Nitrate contamination in the Seine Basin, France

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Introduction

Nitrogen is a critical source of nutrients and organic matter. It is essential for living organisms but can be harmful above a certain concentration. Its reduced forms (NH_4^+/NH_3) are toxic to fish, and its oxidized forms (NO_3/NO_2) are especially known to cause the Blue Baby Syndrome in infants. Moreover, the oxidation of ammonia leads to oxygen depletion. Thus, nitrogen concentration in rivers needs to be closely monitored. The objective of this project is to model nitrate loads to the Seine River using a model that simulates the nitrate loads resulting from non-point sources through groundwater and surface water runoffs and nitrate loads recorded in the effluents of wastewater treatment plants.

The Seine Basin covers a catchment area of about 100,000 km^2. The Seine River is 776 km long and expands from Northeastern France at the boarder with Belgium to the English Channel.

Figure 1 - The Seine Basin, France

The Seine River runs through the large conurbation of Paris with about 10 million inhabitants and surrounded by intensive agricultural areas. Since agriculture requires the use of fertilizers and a high population density affects wastewater quality, it is particularly interesting to study nitrate loads to the river in this Basin.

I. Nitrate leaching in the Seine through non-point sources: Runoff and Groundwater

a. Data and Method

Data

Nitrate loads to the river through runoff and groundwater were provided by Ahmad Tavakoly. He generated daily nitrogen leaching in the Seine for the period of 1970-2009 for 6481 river cells. Coupling the hydrological model of Eau-Dyssée and the agronomic model of STICS, he was able to compute nitrogen loads to the river. Eau-Dyssée calculates flows, runoffs, water levels, and leaching nitrogen to river cells while STICS calculates water, carbon and nitrogen budget leaving the root zone depending on climate and crop management.

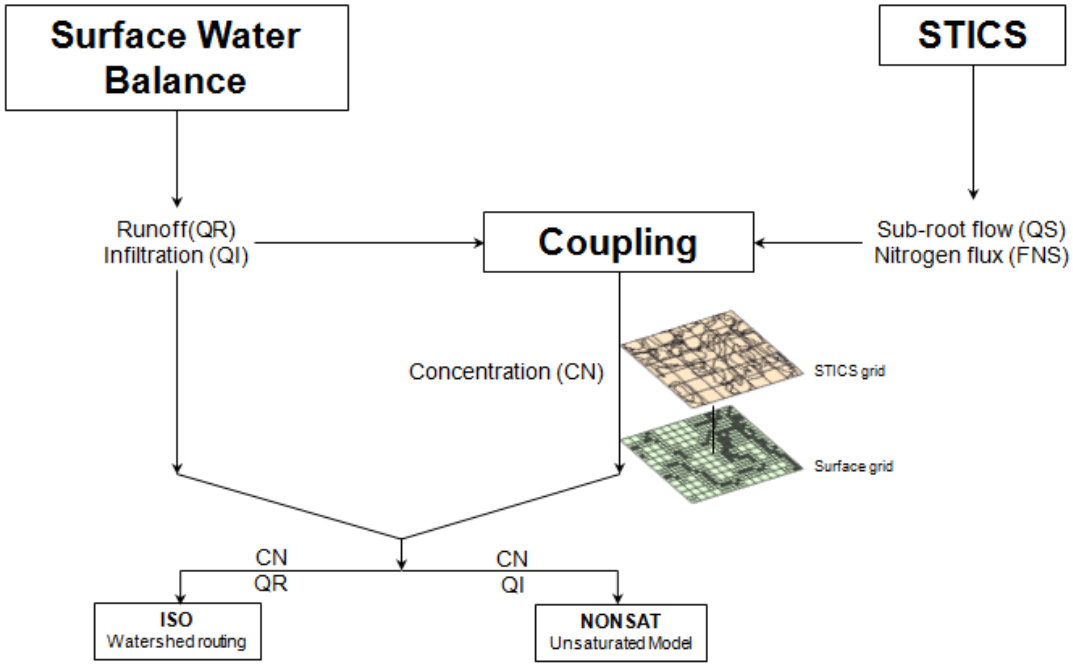


Figure 2 - Schematic framework of Ahmad Tavakoly's model (by Ahmad Tavakoly)

Nitrate leaching to river cells was grouped into two categories: the river cells upstream of the river called “upstream” and the others called “influent” which account for most of the cells (6369 cells).

