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Industrialisation, manure and water quality in the 19th century. The Senne River in Brussels as a case study

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Abstract Like other rivers in European cities, Brussels' Senne River was 'buried' and 'covered' in the second half of the 19th century (1866–1871). The main reason given by authorities for undertaking such huge urban works was the terrible water quality of the river. Filled with dirt and trash, the Senne was systematically associated with insalubrity, even danger. However, beyond the general opinion expressed at that time, it is hard to find any data that reflects the nature, extent, and origins of the pollution at the moment of covering, and in the years after. By addressing the question of water quality in the second half of the 19th century, this paper raises other issues related to the history of industrialisation and the silent transformation of environmental conditions. Reinterpreting an interdisciplinary study by hydro-biologists and historians on the pollution of the Senne, it also enhances the potential of such studies in renewing historical questions.

Keywords Urban rivers · 19th century · Water quality · Industry · Brussels · Transdisciplinarity

Introduction: water quality as driver of transformation[1]

Urban spaces underwent deep transformations during the 19th century. In the name of modernity and hygiene, to put it superficially, their landscapes were profoundly changed. In a European context, this meant the development of numerous urban projects, such as: the

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Fig. 1 The burying of the River Senne around 1866 (Brussels City archive)

building of new roads and communication axes (railways, waterways), the destruction of old and densely occupied spaces, and the reconstruction of entirely new districts designed on bigger scales. In many cities, this also led to the burying of, sometimes important, rivers, which were often transformed into sewers. The Fleet River in London, the Bièvre in Paris, the Neglinnaya in Moscow, or the Senne in Brussels, to name but a few, were among them. In Brussels the vaulted river was separated from wastewater which was collected in two adjacent sewer mains. But beyond the city limits both sewers and the river merged together again.

In Brussels, the disappearance of the main river and the consequent destruction of a significant part of the old town was probably the largest material transformation the city was subject to in the 19th century (Figs. 1, 2). The unsanitary aspects of the river Senne were repeatedly presented as the main reason for undertaking this project. In 1871, after 4 years of important works (Fig. 1), the Senne was made invisible in the urban centre and a parisian-style boulevard was designed in its place (Fig. 2). At that time, Brussels was the very young capital of a new state and, as such, was very active in building visible signs of its new status. Public spaces were transformed and new districts were planned to accommodate a growing national elite working for central public institutions or central economic businesses. In this context, the burying of the Senne appears as part of the larger reconfiguration of Brussels' image during the 19th century (Demey 1990).

The aim of this paper is to explore the history of the water quality of the river. By comparing historical information on the pollution of the river with a quantitative reconstruction on this subject, this paper will give a picture of the state of the river at the moment of its covering and in the decades after. Consequently it will examine the transformation that occurred during the second half of the 19th century (1865–1900), which has often been presented as an indistinct period as far as water pollution is concerned.

Fig. 2 Brussels' boulevards at the end of the 19th century after the burying of the Senne river. The picture is taken approximately at the same place as Fig. 1 (Brussels City archive)

The following set of questions will guide this enquiry.

First, beyond the common opinion expressed over the river's filthiness—ideas found in almost any European city at that time—can we get a better idea of what this pollution was really like in Brussels? What was its reality, nature, and extent? What were the main sources of pollution? How can we determine this? Secondly, did any noticeable change occur in the period? And, if so, how can these changes be explained?

In order to answer these questions I will make use of the work of historians and of a previous interdisciplinary study by hydro-biologists and historians that uses a modelling approach. Comparing and integrating both perspectives will be interesting from an epistemological viewpoint as it will force us to (re)open some historical files.

A transforming waterscape

Before getting to the substance of my paper, I will revisit the main features of the Senne to illustrate the specifics of this case study. The Senne River is small and bears no comparison with great European rivers like the Seine, the Rhine or the Danube, or even with the main Belgian rivers: the Meuse and the Scheldt. Today the Senne's annual flow upstream from Brussels is a little more than 4 m^3/s and its flow downstream around 6 m^3/s; however it can reach values close to 100 m^3/s at the 'entrance' of the city in heavy rains.

The flow of the river Senne might have been greater in Brussels in the first half of the 19th century, before several catchments were diverted upstream from the city for different purposes (to feed a new shipping canal in 1832; to pump drinking water to supply Brussels in 1855), but it has always been a small tributary of the river Scheldt (Fig. 3).

Fig. 3 The Senne, a small tributary of the Scheldt, in present-day Belgium. The Senne basin covers a total surface area of ca 1200 km^2

The Senne River and the development of the city

The small size and the narrowness of the river did not prevent it from playing a major role in the history of the city. From the 11th–12th century onwards it was used for many purposes: mills, industrial activities, disposal of wastewater. As in every European pre-industrial city, the river had a wide set of uses and functions (Guillerme 1983; Deligne 2003).

As for waterway transport, the Senne had played an important role in the first centuries of Brussels' urban development, linking the city to the North Sea area: a major Europe's commercial hub at that time. But from the 16th century its narrowness and meandering course hindered the development of more extensive commercial traffic. After decades of political negotiations with central authorities and competing neighbouring cities, Brussels' commercial elite eventually obtained the right to dig a canal separate from the Senne (even if fed by the river) that would link Brussels more directly to Antwerp and the North Sea. Instead of travelling for sometimes over a week on 120 km of winding river, ships could now travel in one or 2 days the 30 km that separated Brussels from the Scheldt, and Antwerp's gateway.

