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Environmental effects of WWTP discharge on the quality of the receptor river

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ABSTRACT

The aim of this study was to examine the water quality of a small stretch of the Po River in the Piedmont region (northern Italy). Along this stretch the wastewater treatment plant (WWTP) located in Castiglione Torinese treats a large pollution load derived from Turin's metropolitan area (about 2 million population equivalent), and discharges it into the Po River. The objective of the study was the definition of the environmental impact produced by the Castiglione Torinese WWTP on the water quality of the river, based on various hydrological conditions, and to recommend possible interventions on both the point and diffuse loads. In order to obtain this result the different loads in terms of sources, destination, and effects of the emitted pollutants were characterized. The obtained results show that the environmental status of the Po River is only minimally influenced by the Castiglione Torinese WWTP discharge, and hence the necessary intervention would be on the diffuse load rather than the treatment plant.

Keywords: Water quality; Flow rate; Wastewater treatment plant; Pollution load

1. Introduction

The stretch of the Po River that runs through the Turin area is subjected to pollution loads from several sources, and when evaluating the water quality, all the emissions in the metropolitan area must be considered, including the diffused industrial and agricultural activities [1]. Discharge from the Castiglione Torinese wastewater treatment plant (WWTP), one of the largest WWTPs in Italy (serving about 2 million population equivalent), for example, which certainly influences the water quality of the Po River. Therefore, as a part of the implementation of the Water Framework Directive 2000/60/EC [2], it was necessary to determine what effect this major intervention is having on the water quality of the Po River, with particular attention to nutrients that could cause eutrophication [3,4] as identified in the Water Framework Directive 2000/60/EC [2]. Eutrophication [5] is the enrichment of water bodies by nutrients, especially compounds of nitrogen (N) and phosphorus (P), which can cause accelerated growth of algae and higher forms of plant life that produce undesirable aberrations in the balance of organisms and the quality of the affected water [6,7].

Concerning the nutrients there are many studies that cause eutrophication in the literature [8,9]. As the Po River is subject to other essentially non-point pollution loads, and is vulnerable to biological effects, it is necessary to determine the limits that should be placed on the impacts coming from various origins, in order to achieve the desired quality targets for the river water. Consequently, it is important to understand how, and how much, the stretch of the Po River that runs through the Turin area is affected by point and diffusive load sources.

Concerning the Po River there are many literature that try to characterize the river in terms of hydrological [10]

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and morhodynamic modelization [11,12], from the point of view of the quality [13] and of the ecological risk [14] and also from the point of view of the possible effect on climate change [15].

In the previous work [16], a modeling approach was chosen for analyzing the Po River water quality in the stretch of about 10 km between Castiglione Torinese and Gassino—localities in the Piedmont region (northern Italy). This selected river stretch is affected by three principal types of loads that influence the water quality in the Turin area and downstream. Two of these loads are of diffuse origin (one from agricultural discharges and the other from meteoric waters) while the third is of point origin—namely, the discharge of the Castiglione Torinese WWTP [17]. The previous analysis attempted to define, by means of a qualitative study of the water, the nitrogen composition of the loads, and to determine their effect on the water quality of the Po River through a series of load comparisons.

The present work continued the previous study and used the same methodology adopted there, based on the tool of mass balance (this is a traditional approach as demonstrated in the literature [18–20]). In particular, the analyzed stretch was extended up to Chivasso station (increasing the length of the analyzed stretch to about 20 km) in order to understand whether the Po River presents an auto depurative capacity. Moreover, since another study [7] identified the phosphorous concentration as the key element in controlling eutrophication, in this work this parameter has also been considered and analyzed. In addition, a model of the average load was built [18], using the mass balance method [21,22], and the influence of the Castiglione Torinese WWTP on the Po River water quality was analyzed over a period of 4 years, from 2007 to 2011. Subsequently, on the basis of sample collection and analysis, the WWTP discharge influence was evaluated again, and a comparison was performed between the new (from the sampling operation) and historical data, in order to determine whether the pollution loads have been changing over time.

The methodology approach proposed in this work can be helpful for planners and administrators of the river system, in order to develop future intervention policies for the river stretch. In addition, the developed methodological approach can be adopted for other meaningful evaluations of pollution-load impacts, from both concentrated and diffuse sources.

2. Materials and methods

2.1. Studied stretch of the river

This study considered the stretch of the Po River between Castiglione Torinese (approximately 6,500 inhabitants) and Chivasso (approximately 27,000 inhabitants) with a length equal to approximately 20 km (Fig. 1). In this stretch, the river runs through the Castiglione Torinese WWTP and also through a territory employed primarily for agriculture. The SMAT WWTP is one of the largest Italian WWTPs, treating the metropolitan wastewater of the entire Torino area (with more than 2 million inhabitants). The uses of the soil in the Piedmont region are shown in Fig. 2.