The data selected for this analysis is the daily nitrogen load to “influent” river cells for the year 2009.

To describe the land use of the Seine Basin, a map from the Corine Land Cover 2006 inventory is used.

Method

Treatment is first necessary to convert the data to a readable file for ArcGIS. Once the daily nitrogen leaching is uploaded, it is joined to shape files called “Seine_RAPID_cell_manning” representing the Seine River in the Paris Basin (3519 cells)

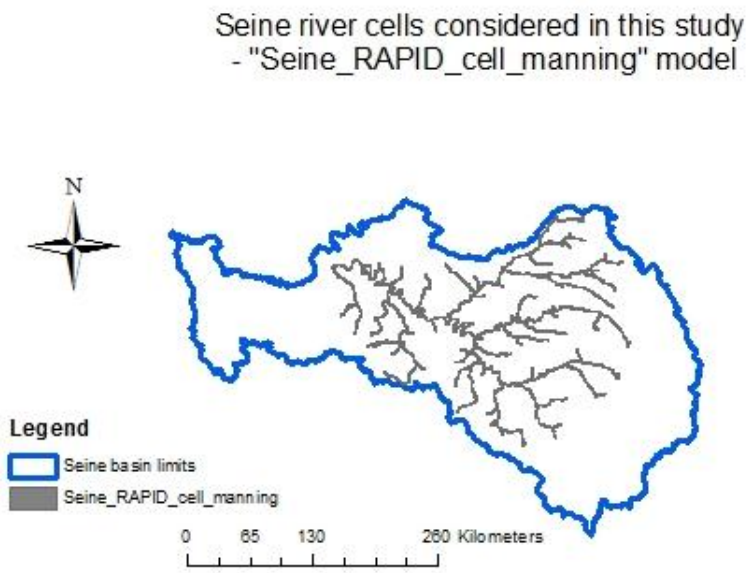


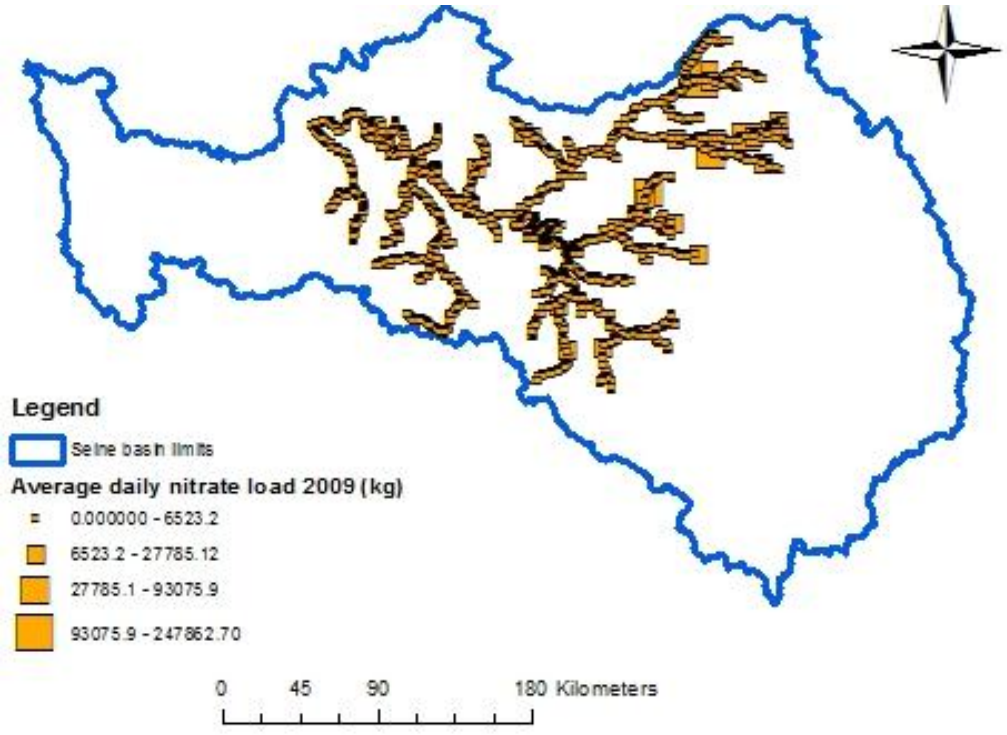
Figure 3 - Seine River cells considered in this study

b. Results

Spatial analysis

For each day of 2009, a map of the nitrate loads to the river in the Seine Basin is generated.

