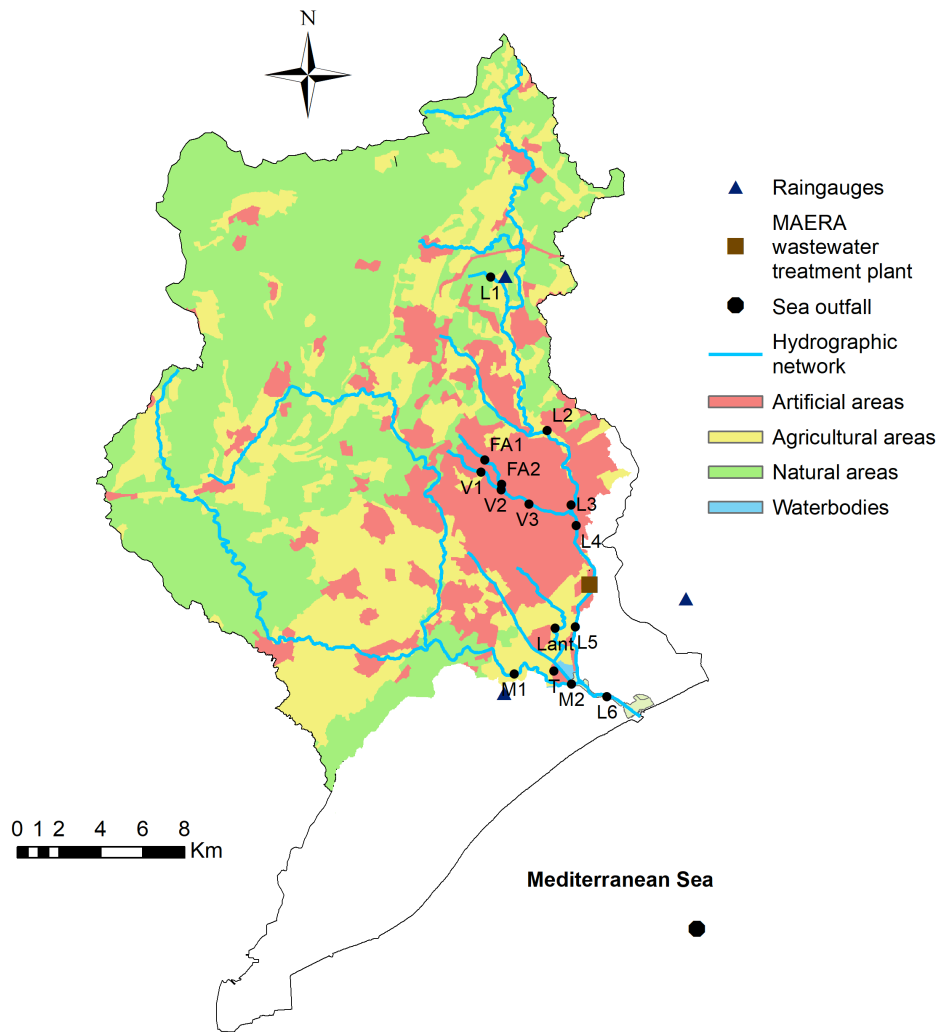


Fig. 1: Sampling stations on the Lez catchment. The black labeled points are the monitored sites along the hydrographic network. The sites L1 to L6 are located along the Lez River, FA1 and FA2, along the Font d'Aurelle tributary, V1 and V2, along the Verdanson tributary, Lant, along the Lantissargues tributary, and M1 and M2, along the Mosson River that is also a tributary of the Lez River. The site T is situated in one of the basins, which receive the landfill leachates of the Thot sanitary landfilling.

Results and discussion

At the catchment scale

The fecal bacterial loadings from the catchment assessed by the regressive model are reported Fig. 2a and 2b for TTC and IE loads, respectively. The model output is the daily load most probable value within a confidence interval. Fig. 2a and 2b also report the loads of the MAERA wastewater treatment plant at the outlet of the sea outfall pipe. The loads are assessed from self-monitoring of discharge and concentration by MAERA manager and provided by the Montpellier Méditerranée Metropole. The self-monitoring is run twice a month. The results are shown for four hydrological years, from August 2009 to July 2013.