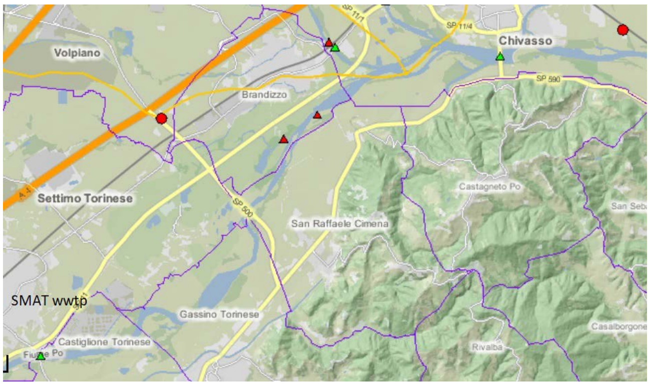

Fig. 1. Studied area.

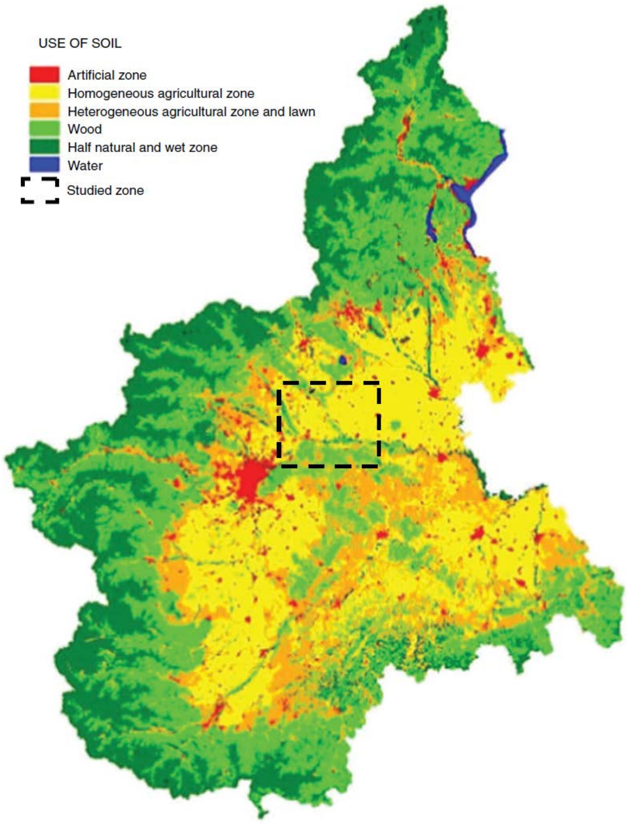

Fig. 2. Uses of soil in the region.

2.2. Analyses performed

Fig. 3 depicts the scheme of the analyzed Po River stretch. In this work, three kinds of analyses were performed:

- The first analysis consisted of the following simulation (after reconstructing the hydrological and qualitative framework using historical data (2007–2011)):
  - Definition of the load increase in the stretch between Castiglione Torinese and Chivasso, as well as separation of this load increase into two parts, one attributable to the WWTP discharge and the other to the diffuse source.

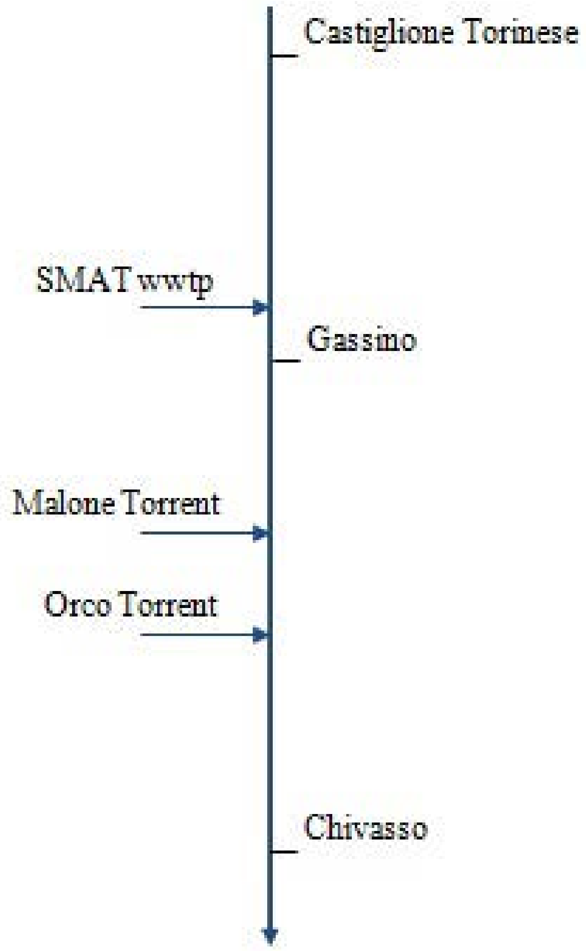

Fig. 3. Scheme of the studied area.

- The second analysis consisted of a simulation parallel to the previous one but based on a sampling campaign to rebuild the hydrological and qualitative framework.
- The third analysis consisted of the environmental state definition of the analyzed river stretch.

2.3. Data acquisition

For the evaluation of the pollution loads, official monthly concentration data were used, but daily flow rates were obtained from the Piedmont Regional Administration [23]. WWTP data were directly supplied by the WWTP manager.