The average daily nitrate leaching to the Seine River is computed.



It appears that the largest daily nitrate loads to the river are in the suburbs of Paris and that there is less nitrate in the center of Paris.

Figure 4 - Average daily nitrate load to the Seine River cells in 2009 through runoff and groundwater

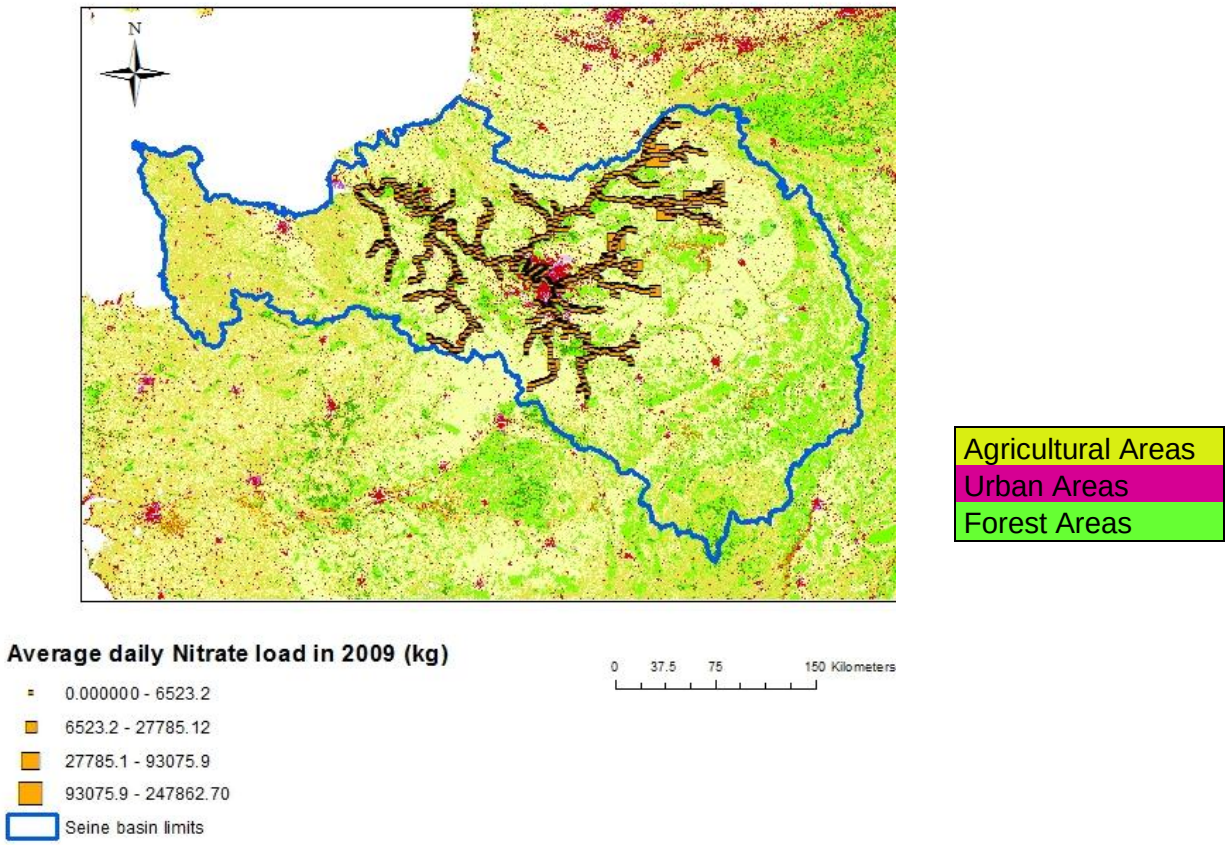


Figure 5 - Nitrate load through runoff and groundwater in 2009 and land use

It is interesting to compare this spatial distribution with land use (Figure 5). The high nitrate loads correspond to the agricultural areas and the relatively low loads correspond to the extensive urban area of Paris and around the city. Thus the high nitrate loads to the Seine are due to the intensive use of fertilizers, and to the nutrients generated by livestock farming.

Temporal analysis

The nitrate loads to the River Seine vary with time.

When looking at 4 different dates in 2009 - respectively from the left to the right and from the top to the bottom in Figure 6 - the 15th of January, the 10th of April, the 19th of July, and the 7th of September, it appears that the load of nitrate changes a lot, but is consistently higher in the provinces than in the Paris conurbation.