Fig. 2 illustrates the significant variability of the daily loads from the catchment. The loads variability is linked with the rainfall temporal variability. The base level of catchment loads are 10^{12} cfu/day for TTC and IE. At the annual scale loads are in the range $3.6 \cdot 10^{15}$ to $1.9 \cdot 10^{17}$ cfu for TTC and $2.0 \cdot 10^{15}$ to $6.0 \cdot 10^{16}$ cfu for IE. The average MAERA loads, $2.3 \cdot 10^{14}$ cfu/day for TTC and $2.0 \cdot 10^{13}$ cfu/day for IE, are slightly larger than base loads from the catchment. But at the annual scale IE loads from MAERA are one tenth to one hundredth less than IE loads from the catchment. There is less agreement on the ratio MAERA vs catchment for the annual TTC loads. MAERA TTC inputs to the coastal area are twice than the catchment inputs for 2009 but are half to 1/60 for 2010 to 2012.

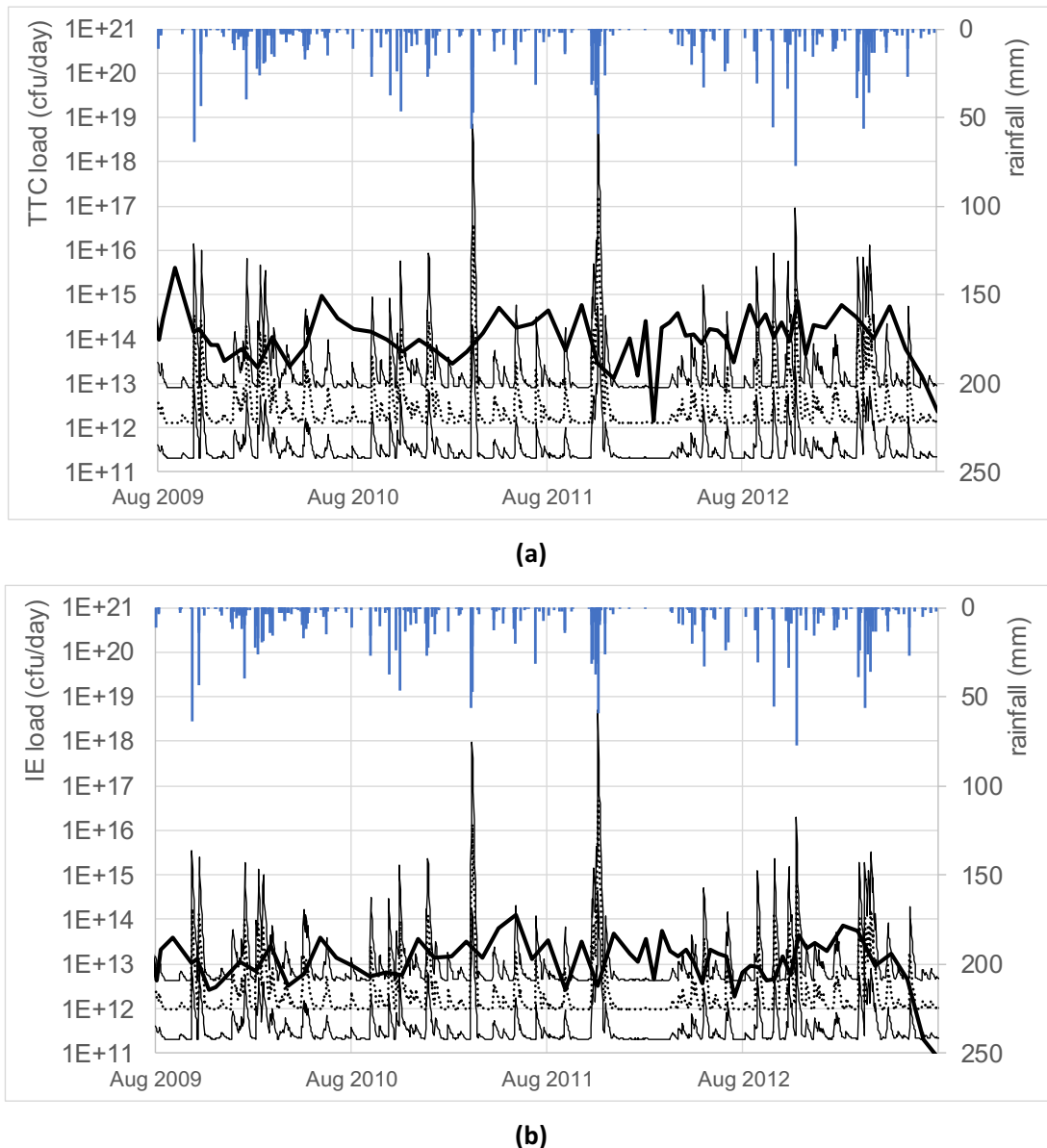


Fig. 2: Loads of fecal indicator bacteria. Daily simulated load from the linear model (most probable value: dotted line; interval of confidence of the prediction: thin line). Observed loads at the outlet of the wastewater treatment plant (bold line). The second axis refers to the daily rainfall (vertical bars) (a) reports for thermo-tolerant coliforms (TTC) and (b) reports for intestinal enterococci (IE).

From the catchment, the inter-annual load variation depends on the magnitude of the major rainfall event that occurs during the year. The major rainfall event can generate most of the annual load. As an example, for the hydrological years 2010 and 2011 the maximum load of 6 consecutive days accounts for at least 93% of the annual load. The magnitude and the abruptness of the loads during those short and intense events can be critical for water quality of the receiving waters. It demonstrates the critical importance of inland sources of fecal bacteria transferred through the drainage network. During dry periods, a large number of fecal bacteria accumulates on land surfaces and stores in the sediments. During intense rain events, runoff and sediments resuspension combined with sewer overflow release fecal bacteria and create major critical loads to the downstream waters. As a consequence, water quality is impacted during extreme