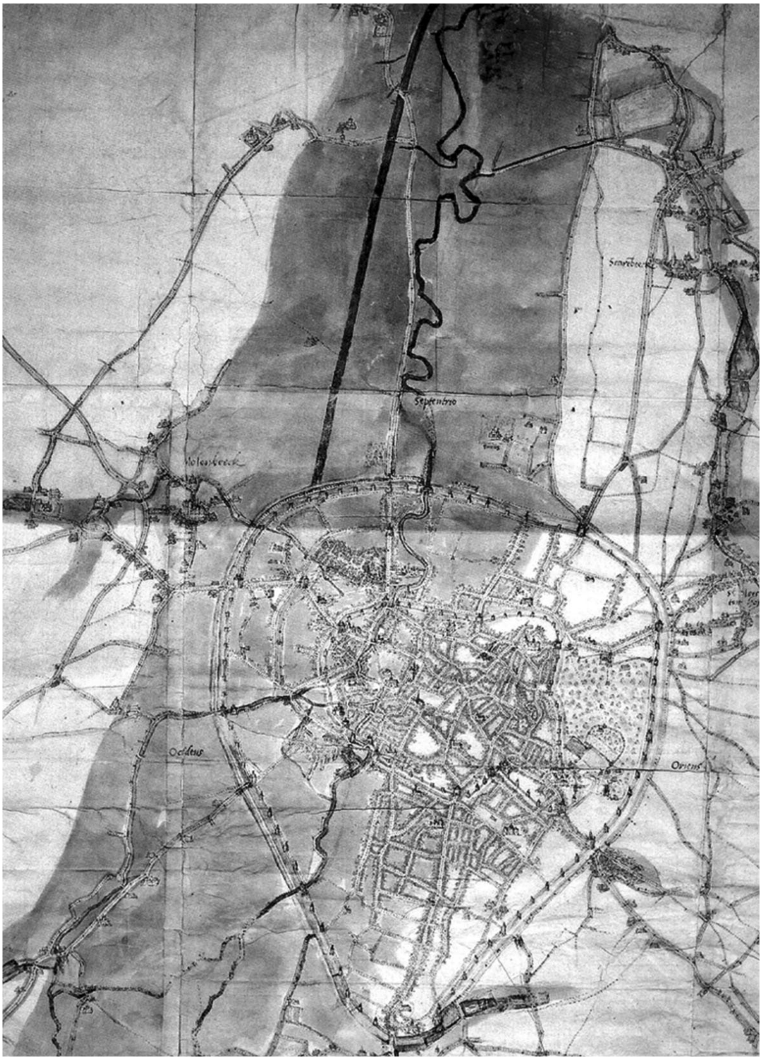

Fig. 4 On the first map of Brussels (Jacob van Deventer, ca 1565), the new shipping canal is already visible to the north of the city even if not finished, next to the meandering Senne (Bibliothèque royale de Belgique)

The creation of the canal can be considered a turning point in the history of the relationship between Brussels and its river (Fig. 4). Briefly, the attention of Brussels' authorities was focused on the new trade artery (the canal) while the Senne River was ignored (Deligne 2003). The 16th-century canal linking Brussels to the north was deepened in 1832 and at the same time a new canal was dug, linking Brussels to the south, and to important places for coal mining.

River pollution, a side effect of industrialisation

During the first half of the 19th century, Brussels' waterscape was transformed (Deligne 2012). Some of the activities that had engendered the necessary coexistence of people and waterways disappeared. The suppression of ecclesiastical institutions in the context of the French Revolution and improved transportation methods that made ocean fish easier to ship meant a rapid end to fish farms and to the hundreds of ponds in the Brussels-area that housed them. At the same time, growing industrial activity contributed to the discharge of a greater amount of organic matter (pollution) into the rivers. Accounts of the contamination of Brussels' rivers multiplied, both within the city and in its suburbs. Farmers downstream of the city complained of no longer being able to water their livestock without poisoning it, manufacturers complained of not being able to use the water from 'their' river due to pollution upstream, and even officials were concerned about the contamination of the lower-city wells that supplied water to the city's most vulnerable inhabitants (Ducpétiaux 1844). This pollution was not new, of course—industry had been dumping its waste into the waterways since the Middle Ages—but, in the context described, it grew.

From the middle of the 19th century, descriptions of the river invariably insisted on the disgusting and dangerous aspects of the Senne. Statements like: "les miasmes délétères que dégage cet égout à ciel ouvert, ce cloaque auquel on donne encore le nom menteur de rivière" (Gorrissen 1866) were countless. The words 'cloaque' (cesspool), 'dépotoir' (waste dump), 'égout infect' (fetid sewer) were associated with the river in the predominant narrative. Brutal outbreaks of deadly epidemics, and more specifically of cholera (1832, 1849, 1853–1855), undoubtedly led people to blame the river for causing contagion. According to the *miasma theory,* prevalent until at least the 1870s in Europe (Thorsheim 2006, pp. 10–18; Corbin 1982), accumulation of dirt, stagnant water and general unsanitary conditions (density of population, absence of light and air) were considered the main causes for the high mortality rates in the central districts of the city. Here, small factories, industrial activities, unsanitary housing conditions, and poverty were concentrated (Ducpétiaux 1844). The problem of waste being discharged directly into the river progressively emerged as one important issue to be tackled.

The response of the authorities

A further step in the transformation of Brussels' water system started in the 1850s; it was characterised both by the search to eliminate 'dirty' water, or waste water, and a drive for 'pure' water for the population (Deligne et al. 2006).

The quest to purify the city from miasma and unsanitary conditions led to the creation of the city's first water distribution system in 1855; entirely organised by the public authorities, it was also the first 'modern' water distribution system in the country. The system of underground channels was designed to draw water from sources in the valley of a small Senne tributary about 30 km south of Brussels, and feed it by gravitation to a large reservoir built in the upper eastern reaches of the city. From there, the water was distributed to various quarters, first to the more affluent inhabitants, the only ones who could afford to subscribe to the service (Viré 1973, 1986).

At the other end of the water cycle, the authorities undertook to systematise and standardise the wastewater drainage system (sewers) in the city streets. In 1848, the first modern pipes were laid in the Brussels subsoil, pipes whose ultimate outlet was the river Senne (Van Mierlo 1878). Far from resolving the water pollution problems in a city whose population density was rising steadily, the new sewage network added a substantial quantity of waste to a river already choked with industrial pollution. The river conditions soon became the main official justification put forward by the authorities for undertaking huge works in the city centre.

Better knowing the pollution and the polluters

So far, Brussels' story does sound like the global trend of cities at the time. However, beyond the common opinion expressed over dirt and filth, can we get a better idea of what this pollution was really like in the mid 19th century? What was its reality, nature, and extent? What were the main sources of water pollution?