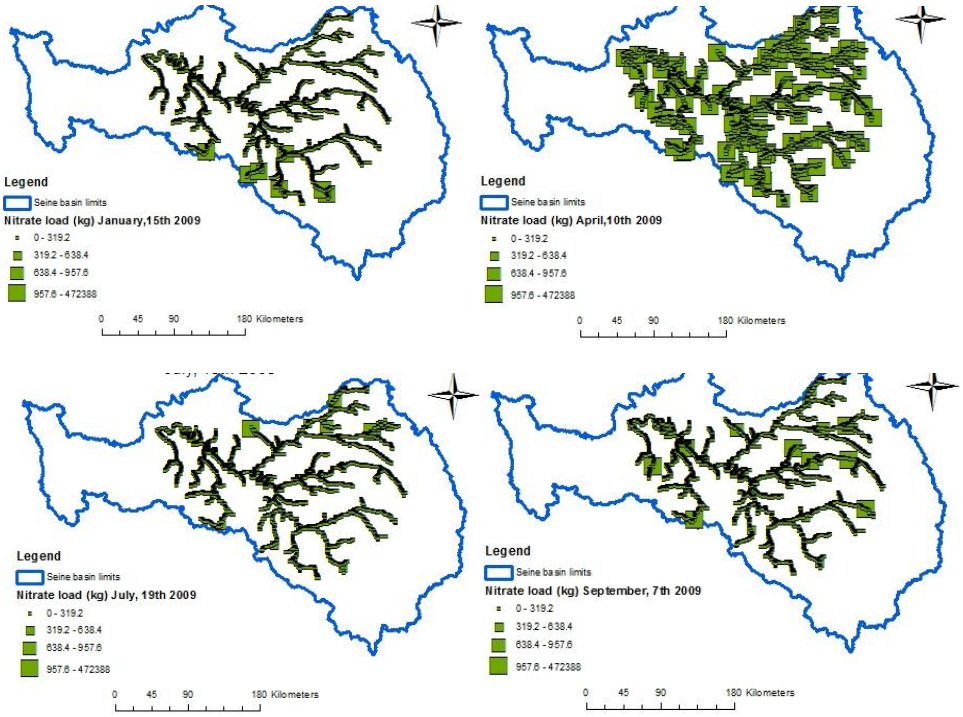


Figure 6- Maps of the Nitrate leaching to the Seine River cells on January 15, April 10, July 19 and September 7 in 2009 (from the top left to the bottom right)

Nitrate loads to the river depend on rainfall. Figure 7 below shows the dependence of nitrate concentration on runoffs in one river cell in 2009. When it rains, the runoffs wash the nitrate on the surface and bring it to the river. This results in an increase in the concentration of the nitrate in the river.