In order to define the pollution load, which is required for the model and for the mass balance method, it was necessary to compile a complete hydrologic description of the area. Unfortunately, it was only with great difficulty that all the necessary data were gathered. The main source for the flow data was the Piedmont Regional Administration. Even these data, though, were incomplete; in fact data from some monitoring stations were not even available. In order to reconstruct the flow-rate data for the missing stations, a chloride balance was performed (considering the conservative nature of this parameter) using the methodology already adopted in the previous work [16].

Table 1
Malone and Orco Torrents' historical flow rates (means of 9 years, from 2002 to 2011)

	$Qm_{Orco\ Torrent}$ (m^3/s)	$Qm_{Malone\ Torrent}$ (m^3/s)	Weight of Malone Torrent on Orco Torrent (%)
January	7.72	4.08	52.9
February	7.78	4.55	58.5
March	13.04	6.30	48.30
April	28.41	9.41	33.10
May	37.23	8.92	24.0
June	42.15	9.39	22.30
July	10.21	4.99	48.90
August	6.44	4.70	73.0
September	14.94	6.18	41.40
October	9.66	4.27	44.20
November	23.81	12.74	53.50
December	12.35	9.19	74.40
Mean	17.8	7.06	39.70

As for historical data, all information concerning the flow rate of the considered stations (Fig. 1) were available, apart from the station of Chivasso, for which, as previously reported, a chloride balance was performed. But for the new sampling data, neither the values for the Chivasso station nor those for the Torrents Malone or Orco were available. For this case, however, it was not possible to use the chloride balance directly, to define the flow rate value for the Chivasso station, because there was one more variable. Hence an approximation was used. Data for the flow rate trends of the two torrents (Malone and Orco), for the 9 years of 2002–2011, were analyzed. Results of this analysis showed that the flow rate of the Malone Torrent was quite low in comparison with that of the Orco Torrent (usually less than half). This observation is confirmed by the information reported in Table 1.

In order to simplify the data calculation, a unique inlet from the Orco Torrent was considered, and 40% (a value obtained from the performed historical analysis) was added to the Orco flow rate.

In this way, the mass balance became the following:

$$\text{Flow rate}_{Gassino} * [Cl^-]_{Gassino} + (\text{Flow rate}_{Orco\ Torrent} * [Cl^-]_{Orco\ Torrent}) * (1 + 0.40) = \text{Flow rate}_{Chivasso} * [Cl^-]_{Chivasso} \quad (1)$$

From Eq. (4), it is possible to derive:

$$\text{Flow rate}_{Chivasso} = (\text{Flow rate}_{Gassino} * [Cl^-]_{Gassino} + (\text{Flow rate}_{Orco\ Torrent} * [Cl^-]_{Orco\ Torrent}) * (1 + 0.40))/[Cl^-]_{Gassino} \quad (2)$$

Data concerning the water quality were obtained, as noted above, partly from the Piedmont Regional Administration and partly from the WWTP manager. The chemical parameters to be monitored were chosen taking into account the necessity of performing the following analyses:

- Study of the Po River water quality in the stretch between Castiglione Torinese and Chivasso.
- Evaluation of the water pollution with reference to the Italian law D. Lgs. 152/06 [24].

Therefore, concerning the water quality analysis of the Po River, the total nitrogen and total phosphorous concentrations were selected, and dissolved oxygen, BOD_5, COD, NH_4, NO_3, total phosphorus, and *Escherichia coli* were chosen as parameters for the water pollution evaluation.

2.4. Methodology adopted

The aim of the analysis was to determine the influence of the Castiglione Torinese WWTP on the increased nutrient concentration between the two stations, Castiglione Torinese and Chivasso, compared with that of the other main sources (diffused sources, primarily from agricultural discharge). For the analysis (taking into account both historical and sampling data), the following equations were used (the load is obtained by multiplying the flow rate by the pollution concentration):

$$\text{Load increase}_{\text{Chivasso-Castiglione}} = \text{Load}_{\text{Chivasso}} - \text{Load}_{\text{Castiglione}} \quad (3)$$

$$\text{Influence of WWTP} = (\text{Load}_{\text{WWTP}} / \text{Load increase}_{\text{Chivasso-Castiglione}}) * 100 \quad (4)$$

$$\text{Diffuse load} = \text{Load increase}_{\text{Chivasso-Castiglione}} - \text{Load}_{\text{WWTP}} \quad (5)$$

As previously indicated, the analysis was performed for the two parameters total nitrogen and total phosphorous.