Origin of the organic pollution: domestic versus industrial

It is assumed that the pollution of the Senne was still mainly organic at this time, as the systematic use of chemicals in the manufacturing processes was still to come. But, beyond general statements, it is hard to find concrete or comprehensive quantitative information about the nature or the amount of dirt and pollution discharged into the river. This is as true for Brussels and Belgium as it is for other countries, notably France and Britain (Massard-Guilbaud 2010). The survey made by French engineer Charles de Freycinet (1828–1923) about the sanitation methods used in Belgium and the Rhine Prussia, offers some overall insights in this matter; one of his chapters is dedicated to "water infection" (de Freycinet 1865, pp. 63–80). He identifies the main polluters as soda fabrics, dyeing fabrics, the paper industries, the distillery, the wool industries, the grease, candle and oil industries, water retting and faeces. If those indications point out the measures taken by some industrialists (mainly the creation settling ponds and filtration processes), it does not really depict Brussels' industrial landscape with accuracy, nor the amount of waste water loaded in the river. The archive of the first chemistry laboratory created within the Brussels municipal administration in 1856 is not of any help as it did not play a significant role in the collection of data on the quality of the rivers. It was interested in other concerns, mainly food or drinking-water quality (Scholliers 2014). It is very difficult to find precise data about the amount of dirt that ended in the river in the Brussels agglomeration.

As far as we know, the first partial quantitative data on nitrogen in the Senne River was collected by Arthur Petermann in 1875–1877 and later in 1899 (Petermann 1899).[2] This means that there is probably no such data dating back to the period before the covering of the river in 1866–1871. What can we learn from Petermann?

Petermann was an agronomist and chemist; all the measurements undertaken as director of the 'Station agricole' (i.e. the laboratory dedicated to agricultural research based in the rural agglomeration of Gembloux, some 50 km from Brussels) were made in order to estimate the quantity of organic fertiliser contained in the Senne River in Brussels, when the quest for manure and fertiliser was the driving force behind agricultural research (Marald 2002) (see below). In the journal where his results were published, no details about the origins of pollution are to be found, nor is there any information about the methods used to conduct his analyses. At this stage it can only be assumed that these were

[2] Arthur Petermann (Dresden 1845–Gembloux 1902) was a German scientist who specialised in Agronomy and Agricultural Chemistry. After having worked as an assistant in different Agricultural (research) Stations in Germany and France, he was asked in Belgium to be head of the 'Station agricole de Gembloux', opened in 1872 by a private association supported by the State and dedicated to research in Agriculture, especially fertiliser and manure. Among others, he published work on the composition of the sewage of Brussels in 1899. He also published data from the Viennese experiment in 1895, see text online on the website of the Koninklijke Bibliotheek/Bibliothèque royale: http://opteron1.kbr.be/gif/LOT/70299_3_70_100/70299_3_70_100_090.pdf. Further information on Petermann is to be found on the website Bestor (Belgian Science and Technology Online Ressources: http://www.bestor.be/wiki_nl/index.php/Petermann,_Arthur_(1845–1902).

Table 1 Data about the nitrogen in the main sewer of Brussels (i.e. the Senne) in 1875–1877 (Petermann, 1899) and information on Brussels' population

	Nitrogen (mg/l)	Flow (m^3/day)	Total N loading (t/day)	Inhabitant equivalent (inh.eq.)[a]	Population drained (inhabitants)
1875–1877	112	100,000	11.2	1,120,000	225,000
1898	521	100,000	5.2	520,000	325,000

[a] The physiological excretion rate is between 10 and 15 g/day/inhabitant. The lowest value (10 g) has been taken into consideration, considering a low connection rate to the sewage system

not the same in 1875–1877 and in 1898 as a new method proposed by the Danish chemist, Johan G. Kjeldhal, had broken through in 1883 (Saez-Plaza et al. 2013). In other words, we only know about the general composition of his sample (Table 1). Further research has to discover if we can know more about these aspects.

The only thing that can be stated with reasonable certainty is that at that time the nitrogen load carried in the sewer in the 1870s exceeded by at least a factor of four the domestic pollution generated by the population drained by the sewer. Indeed, in terms of inhabitants equivalent (inh.eq.), the total organic pollution supported by the river can be estimated at 1,120,000 while the population effectively drained by the main sewer in Brussels reached approximately 225,000 inhabitants (Billen et al. 1999). The industrial activities were thus by far the main contributors to the organic load, representing 895,000 inh.eq. out of the estimated 1,120,000, i.e. 80 %. This ratio may have been even more important since numerous city dwellers were not yet connected to the main sewer and because domestic recycling practices for the benefit of agriculture were still common at that time (see below). The situation must have been quite similar in 1866, when the city authorities decided to cover the river. In other words, the manufacturing processes in use in the second half of the 19th century, probably still close to those in use some decades or even some centuries before, discharged huge amounts of organic matter into the hydrological system; they were by far the main contributors to this pollution.

The data given by Petermann, once again, do not give any access to the identity of the polluters, or to the specific origins of the pollution. How could we then establish who they were and what they discharged in the hydrographic network?

It is not easy to answer these questions as there is no such archive, an industrial census for example, to serve as a unique source of information. Indeed, there is no industrial census at the Brussels scale for the second half of the 19th century. It only exist at the larger Provincial scale and is internally organised by municipalities. The latter do not match either the urban extension or the hydrographic realities; it is therefore difficult to isolate in the census the industries that belonged to the Brussels hydrographic watershed. On the other hand, the municipal organisation of Brussels is not simple to understand as the municipality of Brussels itself is but a small part of the urbanised territory composed of at least seven other municipalities from the 1830s, ten from the 1880s (see Fig. 6), 19 today. This means that many industries were established in suburbs which were—and still are—not part, administratively speaking, of the city of Brussels. Therefore, in order to gather information about industries belonging to the Brussels region—their exact situation, their nature, the way they used the hydrographic network, their evolution—one should explore many archives scattered through numerous municipal (and other) archival materials, without being sure of getting an exact picture of the industrial landscape in the end. In such a complex archival context, we hold a large part of our knowledge from previous historical work that has managed to give a general overview of the main industrial sectors in the region, and of their location (Puissant and de Beule 1989, 1994; Puissant 2009).