rainstorms. Identifying the contribution of anthropogenic activities to fecal bacterial loads and their balance at the catchment scale is nowadays a key issue for the risk assessment and the management of water quality. The statistical regressive model assesses the global fecal bacterial load from the catchment but does not consider the load origin within the catchment. Indeed, considering changes in the hydrosystem in land use, land cover and anthropological activities, the parameters of the statistical model might misfit and make the load prediction unreliable.

Inland activities, fecal bacterial sources and load apportionment

For the 14 monitored sites located along the drainage network in the vicinity of anthropological activities, we collected water quality data and hydrological characteristics. Two spatial sampling campaigns were conducted, on 9-May-2016 and on 12-Dec-2016. For both the hydrological conditions along the hydrographic network correspond to low flow conditions. The first day on 9-May-2016 was a rainy day. A few short rain events occurred during the sample collection. The total daily rain amount was 25 mm. On 12-Dec-16, it was a late autumn sunny day. There was no rain, and the antecedent period was dry. The rain amount for the antecedent ten days was 1 mm. The last significant event last for more than 15 days, on the 24-Nov-2016.

Fig. 3 and 4 are snapshot of the measurements. On Fig. 3, the concentrations of FIB in the water column are given; part 1 of the figure corresponds to the sites along the main drains: L1 to L6, from upstream to downstream of the Lez River that crosses the urban area of Montpellier, and sites M1 and M2, in the downstream part of the Mosson River that drains natural and agricultural areas. Part 2 of the figure is related to sites with specific anthropological activities: T (the disused landfill area), Lant (downstream of a peri-urban area), FA1 and FA2 (upstream and downstream of a hospital) and V1 and V2 (upstream and downstream of a housing area). For both, TTC and IE, the concentrations observed on 9-May-2016 and 12-Dec-2016 are given. Fig. 4 is drawn the same way as Fig. 3, but it describes the FIB load assessed from the product of concentration and discharge at the monitored site.