The water classification methods required in the Italian law D. Lgs. 152/06 [24] were used to evaluate the pollution conditions. The decree establishes that the environmental state[1] (SACA – Stato Ambientale dei Corsi d'Acqua, Environmental State of the River Streams) of the river surface water be evaluated on the basis of both its chemical and its ecological states. The ecological state (SECA – Stato Ecologico dei corsi d'acqua, Ecological state of the water streams) is an expression of: the aquatic ecosystem complexity; the physical and chemical nature of the water; and the flow characteristics and physical structure of the water body; these elements are all based on the state of the ecosystem biotic elements. The ecological state is derived from the value of the pollution level, expressed by the macro descriptors (DO%, BOD_5, COD, NH_4, NO_3^-, total phosphorus, and *Escherichia coli*) (LIM – Livello di Inquinamento dei Macrodescrittori) [24] and the IBE (Biotic Extended Index) index [24]. The chemical state is based on the presence of micro pollutants, mainly hazardous chemical substances (e.g., heavy metals), in accordance with the table in D. Lgs. 152/06 [24]. The environmental state of the river stream can then be obtained by crossing the results of the ecological state evaluation and the chemical state evaluation [24]. The environmental state is expressed as excellent, good, acceptable, poor, or very bad.

1 The environmental state is defined in relation to a reference water course – a river that has been relatively exempt from anthropogenic impacts, as demonstrated by its biological, chemical, and physicochemical characteristics.

3. Results and Discussion

In the following sections, the results of the historical and new sampling data are reported.

3.1. Analysis of the historical data

In order to calculate the pollution load, the values of the pollution concentration and the Po River flow rate provided by the Piedmont Regional Administration and the SMAT WTTP manager were used. Fig. 4 shows the trend of the historical Po flow rate (average over the period 2007–2011).

Table 2 shows the total nitrogen load measured at the two stations, Castiglione Torinese and Chivasso, and the total nitrogen load discharged from the WWTP (historical period 2007–2011).

By analyzing the results reported in Table 2, it can be seen that the maximum values of the total nitrogen loads demonstrate a correspondence with the maximum values of the Po flow rate (Fig. 4).

The following figures show the total nitrogen load increase (between the two stations Castiglione Torinese and Chivasso) and its split between the two sources: the point load source (attributed to the WWTP) and the diffuse sources (expressed as a percentage) obtained using Eqs. (3)–(5).

By analyzing Figs. 5 and 6, it can be seen that the incidence of the total nitrogen parameter decreased as the flow rate increased (a trend probably caused by dilution and auto depuration; Fig. 5). The contribution of the Castiglione Torinese WWTP to the increase in the total nitrogen load between the stations Castiglione Torinese and Chivasso was lower than the contribution of the diffuse sources (Fig. 6).

In terms of average value, the load increase measured at the Chivasso station was 231% (compared with the load measured at the Castiglione station), and splitting this increase between the two sources (point and diffuse) reveals that only 40% was contributed by the WWTP while the other 191% was derived from the other (diffuse) sources.

In order to determine the influence of the auto depurative capacity of the Po River in the analyzed stretch (in particular between Gassino and Chivasso) a comparison was made with previous results (where the stretch Castiglione Torinese–Gassino was studied) [10]. In order to perform this particular kind of analysis, both the increases analyzed (for the two stretches: Castiglione–Gassino, length of about 10 km and

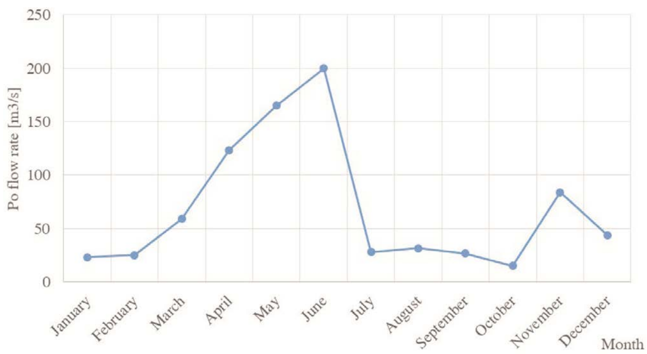

Fig. 4. Historical Po flow rates (monthly averages over the period 2007–2011).

Table 2
Historical total nitrogen loads

Historical data	Total nitrogen load measured in Castiglione Torinese (g/s)	Total nitrogen load discharged from WWTP (g/s)	Total nitrogen load measured in Chivasso (g/s)
January	113.61	82.61	493.04
February	122.25	78.91	617.83
March	272.54	76.44	728.25
April	594.30	70.56	1,124.13
May	492.74	67.53	1,044.21
June	565.29	65.89	1,120.41
July	91.29	47.65	408.74
August	126.74	47.68	325.32
September	104.88	45.87	358.68
October	59.76	55.57	347.21
November	346.95	66.06	864.90
December	193.79	76.33	595.94

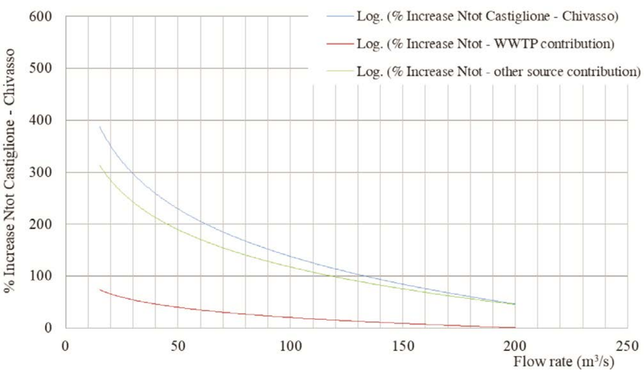

Fig. 5. Trends of the total nitrogen (N_{tot}) load increase, split between point and diffuse sources (historical period 2007–2011), as a function of the flow rate.