Quantifying the industrial pollution

The gap in data about the origins of industrial pollution has been partly filled thanks to research undertaken some years ago by an interdisciplinary team made up of hydrobiologists and historians, who evaluated the contribution of industrial and domestic activities to nutrient loading in the Senne at the end of the 19th century (Billen et al. 1999). Although it contains a certain amount of imprecision due to the lack of quantitative data given at a sufficiently detailed scale of time and space (see above), this study still remains one of the few scientific attempts to describe the Senne pollution (and more generally speaking the pollution of the 19th century industrial rivers) using a quantitative approach to better identify its origins. It is therefore useful to explain the method used and the results obtained.

The method was developed as follows. First, the estimates of the amount of organic matter (nitrogen, carbon) and associated nutrients released by the major industrial processes in use during the second half of the 19th century were reported. This analysis was restricted to those industrial sectors assumed to have represented the major sources of organic matter and nutrient pollution of surface waters at that time in Western Europe, i.e., tannery, hat and felt industries, cotton and wool bleaching, dyeing industries, clothes washing, glue and gelatine production, grease and oil production, candle and soap production, paper industries, sugar refineries and breweries.

In order to make these estimates, the available descriptions provided by the technical and professional literature of the 19th century were carefully scrutinised, as was general literature dealing with the history of techniques (Daumas, 1965). These descriptions allowed researchers to estimate the input–output budgets of the processes by evaluating the loss of organic matter during washing or rinsing phases.

In the leather industry, one of the important industrial sectors in many cities at the time, comparisons between technical manuals and encyclopedias allowed researchers to estimate that up to 20 % of the weight of the fresh skins brought to the factories were lost at the first stages of the fabrication process. These include soaking and what was called 'beamhouse operations' ('travail de rivière' in French), when skins were soaked in water in order to be cleaned and washed. This loss consisted mainly in blood and impurities like dust or mud. In the maceration stage, some organic matter containing natural phosphates, like dog faeces, pigeon droppings or barley flour, were also added in order to remove remaining flesh, fat and hairs (those organic materials were replaced by sulphuric acid later in the 19th century). During the tanning phase itself, a large amount of organic material, usually lime and tannin, was regularly added to the skins which were macerating for months in tanks directly connected to the river or urban streams (those organic materials were partially replaced by soda in the course of the 19th century) (Diderot and D'Alembert 1765; Figuier 1872; Maigne 1883). All estimates are summarised in Table 2. When uncertain, they have been kept to their lowest acceptable values.

For the *textile industries* (bleaching and dyeing), this quantitative method was first used by F. Oncklincx in her study specifically dedicated to this sector in the Brussels region around the middle of the 19th century (Onclincx 1991, p. 33). The results are summarised in Table 3.

In the paper industry, old cloths and rags were mainly used as raw material until the 1880s. The organic loss was extremely important, up to 30–35 % according to specialised

Table 2 Quantification of the loss of organic matter in the tanning process (based on Billen et al. 1999)

Operations	Reagent added	Loss as organic matter in waste water (g)
Tannery	(For 1 kg raw fresh skins)	
Soak	Immersion for 1–2 days in flowing water (loss of impurities)	
Depilation	Maceration in lime water for 2–3 months (10–20 % weight loss)	
Manual scraping in flowing water	Fermented barley and excrement decoction	50
Maceration in acid baths for 6 months		
Maceration with tan for 1 year	800 g tanner's bark (mostly recycled)	50
Rinsing		
	Total	100

Table 3 Quantification of the loss of organic matter in the textile industries (based on Onclincx 1991)

Operations	Reagent added	Loss as organic matter in waste water (g)
Wool bleaching	(For 1 kg raw wool)	
Washing-rinsing cycles successively with soap, soda, and sulphur dioxide + sunlight exposition	30 g soap (loss of raw material amounts to 36–45 %)	
	Total	400
Cotton bleaching	(For 1 kg cotton)	
Washing-rinsing cycles successively with lime or soda, sulphuric or chlorhydric acid hypochlorite	(Loss of raw material amounts to 5–15 %)	
	Total	100
Andrinople Red dyeing	(For 1 kg cotton stuff)	
Washing with lime		
Sheep excrement bath, then drying	300 g excrement + lime	300
Oil bath, then drying	100 g vegetal oil + lime	100
Degreasing by washing-rinsing	Soda lime	
Gall impregnation	250 g gallnut	250
Alum application		
Madder dying	Madder-root + animal blood, 500 g	500
Reviving: boiling with soda, oil and soap	Soda, 50 g oil and 100 g soap	150
Brightening: boiling with tin salts, soap and nitric acid; rinsing	150 g soap, tin salts, nitric acid	150
	Total	1450

Table 4 Estimated specific raw pollution loads and productivity figures for the main industrial processes around 1880–1890 (based on Billen et al. 1999)

Industrial sector	Production unit	Specific pollution load[a] (inheq/unit) 1	Productivity[b] (unit/worker-day) 2	Pollution index (inheq/worker-day) 3
Glue and gelatine	Kg product	140	30	4200
Heavy chemical (fertilisers, explosives,…)	Worker-day	500	1	500
Paper industry	Kg pulp	15	30	450
Grease, candle and oil	Kg product	5	60	300
Textile dyeing	Kg textile	35	5	175
Tannery	Kg skin	2.5	50	125
Soap industry	Kg product	0.9	130	117
Brewery	Hl beer	35	3	105
Felt industry	Kg skin	1.2	22	26
Sugar industry	Kg beets	0.1	200	20
Textile bleaching	Kg textile	4	5	20
Laundry	Kg linen	0.5	10	5

[a] Original data was converted into inhabitant equivalents (inh.eq.). One inh.eq. being defined as a daily release of 40 g organic matter (Billen et al. 1999)

[b] Derived from national economic statistics (Statistique Générale de la Belgique 1907) providing total industrial production and employment by sectors, assuming 300 working days per year

literature (Van den Corput 1860; Doizy and Fulacher 1989). Rags and cloths made from plant material (flax, hemp, cotton) were left for weeks in tanks filled with water while regularly stirred. The consequent fermentation recovered the raw textile fibers. They were then ripped and crushed again with water until transformed into a smooth pulp that was eventually dried in very thin layers. Each sheet of paper was then glued with glue made from animal tissues (tails, bones, ears, tendons, nerves, cartilage) which contain significant quantities of collagen. For this latter industry, the waste produced at the first stage of the treatment was extremely important as shown in Table 4 (Le Normand 1833). It was probably one of the most polluting industries in terms of the 'pollution index' per produced unit (see below).

