WATER QUALITY IN THE ARTIFICIAL CANAL NETWORK IN THE RENO BASIN (BOLOGNA ITALY)

QUALITÉ DES EAUX DU RÉSEAU DE CANAUX ARTIFICIELS DANS LE BASSIN VERSANT DU FLEUVE RENO (BOLOGNE, ITALIE)

QUALITÀ DELLE ACQUE DELLA RETE DEI CANALI ARTIFICIALI NEL BACINO SCOLANTE DEL FIUME RENO (BOLOGNA, ITALIA)

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Abstract

The aim was to provide a physical-chemical characterization of river and canal network water in the area of expertise of the ex Bonifica Reno-Palata between the Reno river and Torrent Samoggia. The monitoring started in July 2007 and stopped in November 2009. The work consisted in the collection, almost monthly, of the waters that were subjected to chemical and physical analyses, some *in situ* (temperature and electrical conductivity) and others at the laboratory (pH, nutrient parameters with Hach-Lange's colorimetric methods, macro and micro elements by ICP-OES). Data from each analysis were processed using statistical software such as Analysis of Variance (ANOVA), Factor Analysis (FA) Cluster Analysis (CA). The results obtained in the three years of sampling show a very complex reality, with many sources of pollution of the surface waters of the canals. These canals, during their course, are unable to abate the load of pollutants present by the process of self-purification. This leads to a deterioration of water quality in the Reno river, the waters not always being suitable for irrigation. Besides, thanks to the multivariate statistical analysis and in particular to the CA, we were able to identify the stations with greater pollution of their surface water.

Keywords: *surface waters; pollution; macro and micro elements; analysis of variance; cluster analysis*

Résumé

L'objectif de cette étude est de donner une caractérisation physico-chimique des eaux fluviales et du réseau de canaux artificiels compris entre le fleuve Reno et le torrent Samoggia, dans la zone de compétence de l'ancienne Bonification Reno-Palata. Le monitoring des eaux a commencé en Juillet 2007 et il s'est prolongé jusqu'en le Novembre 2009. L'étude a consisté dans le prélèvement, presque mensuel des eaux qui ont été soumises à des analyses phtsico-chimiques, quelques-unes in situ (température et conductivité) et d'autres en laboratoire (pH), macro

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descripteurs avec des méthodologies de colorimétrie Hach-Lange, macro et micro éléments chimiques en ICP-OES. Les données obtenues par chaque analyse ont été élaborées au moyen de logiciels statistiques qui ont permis d'effectuer des analyses comme l'Analyse de la Variance ANOVA et l'Analyse des Groupes (CA-Cluster Analysis). Les résultats obtenus dans les 3 ans de monitoring ont montré une réalité d'extrême complexité, qui révèle différentes sources de pollution des eaux superficielles des canaux artificiels. Ces canaux, pendant leur cours, ne réussissent pas à abattre la charge de polluant présente par le procédé d' auto-épuration. Ceci détermine une détérioration de la qualité des eaux du fleuve Reno qui est l'élément récepteur de ces canaux, et ces eaux ne sont pas toujours aptes pour l'irrigation. En outre, grâce aux analyses statistiques de multivariance et en particulier au CA, il a été possible d'identifier les points de prélèvement avec la plus grande pollution des eaux superficielles.
Mots-clés: *eaux superficielles; pollution; macro et micro éléments; analyse de la variance; analyse des groupes*

Riassunto

Obiettivo dello studio è dare una caratterizzazione chimico-fisica delle acque fluviali e della rete di canali artificiali compresi tra il fiume Reno e il torrente Samoggia, nell'area di competenza della ex Bonifica Reno-Palata. Il monitoraggio è iniziato nel Luglio del 2007 e si è protratto fino a Novembre 2009. Il lavoro è consistito nel prelievo, pressoché mensile, delle acque che sono state sottoposte ad analisi chimico-fisiche, alcune *in situ* (temperatura e conducibilità) e altre in laboratorio (pH, macrodescrittori con metodologie colorimetriche Hach-Lange, macro e microelementi in ICP-OES). I dati ottenuti da ciascuna analisi sono stati elaborati tramite l'utilizzo di software statistici che hanno permesso di effettuare analisi statistiche come l'Analisi della Varianza (ANOVA) e l'Analisi dei Gruppi (CA-Cluster Analisys). I risultati ottenuti nei 3 anni di campionamento hanno mostrato una realtà di estrema complessità, che presenta diverse sorgenti di inquinamento delle acque superficiali dei canali artificiali. Tali canali, durante il corso, non riescono ad abbattere il carico di inquinanti presente in essi con i processi di autodepurazione. Ciò determina un peggioramento della qualità delle acque del Fiume Reno, che è il corpo recettore di tali canali, e che non sempre risultano idonee per l'irrigazione. Inoltre, grazie alle analisi di statistica multivariata e in particolare alla CA, è stato possibile identificare le stazioni con il maggiore inquinamento delle acque superficiali.
Parole chiave: *acque superficiali; inquinamento; macro e micro elementi; analisi della varianza; analisi dei gruppi*