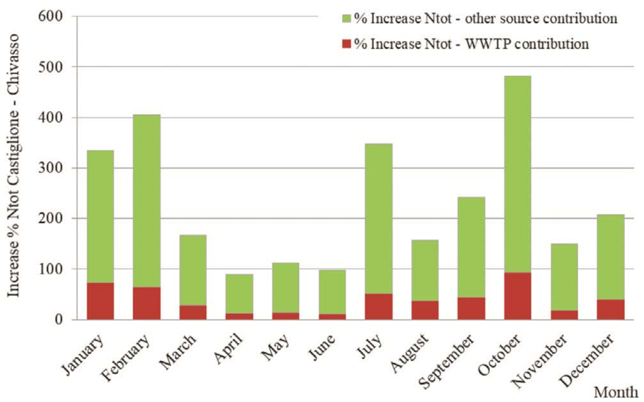

Fig. 6. Total nitrogen (N_{tot}) load increase, split between point and diffuse sources (historical period 2007–2011), as a function of the month.

Castiglione–Chivasso, length of about 20 km) were adjusted to a value based on 100, and then the two different contributions (from the point source WWTP and the diffuse source) were calculated. The obtained results were as follows:

- Castiglione–Gassino stretch: total nitrogen increase attributable to the WWTP source was 35%; total nitrogen increase attributable to diffuse sources was 65%.
- Castiglione–Chivasso stretch: total nitrogen increase attributable to the WWTP source was 17%; total nitrogen increase attributable to diffuse sources was 83%.

It should be noted that the contribution attributable to the WWTP source (in terms of mean value) was higher in the first stretch (between Castiglione and Gassino) than in the second stretch: the percentage value was 35% for the first and 17% for the second. By contrast, it should be noted that the increase in the contribution from the diffuse sources (in this case the percentage rose from 65% to 83%) shows that in this stretch other diffuse loads were present.

The above reported results can probably be attributed to the fact that the Gassino station is located very close to the WWTP discharge point (as indicated in Fig. 2), so that the load is heavily influenced by this discharge, whereas the Chivasso station is located farther away and is therefore less influenced by it.

Table 3 shows the load of the total phosphorous measured at the two stations Castiglione Torinese and Chivasso, and the total phosphorous load discharged from the WWTP (historical period 2007–2011).

The results reported in Table 3 show that the maximum values of the total phosphorous loads demonstrate a correspondence with the maximum values of the Po River flow rate (Fig. 4).

The following figures show the total phosphorous load increase and its split between the two sources, the point load source (attributable to the WWTP) and the diffuse sources (expressed as a percentage) obtained using Eqs. (3)–(5).

By analyzing Figs. 7 and 8, it can be seen that the incidence of the parameter total phosphorous decreased as the flow rate increased. The contribution of the Castiglione Torinese WWTP to the increase in the total phosphorous load between the Castiglione Torinese and Chivasso stations was lower than the contribution of the diffuse sources.

Table 3
Historical total phosphorous loads

Historical data	Total phosphorous load measured in Castiglione Torinese (g/s)	Total phosphorous load discharged from WWTP (g/s)	Total phosphorous load measured in Chivasso (g/s)
January	2.57	4.33	12.30
February	3.03	4.10	11.80
March	8.27	5.53	18.94
April	12.33	5.85	33.43
May	13.19	5.74	32.01
June	12	5.81	25.66
July	1.97	3.79	9.45
August	3.16	3.92	10.04
September	2.15	2.75	9.27
October	1.36	2.84	9.17
November	9.24	3.72	27.98
December	4.82	6.75	16.58

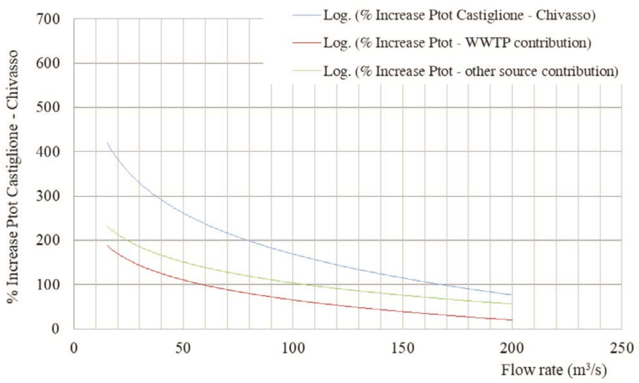

Fig. 7. Trends of the total phosphorous (P_{tot}) load increase, split between point and diffuse sources (historical period 2007–2011), as a function of the flow rate.