A last example is the *production of stearic candles*, which replaced the old fabrication process of tallow candles after 1825. It can be estimated that at least 55 % of the tallow was eliminated at the beginning of the first stage of the production process, i.e. the saponification (Laboulaye 1891; Privat-Deschanel and Focillon 1908).

This close examination of the different manufacturing processes not only confirms their important contribution to the organic losses of the selected industrial sectors, it also allows a first quantitative estimate of these losses (Table 4).

When combined with productivity figures (e.g. the amount of products handled by one worker in a day) these estimates on specific pollution loads provide an approximate measure of the pollution generated per worker-day. Productivity estimates were obtained from general industrial statistics (whole country), by dividing the total production of a given industrial sector by the number of workers employed in that sector (Table 4).

Table 5 Estimated industrial loading (in inh.eq.) of the Senne River basin in 1897 (based on Billen et al. 1999)

	Number of workers	Pollution indexes with 50 % abatement (inh.eq./worker-day)	Industrial loading (inh.eq. $\times$ 10^3)
Glue and gelatine	238	2100	500
Paper industry	651	450	293
Brewery	3800	52.5	200
Grease, candle and oil factories	1040	150	156
Textile industry (dyeing)	824	87.5	72
Tannery	1040	62.5	65
Chemistry	196	250	49
Soap industry	348	58	21
Felt and hat factories	1600	12.5	20
Sugar industry	1500	10	15
Linen washing	4400	2.5	11
Textile bleaching	249	10	2.5
Total industrial organic loading			1404.5
Total domestic load (<population of the watershed)			880
Total			2284.5

These figures have been slightly modified since the publication of 1999 where some data was missing (Billen et al. 1999). They also slightly differ from the ones given by Garnier et al. (2013). These differences do not call into question either the main features or the order of magnitude of the present analysis

For several activities (like dyeing, bleaching or tannery), historic pollution was extremely high compared to the values known at the end of the 20th century, owing to the traditional technology used, which often involved long maceration in plant decoctions, animal excrement, blood, etc., followed by ample rinsing in running water.

Of course, the figures in Table 4 represent raw pollution rates: they do not take into account any treatment applied to industrial effluents before their discharge into surface water. However by the mid 19th century, some reduction of organic pollution did occur through settlement in wastewater stabilisation ponds. These ponds became compulsory during the second half of the 19th century, at least theoretically. In this estimation of pre-industrial loadings, the conservative assumption of a maximum of 50 % abatement of the nutrient loads was used (Billen et al. 1999, p. 47).

The pollution indexes of Table 4 (column 3) can be directly used to evaluate the order of magnitude of the industrial pollution load per sector thanks to an industrial census by municipality and industrial sectors (Recensement général des industries et des métiers 1896). The results allow us to establish a first ranking of industries according to their contribution to the pollution of the river in the second half of the 19th century (Table 5). At that time, the glue and gelatin industries held the top position, followed by chemistry, paper industries, textile industries and tannery. Although this ranking may have to be slightly modified upon closer analysis, it serves to underline the ‘polluting potential’ of 19th-century industries and could be applied to other local case studies.

Pollution load: industrial versus domestic contribution

In a final step, the pollution indexes can be used to estimate the overall industrial load of the Senne River. For the needs of the original study, this estimation was made at the watershed scale. It is worthwhile mentioning that it has been assumed that all industries were connected to the Senne water system and discharged their wastewater into the river. The results are presented in Table 5 and compared with the estimates of the domestic load, based on population figures. In this table, however, the domestic contribution is probably overestimated because application of domestic waste as fertiliser onto cropland was still in use at that time, even if it decreased after the covering of the Senne and the extension of the sewage system, at least in Brussels.

These estimates confirm once again that industrial pollution at the end of the 19th century not only represented the largest part of organic pollution, i.e. about 61 % of the total organic pollution discharged in the whole watershed, but also generated a high amount of organic matter. This was confirmed by further analysis (Garnier et al. 2013). The above mentioned study conducted on the textile industry (dyeing, bleaching) in only three municipalities immediately south of the city has already shown that this sector was responsible for discharging organic waste estimated at about 15 tons per day into the hydrographic system, the equivalent of the domestic organic waste generated by a population of at least 150,000 inhabitants today (Onclincx 1991, 1994).

These figures also shed light on the industrial sectors that most contributed to the organic pollution of the Senne. The four greatest were: glue and gelatine factories, paper factories, breweries, and grease and oil factories. These details about the structure and significance of industrial pollution in the second half the 19th century in the Senne basin could lead to a broader comparison with other basins/cities on the one hand, and to a more refined analysis of the Brussels region on the other.

Although they must be read with care given the inherent inaccuracies and uncertainties that have already been mentioned (i.e. the degree of abatement taken into account, the existence of recycling practices and processes, the domestic uses of organic fertiliser, the precise number of workers, and the seasonal nature of workers' activities), these figures surely indicate realistically the order of magnitude of industrial loading into the river at the end of the 19th century.