Introduction

The quality of surface water is a very sensitive issue. Anthropogenic influences (urban, industrial and agricultural activities) as well as natural processes (change in precipitation input, erosion, weathering of crustal material) degrade surface waters

and impair their use for drinking, industrial, agricultural, recreation or other purposes (Simeonov et al., 2003). The municipal and industrial wastewater discharge constitutes the constant polluting source, whereas the surface run-off is a seasonal phenomenon, largely affected by climate in the basin. The rivers constitute the main inland water resources for the domestic, industrial and irrigation purpose, it is imperative to prevent and control the rivers pollution. The artificial canals network are the reality of the reclaimed lands of the Po Valley (Italy). These artificial canals have a promiscuous management, in fact they receive the waters by drainage and run-off from the urban, industrial and agricultural lands and their waters are also used for the irrigation purpose during the Spring-Summer season. The aim of this work has been that to asses the waters quality of a network of artificial canals that is introduced into the Reno river. The waters of the canals have a different sources of pollution and are a possible sources on the contamination of determined water quality parameters of the Reno river (Po Valley basin, Italy).

Materials and Methods

Study area. The study area is between the Reno river and the Samoggia stream, north of Bologna city (Italy). The territory has been subject since antiquity of reclamation land and is therefore affected by dense artificial canals network. The canals network is divided into two groups: the "High Waters" (the most important here is the Dosolo canal -DOS-) is the definition given to the water present in canals with a more prominent morphology (>0 m sea-level), while "Low Waters" (the most important here is the Low Water canal -AbC-) stands for the canals that receive the water of the newly reclamation areas because they are below the sea level and they have a marshy feature. The Dosolo canal flow into the Reno river through the Sostegno's sewer whereas the Low Water canal pours its waters in the Reno river through the Bagnetto's water-pumping plant.

The area is submitted to a serious anthropogenic impact caused by urban and industrial settlements, located in a territory largely given to agriculture and zootechny (Fig. 1) as municipal and industrial wastewater plants, drainage water from agricultural soils and several towns with craft made areas. The Dosolo canal (DOS) receives, after the sampling station1 (DOS1), the wastewater treatment plant of Calderara di Reno (36000 people equivalent), whereas the Low Water canal (AcB) receives, after the sampling station1 (AcB1), the wastewater treatment plant of Sala Bolognese (8000 people equivalent). Table 1 shows sampling stations. Some sampling station are positioned in artificial canals that flow together in Lavino stream in the Paltrone's sewer therefore flow into Samoggia steam through the Forcelli's water-pumping plant. The Reno river drains about 5.040 km² from the Appennino Tosco-Emiliano, where he spring, to the Adriatic Sea. The river in the mountain flows through the pelitic- arenaceous geological formations while in the middle hilly course encounter clayey formations. When the Reno river arrives

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in the flat land the course becomes very anthropized and the river banks manifest a reduced biodiversity vegetation. The average flow rate in the closure of the mountain basin is 26,5 m^3/s while in the mouth is 95 m^3/s.