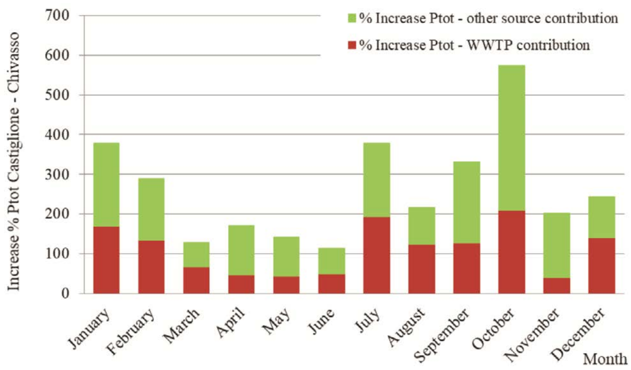

Fig. 8. Total phosphorous (P_{tot}) load increase, split between point and diffuse sources (historical period 2007–2011), as a function of the month.

3.2. Sampling data

In order to define how the actual water quality in the Po River has changed, compared with previous years, a sampling campaign was performed, to build a representative database and to analyze the changes in the Po River system. The sampling was performed at five different stations: San Mauro, Castiglione Torinese, Gassino, Orco Torrent, and finally at the Chivasso station. Using the data obtained from the sampling campaign and subsequent calculations, the same analyses were performed with the historical data, focusing in particular on the total nitrogen and total phosphorous pollutant increases between Castiglione Torinese and Chivasso stations, and the pollutant increase was then split into two parts, one attributable to the WWTP and the other to the diffuse sources.

3.2.1. Analysis of the sampling data

On the basis of the sampling campaign the influences of both the Castiglione Torinese WWTP and the diffuse sources (due primarily to agricultural discharge) were defined, for the increased pollution between the Castiglione Torinese and Chivasso stations. Analyses were conducted separately for the two parameters total nitrogen and total phosphorous.

Table 4 shows the total nitrogen load measured at the two stations Castiglione Torinese and Chivasso and the total nitrogen load discharged from the WWTP. Figs. 9 and 10 show the total nitrogen load increase and its split into the two sources, the point source (attributable to the WWTP) and the diffuse sources (expressed as a percentage) obtained using Eqs. (3)–(5).

Fig. 9 shows, for the total nitrogen parameter, the trend of the pollution increase between Castiglione Torinese and Chivasso stations as a function of the flow rate measured at Castiglione station, and Fig. 10 shows how this load increase is split between the two sources. By analyzing Figs. 9 and 10, it can be seen that:

- The amount of load increase in the stretch under consideration decreased as a function of increasing flow rate.
- The contribution of the Castiglione Torinese WWTP was very low in comparison with the contribution of the diffuse sources.

Table 4
Sampled total nitrogen loads

Sampling data	Total nitrogen load measured in Castiglione Torinese (g/s)	Total nitrogen load discharged from WWTP (g/s)	Total nitrogen load measured in Chivasso (g/s)
9 September 2014	579.28	37.57	1,078.10
7 October 2014	111.88	24.58	465.59
1 April 2015	260.01	30.00	585.02
24 May 2015	450.03	29.00	802.05
8 July 2015	297.52	17.40	678.35
15 September 2015	327.06	49.12	779.87
20 October 2015	136.02	13.91	288.09

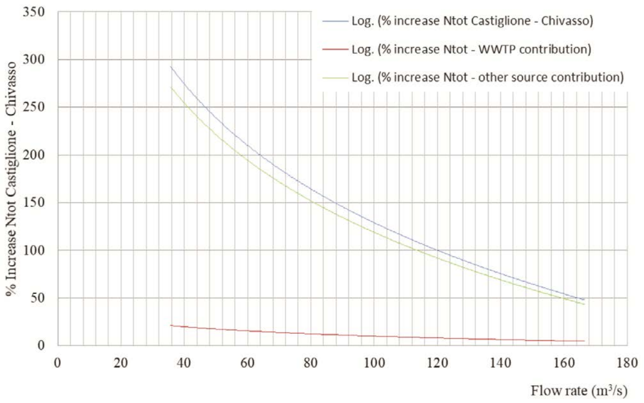

Fig. 9. Trends of the total nitrogen (N_{tot}) load increase, split between point and diffuse sources (sampling data), as a function of the flow rate.

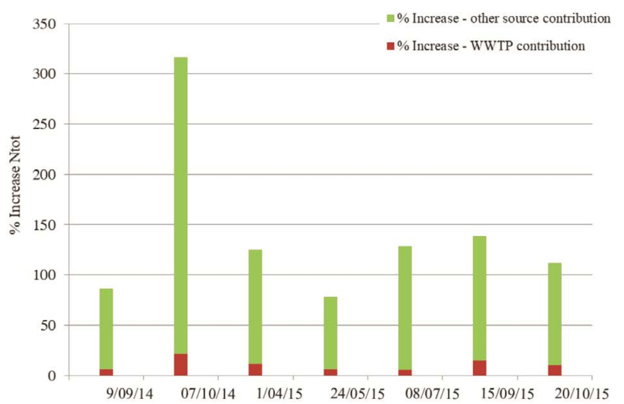

Fig. 10. Total nitrogen (N_{tot}) load increase, split between point and diffuse sources (sampling data), as a function of the month.