The ratio of 61 % of organic load generated by industrial activities corresponds but approximately to the estimates obtained by the above-mentioned agronomist, Arthur Petermann (Table 1). According to his measurements, made in 1898, the nitrogen loss carried in the sewer at that time was estimated to be 520,000 inh.eq. while the population drained by the sewer was about 325,000 inhabitants. In other words, extrapolating from Petermann's figures, "only" 195,000 inh.eq. of the nitrogen load was attributable to the industrial activities, which means 37.5 % of the organic pollution. The difference between the results obtained for the reconstructed quantitative approach (61 %) and the data given by Petermann (37.5 %) is even more significant than it appears at first glance. Indeed, the first ratio (reconstructed approach) is estimated for the whole watershed while the second one (Pertemann's data) only concerns the Brussels region. The Brussels region (i.e. 10 municipalities at the end of the 19th century, see Table 6) is known as the most industrialised part of the watershed (Puissant and de Beule 1989). We would have expected that the industrial contribution should have been proportionately greater at the Brussels scale than at the watershed scale. How can this gap be explained?

Table 6 Population figures for Brussels (approximate number of inhabitants) (based on Daelemans 1989)

	1780	1831	1866	1900
Brussels (city center)	ca 70,000	ca 100,000	ca 160,000	ca 185,000
Main suburbs (‘*faubourgs*’)	(Not relevant < not ‘urbanised’)	ca 22,000 (7 municipalities)	ca 115,000 (7 municipalities)	ca 365,000 (9 municipalities)
Total		ca 122,000	ca 275,000	ca 550,000

Note that Brussels and its adjacent municipalities never merged into one administrative territory. Since 1989, the Brussels-Capital Region existed as one of the three federal entities of Belgium. Nevertheless, it remains composed of 19 independent municipalities

The first reason for this difference could be a general overestimate of pollution indexes in our attempts to quantify them (Table 5). If so, this overestimate could be due to other under-valuations, either an unsuspected generalisation of waste abatement measures, or a more rapid conversion to the use of chemicals in industrial processes than assumed, or an understatement of the importance of industrial recycling processes. These assumptions are all valid, but the first one is the most unlikely, and it will be discussed further below.

Alternatively, it could also be explained by a structural difference between town and countryside. In the urban areas of the watershed, the manufacturing processes in use and the existence of possible control may have somehow led to less polluting industrial practices that are reflected at the Brussels scale, and not at the watershed scale.

In any case, this question and its potential answers invite historians to reconsider the history of industrialisation by looking at the differences between urban industrialisation and rural industrialisation. Comparing our quantitative estimates to the scarce quantitative data directly available suggests that these neither followed the same processes and practices, nor did so at the same pace. Working between disciplines on a specific issue raised by hydro-biologists leads us to identify some patterns that can hardly be approached by a sole qualitative analysis. In this particular case, it leads us to raise the issue of polluting industries in terms of an urban/rural difference.

A socio-ecological perspective

The difference observed between the pollution in Brussels and the quantitative estimates at the watershed scale can be related to another observation. The data collected by Arthur Petermann in the years 1875–1877 (Table 1) shows that industrial activities in this time represented 895,000 inh.eq. and 80 % of the total nitrogen loss, while they represented “only” 195,000 inh.eq. and 37.5 % in 1898. In other words, the industrial organic discharge in 1898 is drastically lower than it was in 1875–1877. This trend is confirmed by other measurements made by physician Emile Van Ermengem (1851–1932) in 1897 (Van Ermengem 1898) which establish an industrial share of 55 % (Billen et al. 1999). Furthermore, the total nitrogen loading (industrial and domestic) in the river in 1898 represents less than half of what is was in 1875–1877.

Reflecting on this observation, one could conjecture that the years following the covering of the Senne (completed in 1871) and the extension of the sewer system in Brussels that followed (Van Mierlo 1878) correspond—chronologically speaking—to a general improvement of the quality of the water collected by the main sewer and eventually by the Senne River. This noticeable decrease in pollution is very difficult to explain as the covering was not coupled with any legal measure capable of significantly diminishing the pollution load. Indeed, the Belgian legislation on industrial nuisances cannot be considered as having had a significant impact on industrial pollution in the second half of the 19th century. The same conclusion has been drawn in other countries (Massard-Guilbaud 2010; Luckin 2000). For Belgium, it is even characterised by a step backwards in its consideration for "environmental" matters (Maréchal 2016; Verbruggen (2012) ; Devos 1980).

Furthermore, unlike other European cities, Brussels was not equipped with any water treatment plant at this time (or during the entire century that followed!) The legislation and law enforcement against waste discharge into rivers was still very mild. Some factors have even have increased the organic pollution discharged into the river, among which were the progressive disappearance of the collection of domestic waste as manure for agriculture.

Recycling the urban waste to agriculture

Until the 1860s, the importance of domestic waste and faeces for use as manure in agriculture (Figs. 5, 6) was well established. In the context of a general hunger for manure in European agriculture (Barles 2005a, b), urban domestic waste and excreta were still largely used as fertiliser in a wide area around Brussels, as they had been since the Middle Ages in many Brabant and Flemish cities. The Brussels municipality ran its own collection service, the 'Ferme des boues', responsible for emptying latrines and cleaning the streets. The faecal and organic matter was taken to the 'Ferme des boues' and poured into pools in order to ensure evaporation of surplus water (Fig. 5). The collected material was thus transformed into 'urban manure', sold to farmers and transported to the neighbouring fields. Brussels' faeces had a market value and constituted a substantial source of income