The concentrations observed along the drainage network are from 21 to $9 \cdot 10^4$ TTC/100 mL and from 50 to $9.7 \cdot 10^4$ IE/100 mL. The concentrations are higher for tributaries than in the Lez and Mosson rivers. The runoff water on the surface of the Thot disused landfill area shows the lowest TTC concentration. As there is no anthropic activity in the area, the main source for this contamination should be the wild rabbits and birds that have their habitats in this free zone as well as some roaming dogs. Along the

Lez River, the TTC concentration slightly increases from the spring (L1) to downstream of the city (L4). For the 2 sites located downstream, L5 and L6, TTC concentration level off and slightly fall down. The combination of sunlight self-purification process and the presence of marine salt water can be the basis of the decrease. The TTC levels in the Mosson River are in the same range as in the Lez River. The level of FIB concentrations is significantly higher on the 9-May than on the 12-Dec for the tributaries and does not vary a lot for the two main rivers. The rainy event, on the 9-May, induces larger FIB concentrations in small tributaries for TTC as well as for IE. Actually, the small rain event of the 9-May leads to a flash variation in the discharge of the small tributaries in low flow period, but poorly affects the discharge of the Lez and Mosson rivers for which the time transfer of water is larger.

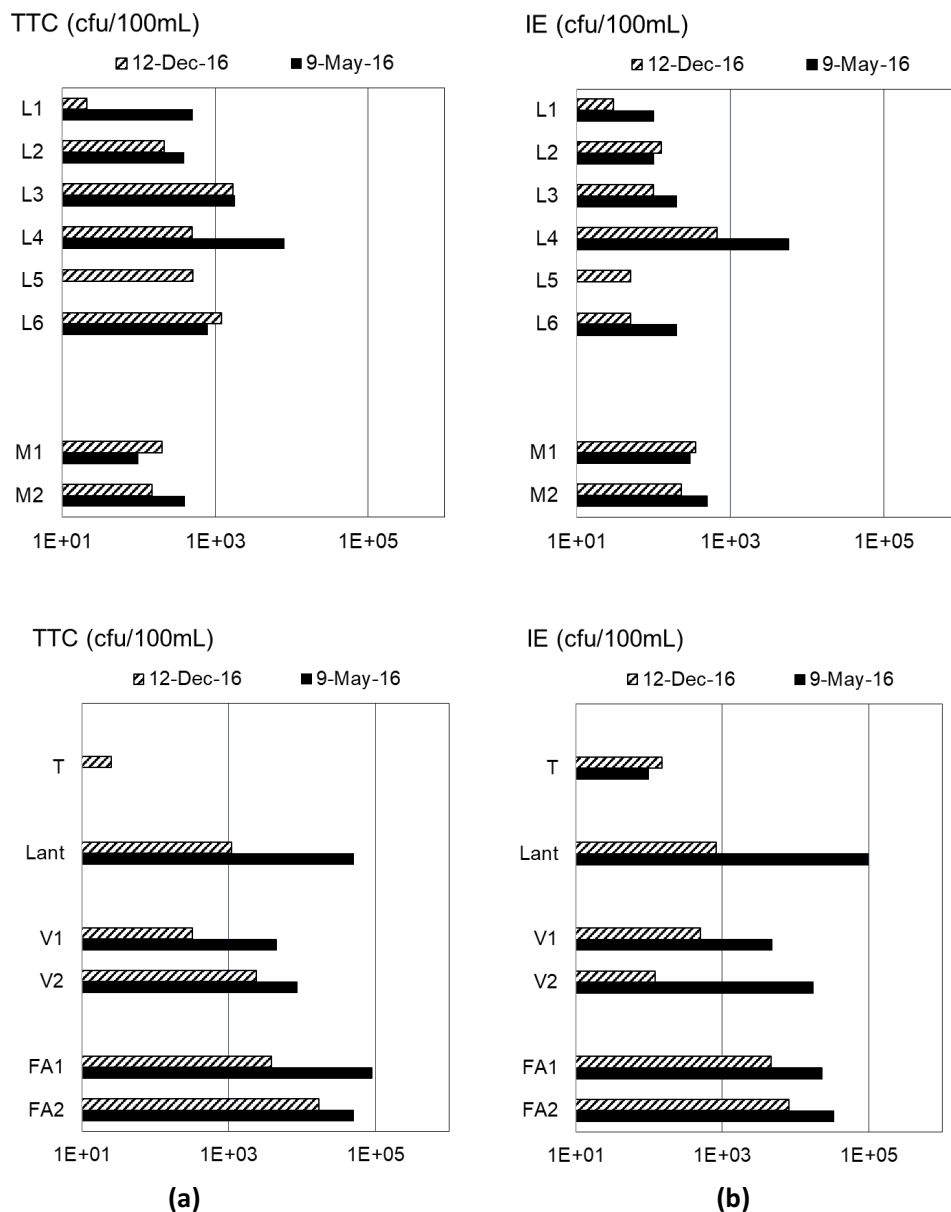


Fig. 3: Thermo-tolerant coliforms (TTC) (a) and intestinal enterococci (IE) (b) concentrations, at the monitored sites along the drainage network. Black bars represent observation on 9-May-2016, right hatched bars are on 12-Dec-2016.

The bacterial loads at the monitored sites are reported on Fig. 4. The TTC loads vary from 8×10^8 To 2×10^{12} cfu/day. IE loads are in the range 5×10^8 to 3×10^{12} cfu/day close to TTC loads. The loads are not assessed for sites L4 and L5 as no discharge measurements were processed in this sites. Neither, load is not associated to the site T that refers to the basin that collect runoff water from the Thot disused landfill surface. The general pattern of loads along the drainage network differs than concentration pattern. Loads are related to concentration and discharge. The discharges of the tributaries are an order of magnitude lower than discharges of the two rivers. Tributaries discharge range from 5 to 45 L/s while rivers discharge range from 400 to 4000 L/s.