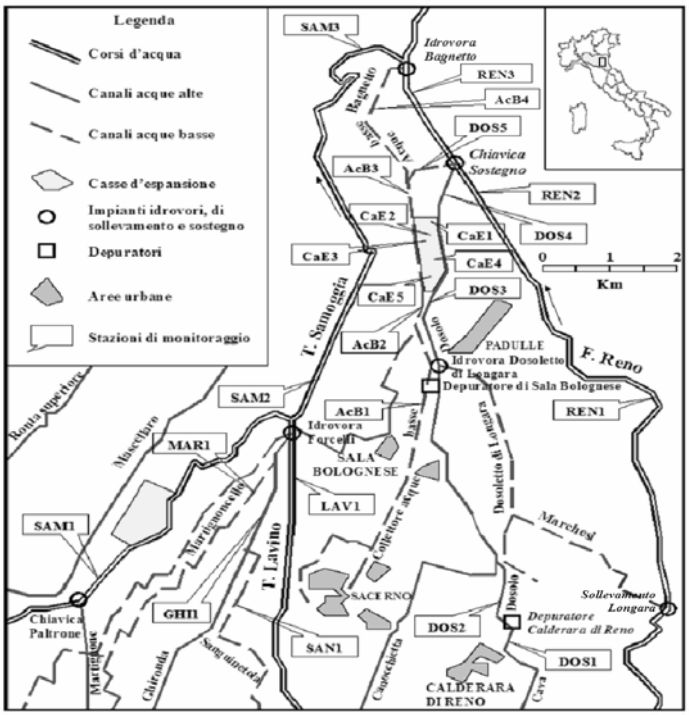

Figure 1

Localization of monitoring stations in Reno river (REN), Samoggia Stream (SAM), High Water canal "Dosolo" (DOS) and Low Water canal (AcB), respectively. The Ghironda (GHI) stream and the artificial canals Martignoncello (MAR), Sanguinetola (SAN) flows into the Lavino (LAV) stream and this flows into Samoggia stream. Samoggia stream flows into Reno river next to SAM3 station.

Superficial Stream	Sample	N	E
Reno River	REN1	44° 36' 45.2"	11° 18' 59.3"
	REN2	44° 40' 01.6"	11° 16' 22.1"
	REN3	44° 15' 45.3"	11° 15' 45.3"
Dosolo Canal *	DOS1	44° 34' 15.2"	11° 16' 56.9"
	DOS2	44° 34' 07.0"	11° 16' 56.6"
	DOS3	44° 38' 09.6"	11° 15' 55.9"
	DOS4	44° 39' 13.3"	11° 16' 07.0"
	DOS5	44° 39' 54.0"	11° 16' 19.4"
Low Water Canal *	AcB1	44° 37' 16.0"	11° 15' 56.6"
	AcB2	44° 38' 09.7"	11° 15' 54.0"
	AcB3	44° 39' 15.9"	11° 15' 49.0"
	AcB4	44° 41' 05,1"	11° 15' 35.5"
Samoggia Stream *	SAM1	44° 34' 46.1"	11° 10' 58.5"
	SAM2	44° 37' 47.6"	11° 14' 7.30"
	SAM3	44° 41' 23.3"	11° 15' 27.0"
Sanguinetola Canal **	San1	44° 36' 31.6"	11° 13' 49.1"
Ghironda Stream/Canal **	Ghi1	44° 36' 31.6"	11° 13' 48.0"
Martignoncello Canal **	Mar1	44° 36' 43.0"	11° 13' 51.0"
Lavino Stream **	Lav1	44° 36' 34.1"	11° 13' 59.1"

Table 1

Denomination and Geographic coordinates of the monitoring stations.

** They flow together Reno*
*** They flow together Samoggia*

The Samoggia stream in the flat land, after the hilly course, becomes suspended with embankments very high to assure the water safety in the flood periods. Before to flow together in the Reno river in locality Passo Bagnetto, he receives the water of the Lavino stream.

Sampling and Analysis. From July 2007 till November 2009, samples of surface water were collected monthly from 20 sites chosen on the basis of different criteria and the sampling stations are located from upstream to downstream. The sampling point were georeferenced (UTM WGS '84 reference system) using a GPS system; the geographical coordinates of the different sites are shown in figure 1 and in table 1. At each station, samples were collected in a glass bottle for the Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), total phosphorus (TP), chlorides (Cl^-) and in acid-washed polyethylene containers to provide reliable and accurate trace metals data. In order to measure acid-extractable metal constituents bound to suspended particles and to preserve samples, the latter were adjusted to pH 2 with ultrapure 69.5% nitric acid (Suprapure, Merck, Germany). The major and trace elements were determined by Spectros (Circular Optical System CIR.O.S. ccd) Inductive Coupled Plasma Optical Emission Spectrometry (ICP-OES) according to Vittori Antisari et al. (2010). The nutrient major elements were determined according to Hach-Lange colorimetric methods. Water temperature, pH, and Electrical conductivity (EC) were measured in the field.