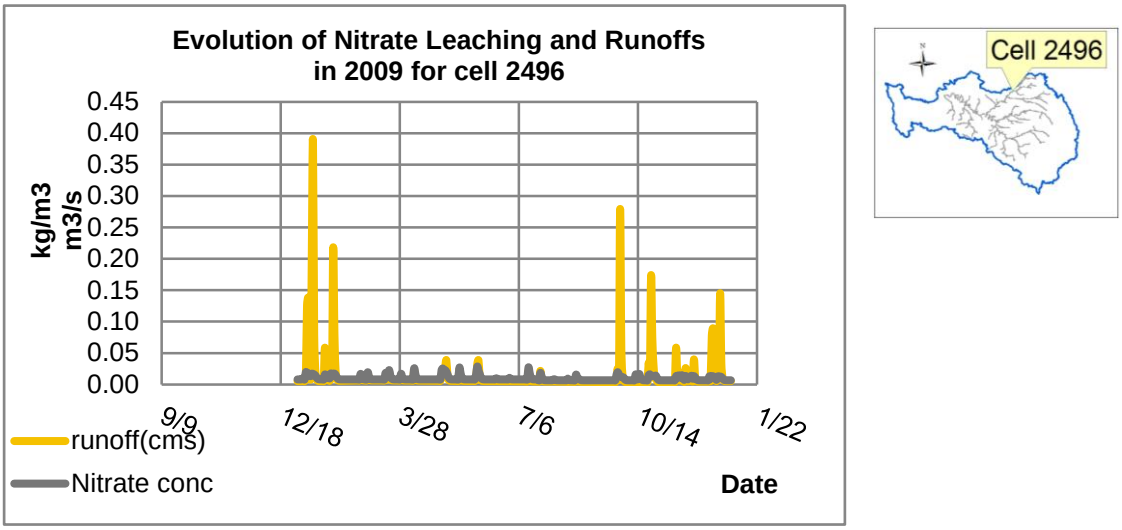


Figure 7 - Comparison on Nitrate leaching and of runoffs in cell 2496 in 2009

II. Nitrate loads in the Seine through point sources: Wastewater Treatment Plants effluents

a. Data and method

Data

Nitrate in the effluents of wastewater treatment plants is analyzed using data provided to Ahmad Tavakoly by the Centre de Géosciences, MINES ParisTech, France. It is composed of the daily nitrate load averaged over one year for the period of 1999-2007 for each one of the 2596 wastewater treatment plants of the Seine Basin.

To represent the population density, data from Geofla – Institut National Géographique is used.

Method

The data is first aggregated into one file readable by ArcGIS describing, for each wastewater treatment plant and for each year, its average daily nitrate emission.

Given that 2% of the effluents were directed to groundwater, in 2007, only the wastewater treatment plants emitting to surface water are selected in this project. The daily nitrate emission is then averaged over 1999-2007 for each treatment site. Finally, only the 10% highest emitters are selected and the wastewater treatment plants that are located within 1km of a river cell.

b. Results

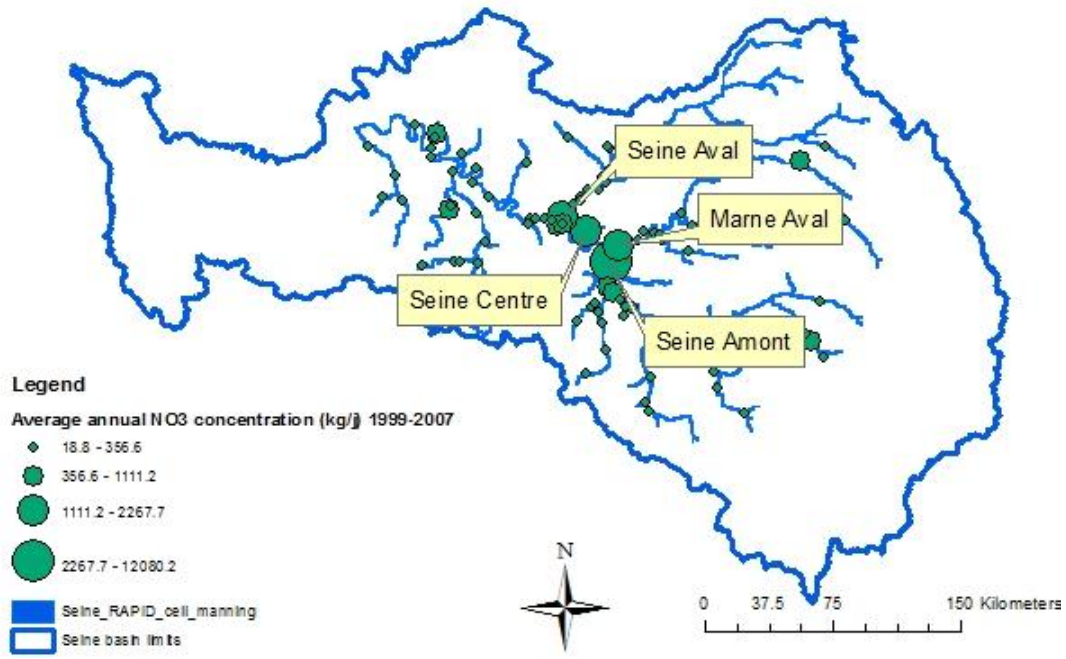


Figure 8 - Wastewater treatment plants for the Seine Basin and their annual average emissions of NO3 (kg/day) in 1999-2007

The biggest emitters are located in the Paris area.

They correspond to the four wastewater treatment plants in use in 1999-2007 for the city of Paris: Marne Aval and Seine Amont upstream of Paris, Seine Centre downstream of Paris and Seine Aval downstream of the conurbation.