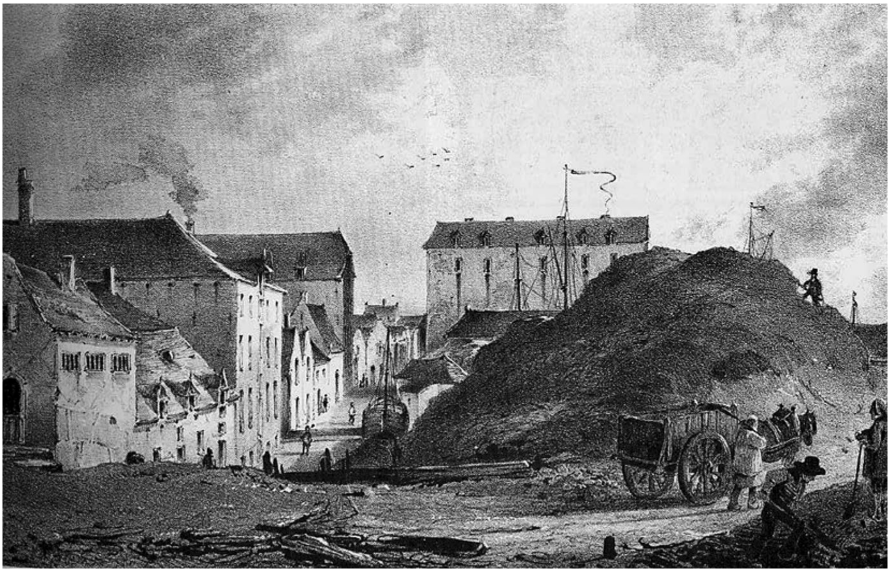

Fig. 5 The 'Ferme des boues' or 'manure heap' of the city at the beginning of the 19th century. It was moved outside the city in 1864, a few years before the burying of the Senne (J. Borremans, Brussels City archive)

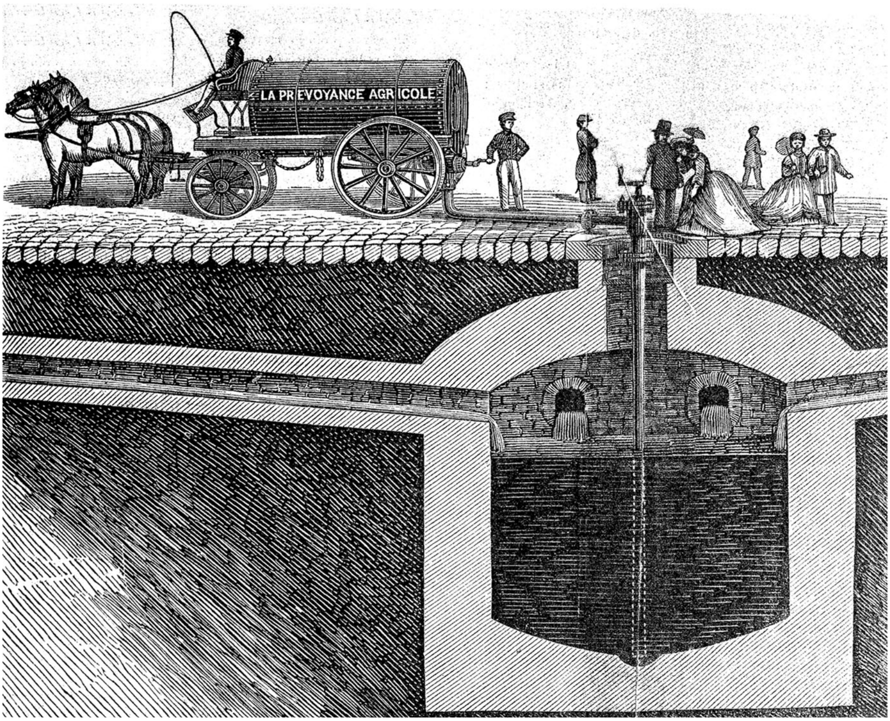

Fig. 6 Illustration for a project presented by a private company to municipalities aimed at reconciling health and agriculture interests. In: La prévoyance agricole. Programme de la société. La ville assainie et les campagnes fertilisées. Brussels, E. Guyot (19th century, no precise date, Brussels City archive)

for the municipal administration. As such, it indirectly contributed to the wealth of the urban population as much as the urban population contributed to the growth of the yields and profits of agriculture.

Disconnection between the city and its rural hinterland

But between 1860 and 1880 things changed progressively. Due to the general urban growth of Brussels (Table 6), and more generally of cities in Belgium, the volume of excrement increased considerably in big cities. The Brussels 'Ferme des boues' was faced with competition from neighbouring cities (mainly Antwerp and Leuven) and also from rapidly urbanising smaller neighbouring municipalities (Schaerbeek, Saint-Josse, Molenbeek), which also tried to sell their manure to farmers. In addition, and probably more significantly, new sources of fertiliser appeared on the market (guano, mineral fertilisers, industrial fertilisers, chemical fertilisers) and contributed to the decrease in demand for urban manure. In that respect, the decades 1860–1880 were a turning point.

Sanitation: a long process of decision

On their way to 'purifying' the city, Brussels authorities were faced with numerous projects for the sanitation of the city developed by private individuals (Fincoeur et al. 2000).

As in many cities at that time (Frioux 2013), many prominent and influential citizens competed to sell their more or less visionary projects for the future of Brussels to the urban authorities. Regarding the Senne issue, the projects proposed a wide range of solutions. While some of them promoted the 'covering' of the Senne in the city centre, others suggested the river could be diverted outside the city. Most of them insisted on the necessity of having the river water free from pollution and wastewater.

When the authorities decided in 1866 to cover the Senne, they were confident in their ability to maintain the recycling of wastewater for the fertilisation of crops. In the selected project of architect Léon Suys (1823–1887), wastewater from houses and industries was collected in separated sewers running along both sides of the covered river. This water should have been led to a treatment plant built outside the city, before irrigating the fields around it (Kohlbrenner 2014). While the first part of the project was realised, the second was not; the municipal council hesitated.

In 1866, a special committee was sent to England to observe the results of irrigation operations carried out in London. After crossing the sewage farms[3] in Blind Corner, the committee positively concluded that "the system used had no disadvantages with respect to the surroundings and that it lacked nothing in terms of water treatment" (Bulletin communal de la Ville de Bruxelles 1866; Kohlbrenner 2014). However, after the river was covered (1871), the municipal authorities gave most of their attention to building the boulevards that 'replaced' it in the city centre (see above, Fig. 2). The treatment plant and irrigation of the fields were delayed until the following years.