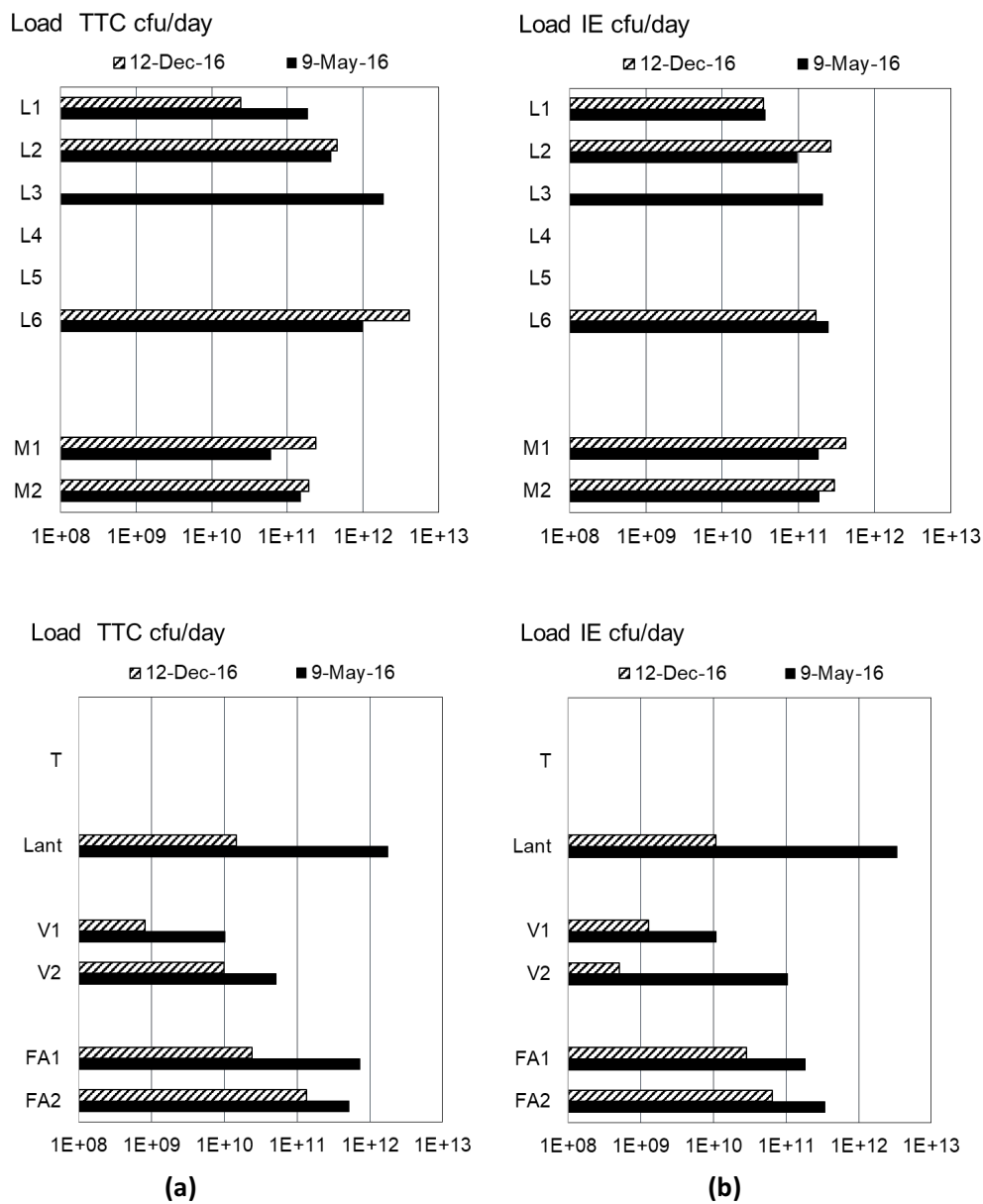


Fig. 4: Thermo-tolerant coliforms (TTC) (a) and intestinal enterococci (IE) (b) concentrations, at the monitored sites along the drainage network. Black bars represent observation on 9-May-2016, right hatched bars are on 12-Dec-2016.

Thus, for the low flow conditions of the two sampling days, river loads are the same order or higher than tributaries loads. Loads at the outlets of the two rivers (M2 and L6) remain quite stable between the two sampling days, while the loadings in the Lantissargues and Verdanson sites vary by two order of magnitude in between 9-May and 12-Dec. The highest TTC and IE loads were observed the first day, on 9-May, downstream of the Lantissargues site. This tributary drain a peri-urban area that contains an equestrian centre very close to the sampling points. This site needs more investigation to identify the actual origin of the FIB load. The hospital area and the residential zone generate similar increase of FIB load that differs from less than one order of magnitude. The first data analysis shows that in low flow condition, the contribution of the various anthropogenic activities (residential, hospital and agricultural) are comparable, but tributary loads show a large variability.

Conclusions

This study analyses the fecal indicator bacteria loads at the global scale of the catchment and locally downstream of spots of anthropogenic activities. The fecal bacterial loading of the basin is assessed from a statistical linear regression model. Simulations over a four years period illustrate the balance between loads from the catchment and loads at the output of the wastewater treatment plant. The relevance of the major rainy event, that can provide in a few days more than 90 % of the annual load, is shown.

Within the basin, anthropogenic activities such as a residential area, a hospital zone, a former landfill area, a peri-urban area and an agricultural area are monitored for their FIB loads. The measurements, conducted during low flow periods, point out the great variability of FIB concentration within the tributaries and the comparable level of FIB loads from the various considered activities.

The main flaw of the statistical model is the hypothesis of temporal stationarity of the activities within the catchment. To better assess the contributions of anthropogenic activities to FIB load, a thoughtful analysis and monitoring during flood events is planned.

Acknowledgements

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Keywords

Fecal indicator bacteria, Mediterranean area, anthropogenic activities, bacterial load, urban area, regressive model.