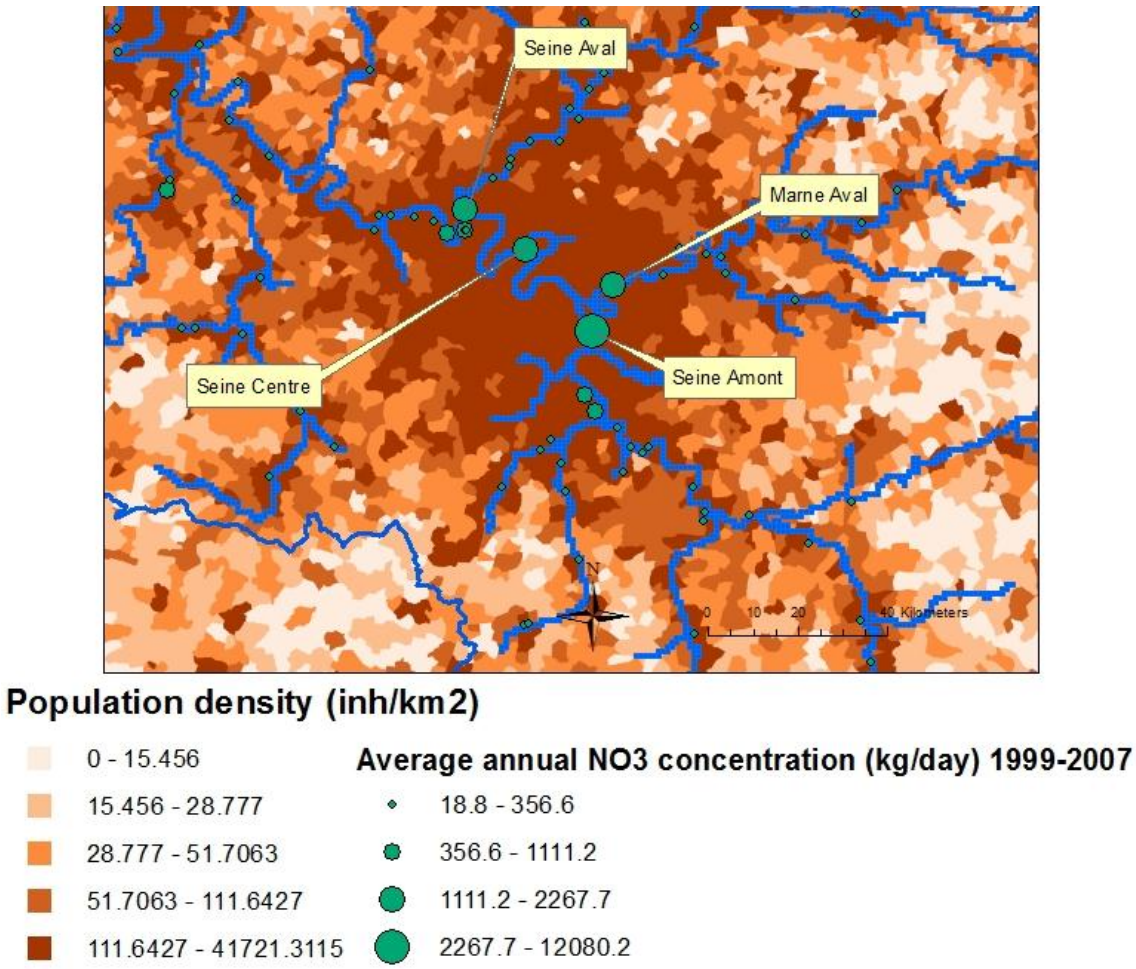


Figure 9 - Wastewater treatment plants for the city of Paris 1999-2007 and Population density

In Figure 9, high population density areas match high nitrate loads.

Moreover, the annual variations of NO_3 can be closely related to changes in population. For example, Figure 10 below shows the increases in population and in nitrate from one year to another around the Seine Amont treatment plant.