The results of the comparison between the Castiglione–Gassino and the Castiglione–Chivasso stretches were:

- Between Castiglione and Gassino [16] the total nitrogen increase attributable to the WWTP was 39%, and the increase attributable to the diffuse sources was 61%.
- Between Castiglione and Chivasso the total nitrogen increase attributable to the WWTP was 8%, and the increase attributable to the diffuse sources was 92%.

It can be seen that the contribution attributable to the Castiglione Torinese WWTP source (in terms of mean value) was higher in the first stretch (Castiglione–Gassino) than in the second stretch (Castiglione–Chivasso), as the percentage dropped from 39% to 8%. By contrast, it is also possible to note an increase in the contribution attributable to the diffuse sources: in this case the percentage rose from 61% to 92%.

Table 5 shows the load of the total phosphorous measured at the two stations Castiglione Torinese and Chivasso and the total phosphorous load discharged from the WWTP.

The following figures show the total phosphorous load increase and its split between the two sources, the point load source (attributable to the WWTP) and the diffuse sources (expressed as a percentage) obtained using Eqs. (3)–(5).

Fig. 11 shows the total phosphorous trend of the pollution increase between Castiglione Torinese and Chivasso stations as a function of the flow rate measured at the Castiglione station, and Fig. 12 shows how this load increase is split between the two sources. Total phosphorus shows a behavior parallel to that of total nitrogen, as depicted in the previous figures: the amount of load decreased as a function of increasing flow rate, and the contribution of the Castiglione Torinese WWTP was very low in comparison with the contribution of the diffuse sources. The increase from the WWTP discharge results were more significant in the first stretch, just after the point of emission into the Po River, as is evident from the collected data at the intermediate Gassino station.

Comparing the historical and sampling data, it can be seen that the current values (corresponding to the sampling results) are very low in comparison with the historical data. This evidence has also been confirmed by analyzing the total load of the two analyzed pollutants. In fact, the average load of the total nitrogen dropped from 65.09 g/s (historical data) to 28.80 g/s (sampling data), and the average load of the total phosphorous decreased from 4.59 g/s (historical data) to 4.16 g/s (sampling data). These results can be explained by a steady improvement of the WWTP total nitrogen and phosphorus removal treatments.

3.3. Evaluation of the pollution conditions

By utilizing the methodology described in the paragraph "Methodology adopted" the classifications for the Torino, San Mauro, Gassino, and Chivasso stations for the year 2014

Table 5
Sampled total phosphorous loads

Sampling data	Total phosphorous load measured in Castiglione Torinese (g/s)	Total phosphorous load discharged from WWTP (g/s)	Total phosphorous load measured in Chivasso (g/s)
9 September 2014	36.62	4.04	99.38
7 October 2014	3.24	0.92	17.67
1 April 2015	18.10	1.19	68.78
24 May 2015	28.01	3.00	83.03
8 July 2015	32.01	8.00	80.03
15 September 2015	5.04	3.53	16.38
20 October 2015	28.11	8.43	89.95

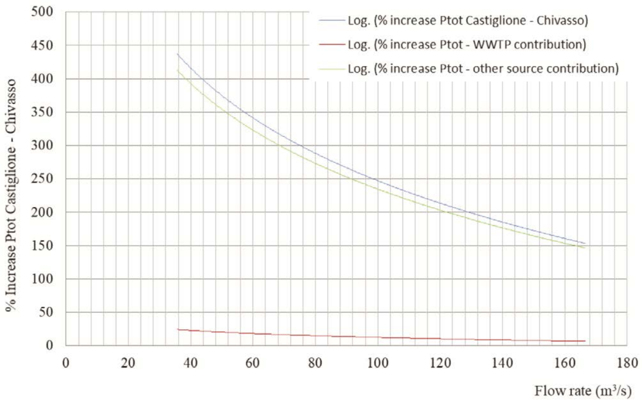

Fig. 11. Trends of the total phosphorous (P_{tot}) load increase, split between point and diffuse sources (sampling data), as a function of the flow rate.

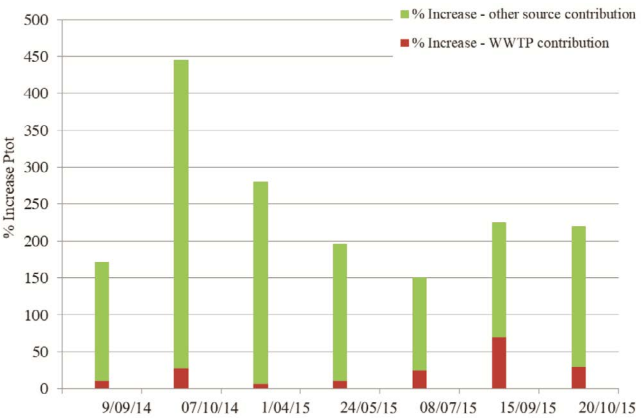

Fig. 12. Total phosphorous (P_{tot}) load increase, split between point and diffuse sources (sampling data), as a function of the month.

were determined (the year 2014 is the most recent year for which all the data needed to perform this analysis were available); the analysis results are shown in Fig. 13.