In 1873, the city decided to irrigate 50 ha of land downstream of the city as a trial for a possible larger scale project. After long discussion, notably about the controversial case of Gennevilliers,[4] near Paris, the project was accepted and in October 1879, the members of the city council went to the site to observe the results. According to the alderman for finances, the experiment had not been a success; the expenses had outweighed the takings. Therefore, in order to study alternatives, a new committee was established in 1880. In its report of 4th March 1882, the committee considered two new projects for wastewater treatment. Significantly, they pointed out that no law was opposed to "the sewage from a city mixing naturally with the water in a river which would pull it away and pollute and infect the water downstream". Moreover, the committee maintained that "one of the roles of waterways in nature was precisely to sanitise their banks by pulling all putrescible matter far away". In other words, the evacuation of urban waste was presented as the main quality of rivers! In conclusion, the committee pointed out that "the City of Brussels simply made use of a natural law by dumping its sewage in the Senne, and that if this resulted in a disadvantage for the downstream area, the community, i.e. the province and the government, was responsible for dealing with it" and not the city! (Bulletin communal de la Ville de Bruxelles 1882; Kohlbrenner 2014)

Between the beginning of the covering works and the early 1880s things had changed much: the reuse of urban waste as fertiliser for agricultural needs was clearly not on the agenda anymore. In this light, the decrease of the total organic loss observed in the river

[3] The term 'sewage farm' was used to describe the peri-urban territories where collected wastewater was distributed onto croplands in order to stimulate their productivity. Such experiments were conducted in many cities at that time in Paris, London, Vienna, Berlin for example.

[4] The municipality of Paris developed an impressive irrigation network for spreading its sewage and sludge in the second half of the 19s century. Gennevilliers, a municipality just outside and downstream of Paris, was one of the largest area where this spreading occurred. In 1879, some 380 ha where fed by urban manure. Nevertheless, opinion was divided about the case, its sanitary aspects, its effect on the value of the land, etc. It led to never-ending discussions and trials (Barles 2005a, b, pp. 285–303).

Senne during the second half of the 19th century appears all the more surprising as we can assume that a great deal of the waste that was still collected by the 'Ferme des boues' in the 1870s ended up in the sewer-river by the 1890s. If so, the decrease of the total organic load seems even more enigmatic and can only be attributed to a severe decrease of the industrial load.

Yet, legislation and law enforcement did not play a crucial role in the decline of the industrial contribution to water pollution, despite some attempts by the provincial powers responsible for water quality management. In 1861 the provincial administration, among some other measures, appointed an inspector who was in charge of watching the "insalubrious factories located along the Senne and its tributaries". This public servant had to monitor whether the factories that were officially listed as insalubrious (about twenty in Brussels' territory) complied with the 1860 provincial rules on the construction of retention ponds, where wastewater had to be stored for settling before being discharged at night into the river (Deligne 2001).

However, the way Brussels authorities treated the reports made by this inspector on several occasions clearly indicate that it was not their priority to act against 'oblivious' industrialists. Many inspectors did not hold themselves to the highest level of integrity and honesty in that matter, but Brussels' authorities were not very quick or efficient to react to their failures. If industrial waste appeared as a concern in the middle of the 19th century, it was by no means considered a priority. The protection of industrial activity, considered as the guarantee of prosperity, was another important reason for this inaction (Balcers and Deligne 2011).

In other words, the project for the treatment and use of wastewater was delayed, reduced to the bare bones, and eventually abandoned. In the end, the emptying of the wastewater of Brussels into the Senne—first presented as a provisional situation—became a long-lasting reality. The burying/covering of the Senne had no direct impact on the treatment of its water; in fact, it reinforced its role as the "ultimate sink"(Tarr 1996). Indeed, in the course of the second half of the 19th century, a growing amount of Brussels' faeces was gradually discharged into the river/sewer system instead of being integrated in recycling processes (Van Mierlo 1878).

And yet, organic industrial pollution decreased significantly between the 1870s and the 1890s. Three main phenomena can explain this phenomenon and may have been combined. The first is the rapid conversion of industrial manufacturing processes towards chemical resources; the second is the implementation of recycling processes inside and between different industrial sectors; the third is the quick reconfiguration of the industrial landscape of Brussels in those years. The rapid relocation observed for the brewing sector after the covering of the river in the city center (De Keukeleire 1990) may also have been true, and perhaps for other reasons, for other identified polluting factories like glue and gelatin industries, paper industries, etc. (Table 5).

Conclusions

This study started with questions about the quality of the Senne River in the years following its covering. The study ends with an invitation to historians to deepen their knowledge of the transformation of industrial activities during the last decades of the 19th century in general and Brussels in particular. Despite the difficulties in collecting relevant historical sources on this question—it is indeed very difficult to 'get inside' vanished factories through archival material—it should be possible, next to the census data, to get relevant information, especially from the numerous local professional, technical and scientific journals which flourished in the second half of the 19th century. One or two significant industrial sectors could be taken as first samples, for example the brewery sector.

For now, combining a ‘traditional’ historical approach and a reconstructed quantitative analysis, my survey of the water quality of the Senne and its evolution during the 19th century allows us to better understand the reality of the pollution in the second half of the 19th century.

On the one hand, the quantitative approach clearly demonstrates that the river was filled with dozens of tons of organic matter, discharged into the water system on a daily basis. The material available allows us to rank the different industrial sectors according to their ‘pollution potential’ and to give a better view of the nature and structure of polluting activities. As such, it opens the way for comparison with other industrial cities.

On the other hand, the historical approach tells us that water quality was an ambiguous issue for urban authorities. The unsanitary nature of the river was systematically denounced. What was important for authorities was the value of the manure they could take advantage of, at least as long as it had a real value. When this value became insignificant, the most important thing for Brussels’ city authorities was not to give a penny to the water treatment but, if possible, to make other institutions or levels of power carry the costs.

Finally, review and reinterpretation of previous interdisciplinary work and its data suggest a rapid transformation of industrial activities and industrial landscape in Brussels between the 1870s and the 1890s, i.e. a little over two decades. The transformation becomes visible in terms of the number and types of industries and in the industrial processes in use. In other words, this paper opens the path to further research about how to understand the transformation of industrial practices, in particular when reasons are not likely to be found in any evolution of relevant legislation.

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