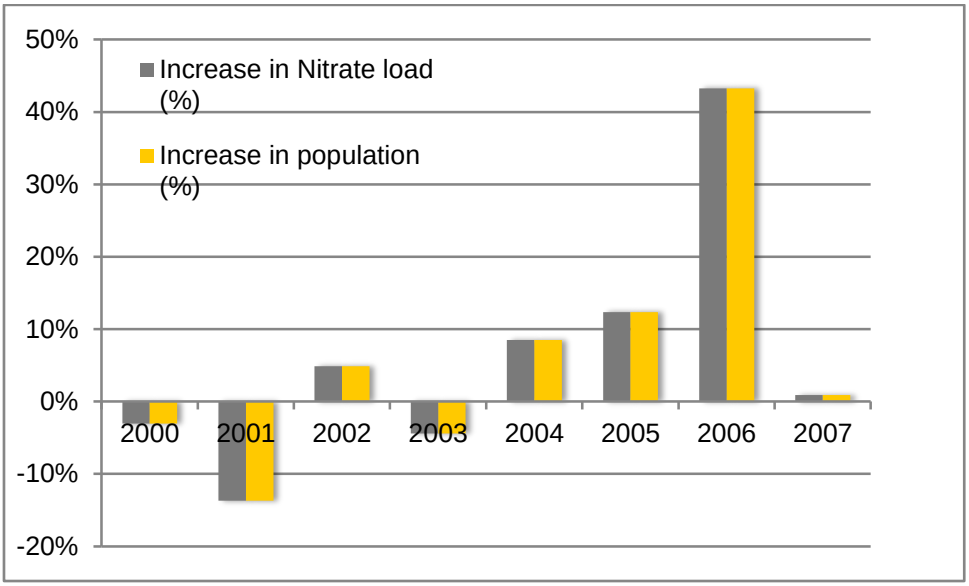


Figure 10 - Changes in population and in nitrate load in the effluent of the treatment plant Seine Amont

Thus, high nitrate pollution is caused by the anthropogenic activity in Paris.

c. Comparison with published data

The wastewater treatment files provided by the MINES ParisTech don't display full denomination of the items described. Acronyms are used, and units are not shown. The names of some wastewater treatment plants change over time. It is assumed that the NO_3 concentration is in kg/day and that the volume of wastewater treated is in m^3/d. Thus, the daily NO3 concentration is obtained by kg in mg, m3 in L and NO3 (mg/L) in N-NO3 (mgN/L) using the coefficient 4.429.

Plant	Marne Aval	Seine Amont	Seine Centre	Seine Aval
Q effluent (m3)	**43217**	**431750.5**	**154183**	**1323567**
	30000	600000	240000	1800000
N-NO3 (mgN/L)	**8.9**	**8.9**	**3.4**	**0.1**
	30	15	15	2
DBO (mgO2/L)	**19**	**3.9**	**10**	**15.6**
	25	4	9	25

Source	Year
Calculated with data provided by Centre de Géosciences, MINES ParisTech	**2007**
L'Assainissement de l'Agglomération Parisienne, J-P Tabuchi, Mai 2008	2006

Figure 11 – Nitrate loads and volume of treated water calculated in this study and values published for the years 2006 and 2007

The calculated concentrations of nitrate (in bold in Figure 11) are much lower than the values found in the literature. A possible reason for that is either a wrong interpretation of the units of the raw data and of the multiple names attributed to the same treatment sites or an incomplete data initially. However, the calculated values show the same trend as the published values : High concentrations of nitrate in Marne Aval and Seine Amont, and lower concentrations in Seine Centre and Seine Aval. The nitrate concentration decreases downstream of the river. It is interesting to note that three out of four of the wastewater nitrate concentrations published are above the trigger value of 11.3 mgN/L set in the EU – Nitrates Directive and one is below 0.5 mgN/L.

III. Contributions of wastewater treatment plants to the overall Nitrate loads to the Seine River

Nitrate (kg/d)	Total	Paris	Malesherbes	Reims
2009 -Non Point sources- Runoff/Groundwater (number of river cells)	1416712 (3408)	0 (4)	27785.1 (1)	894.6 (1)
1999-2007 -Point sources- Wastewater treatment plants (number of river cells)	27657 (81)	16165.6 (4)	52.6 (1)	740.3 (1)
Contribution of point sources of nitrates to the overall nitrate load	2%	100%	0%	45%

Table 1- Comparison of Nitrate load to the Seine River due to point sources (wastewater treatment plants) and non-point sources (runoff and groundwater)

In Paris, 16,165 kg of NO_3 are delivered daily to the Seine through wastewater treatment plants and there is no detectable nitrate leaching through runoff and groundwater.

However, the overall nitrate balance in the studied area is mostly due to runoff and groundwater with only less than 2% of nitrate loads due to wastewater treatment. Moreover, the highest nitrate loads due to leaching are found in cities like Reims and Malesherbes, at a distance of 150 and 100km from Paris and which are characterized by husbandry as well as urban activities.