By analyzing the results reported in Fig. 13, it is possible to observe that for all the analyzed stations the pollution levels of the macro descriptors (LIM – Livello di Inquinamento dei Macrodescrittori) were all acceptable. The Chivasso station presented the best results (the values of the pollution levels of the macro descriptors were all around 400), but the Gassino station presented pollution levels of the macro descriptors that were a little less than acceptable (pollution levels of the macro descriptors were all around 190). In order to establish the ecological state (SECA – Stato Ecologico dei Corsi d'Acqua, Ecological State of Water Course) of the river water, the scores from all the macro descriptors had to be combined with that from the IBE index. Based on that result, the respective classes for the environmental state (SACA – Stato Ambientale dei Corsi d'Acqua, Environmental State of the River Course) for each river stretch were determined. Table 6 shows the obtained results.

The results obtained and shown in Table 6 highlight that only the Chivasso station presents a "good" environmental state of river quality. The Torino station presents an "acceptable" environmental state, while the other two stations present "poor" environmental states. In particular, it is important

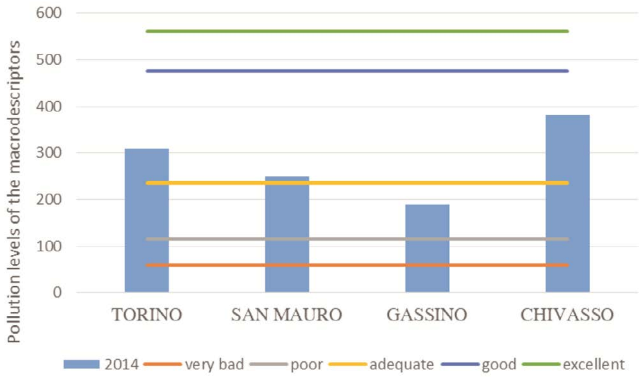

Fig. 13. Pollution levels of the macro descriptors (year 2014).

Table 6
Environmental states of the river water (year 2014)

Station	Year	Environmental state
Torino	2014	Acceptable
San Mauro	2014	Poor
Gassino	2014	Poor
Chivasso	2014	Good

to note that the environmental quality of the Po River is already "poor" upstream of the Castiglione WWTP (in fact the environmental state of the Po River is "poor" in both the stations San Mauro and Gassino, which are located, respectively, upstream and downstream of the Castiglione WWTP).

The above-reported analysis is relative to a 70% removal rate of nitrogen for the Castiglione WWTP (the removal level actually obtained by the WWTP). The same analysis was conducted using a 90% removal rate (assuming an exceptional level of performance after the introduction of the Anammox technology for denitrification, currently in progress in the WWTP in Castiglione). The results obtained from that analysis, for the Gassino station (the station located immediately downstream the WWTP discharge) were the same as those reported in Table 6. It can be concluded that the environmental state of the Po River has been only minimally impacted by the Castiglione Torinese WWTP discharge.

In order to achieve a "good" environmental state in S. Mauro and Castiglione T.se stations it will be necessary to perform further interventions upstream from the Castiglione station, since the situation is already compromised in the San Mauro Torinese area. A useful measure would be to reduce the withdrawal amount from Canale Cimena. This withdrawal is necessary for the operation of the ENEL Cimena power plant, which takes up a large hydraulic volume from S. Mauro but returns the same volume just before the Chivasso station; therefore in some periods of the year the river flow rate between San Mauro and Chivasso is very low. As a consequence, the environmental impact of the plant discharge is increased in this stretch of the river, where the situation is already hydraulically endangered. Some type of intervention on the diffuse loads (e.g., imposing a limitation on fertilizer use) would also help to achieve the river water quality goals.

4. Conclusions

The results of this interpretation of historical water quality data for the Po River and analysis of the current conditions indicate some general trends, as follows:

- The influence of the discharge of the Turin WWTP on the quality of the Po River can be considered low in comparison with that from the diffused loads coming from agricultural activities or from surface leaching waters (considering the entire Castiglione T.se–Chivasso stretch).
- By comparing the historical and current data, it is possible to observe a significant decrease in the impact of the WWTP on the river quality, because of increased removal efficiency of the plant.
- Both total nitrogen and total phosphorus loads must be considered, in order to evaluate the potential eutrophication effect on the Po River.

The results of this evaluation of the pollution state of the Po River indicate some improvement of the environmental state, as the river flows from Castiglione T.se station to Chivasso station: the environmental state at Castiglione T.se station is "poor", at Gassino station it is "acceptable," and at Chivasso station it is "good".

The proposed methodology has the merit of bringing back all the real situation measured to the same basic situation. In this way, comparisons and evaluations are easier but always true to reality.

In general, using the methodology adopted in this study, it is possible, by evaluating sample data from field measurements (or obtained from public authorities), to draw some conclusions concerning the concentrations, load scenarios, and environmental states of the studied area, and to recommend some appropriate interventions in order to improve the environmental quality and comply with local environmental regulations.

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