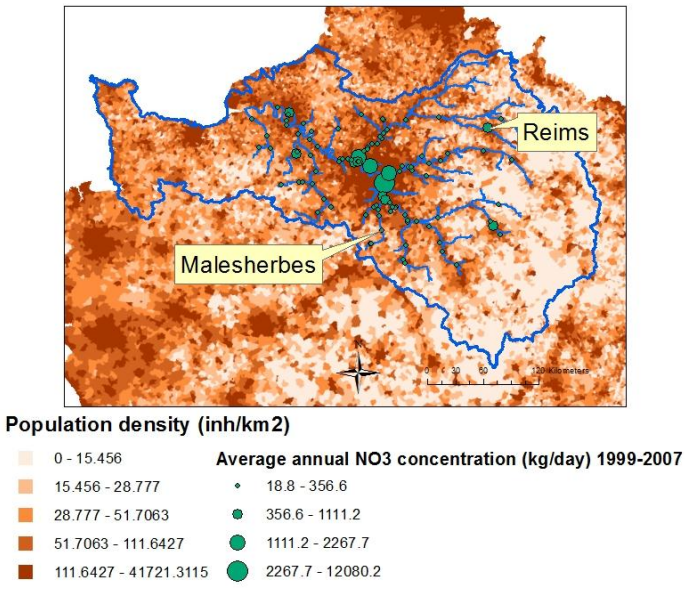


Figure 12- Reims and Malesherbes

In order to simulate local and daily nitrate contamination in the Seine River, wastewater treatment plants impacts should be taken into account

in the nitrogen modeling in the Paris Basin for the period of 1999-2007.

IV. Limitations

Two different time periods

The timespans considered are the year 2009 for the nitrate leaching to the river through runoff and groundwater and 1999-2007 for Nitrate loads due to wastewater treatment plants effluents. Even though it is acceptable to consider that the average nitrate leaching through runoff and groundwater are similar in 2007 and in 2009, it might not be relevant to consider that the emissions of wastewater treatment plants in 2009 are similar to the emissions of wastewater treatment plants in 1999-2007. Because of high nitrate concentrations in the effluents of the wastewater treatment plants of Paris, a plan of action was decided in 2007 to improve water quality and comply with the requirements of the European Union Nitrate Directive (1991) “Directive on Urban Waste water”.

Consequently, a new wastewater treatment plant was built in 2008 at Triel-Sur-Seine, the wastewater treatment plant Marne Aval was remodeled in 2009 and it divided by 2.5 the nitrate contamination in its discharge. Moreover, an additional treatment unit of nitrification/denitrification was implemented in the main wastewater treatment plant Seine Aval in 2007.

Thus, the reason why the available data provided by the Centre de Géosciences, MINES ParisTech, France is limited to 1999-2007 might be because of important changes in the management of Parisian wastewater systems after 2007. Over the period of interest for Ahmad Tavakoly’s project (1977-2009) and for a local analysis, it would be relevant to compare the nitrate leaching to nitrate loads in waste water treatment plants effluents before 2007. In any case, this study demonstrates that the nitrate in the river is mostly due to nitrate leaching through runoff and groundwater and so this contribution should even increase with the improved nitrate treatment in plants after 2007.

Spatial limitation

Only the river cells around the Paris Basin (“Influent”) are studied. It is important to keep in mind that the river cells of the Seine river farer from urban areas and that might not have been taken into account might have a large impact in terms of nitrate leaching due to agriculture.

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Conclusions

ArcGIS is used to analyze the main sources of nitrates in the Seine Basin in 1999-2009: On the one hand, nitrates generated in the crop-soil system and enriched by the use of fertilizers and by farming are transported to the Seine River through runoff and groundwater. On the other hand, nitrate concentrations in wastewater treatment plants effluents are often high in urban areas. Outside of the conurbation of Paris, the water quality of the Seine River is degraded because of the agriculture and husbandry whereas the intense anthropogenic activities around the capital city cause high nitrates concentrations in wastewaters and thus in wastewater treatment plants effluents when the plants are not fully efficient.

Thus, the levels of nitrates in the Seine Basin are high in the studied period and are even sometimes above the level of 50 mg/L. In 2007, the French Government took a series of measures to improve water quality in the Seine Basin and comply with the requirement of the European Union on nitrate concentration in the waters.

On a large scale, nitrate leaching to the Seine River through runoff and groundwater is much more important than nitrate concentration due to wastewater treatment plants effluents. On a local and daily scale, urban areas affect nitrate loads to the river and should be considered for a proper analysis especially as water treatment systems are evolving to comply with the legislation and to better protect the environment.

Acknowledgements

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