Data processor and statistical analysis. Multivariate statistical method for classification, modelling and interpretation of large datasets from environmental monitoring programs allow the reduction of the dimensionality of the data and the extraction of information that will be helpful for the water quality assessment and the management of surface waters (Wunderlin et al, 2001). In the present study Cluster analysis (CA) is employed and the Euclidean distance was used to measure similarity among clusters while Ward's method was used as an agglomeration techniques. The results of a CA are usually summarised using a dendrogram.

Results

Table 2 shows the statistical summary of nutrients and physicochemical parameters concentrations (BOD_5, COD, CE, pH, NH_4, NO_3, NO_2, Cl, TP), the analysis was carried out on the water of natural surface water bodies (REN, SAM) and artificial canals (DOS, AcB). The Cluster Analysis (CA) identifies 5 different groups between the sampling stations and the dendrogram is shown in Fig. 2. The CA did not give clear indications in fact the 5 different groups are very promiscuous, that belong both artificial canals and natural water bodies. The exception is represented from the data including in the cluster n° 5 which belong just the waters sampled in the Dosolo canal. The cluster n°5, in fact, shows a higher concentration of Electrical Conductivity (EC) and a chlorine (Cl), total phosphorus (TP) and

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ammonium (NH_4) than other groups. The cluster n°2 instead includes almost exclusively the samples taken in the monitoring stations of the Reno river and some of the Samoggia stream. This cluster is characterized by a lower concentration of nutrients parameters. The cluster n°3 consists primarily by the samples taken in the Samoggia stream and just some in the Reno river and the concentration values of nutrients and physiochemical parameters are higher than the other monitoring stations of the same fresh waters. The water samples were also analyzed for concentrations of major (Ca, Mg, K, Na, P, Si e S) and trace elements (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, V e Zn).

Table 2 - *Summary basic statistic (mean standard deviation and range value) of concentration of major elements, temperature, pH and EC in Reno river (REN), Samoggia stream (SAM) and Dosolo (DOS) and Low Water (AcB) canals, respectively.*

		BOD_5	**COD**	**NH_4**	**NO_2**	**NO_3**	**TP**	**Cl**	**T**	**pH**	**EC**
					mg/L				°C		(µS/cm)
REN	Mean	7.3	13.2	0.4	0.0	0.5	0.1	53.2	20.0	7.7	578
	S.D	5.5	8.4	0.5	0.0	0.4	0.1	55.1	7.7	0.3	287
	Max	24.0	47.4	2.6	0.1	1.5	0.8	268.0	28.4	8.2	1856
	Min	0.3	4.8	0.0	0.0	0.1	0.0	3.7	6.0	6.8	345
SAM	Mean	8.5	20.4	0.7	0.1	1.8	0.3	72.8	18.2	7.9	1238
	S.D	6.2	7.7	0.8	0.2	1.6	0.4	35.6	8.9	0.4	552
	Max	23.0	45.7	3.1	0.7	5.3	1.7	145.0	30.3	8.7	2950
	Min	0.3	10.4	0.0	0.0	0.2	0.1	10.6	0.2	7.0	677
DOS	Mean	11.1	37.1	0.6	0.1	1.6	0.5	146.5	21.8	8.0	1259
	S.D	8.0	18.0	0.7	0.1	2.1	0.6	81.1	9.2	0.5	580
	Max	42.0	74.6	3.5	0.7	10.3	2.8	316.0	33.3	9.1	3160
	Min	0.3	15.0	0.0	0.0	0.0	0.0	4.7	4.0	6.7	410
AcB	Mean	11.3	40.6	0.9	0.2	2.3	0.4	88.8	21.7	8.3	977
	S.D	7.9	16.0	1.2	0.2	3.0	0.4	52.1	9.6	0.6	345
	Max	33.0	75.1	6.0	1.1	12.1	1.7	228.0	33.7	9.4	1952
	Min	0.0	18.8	0.0	0.0	0.1	0.0	9.1	3.4	7.1	540

Table 3

Summary basic statistics (mean, standard deviation and range value) of concentration of some trace elements in Reno river (REN), Samoggia stream (SAM), Dosolo (DOS) and Low Water (AcB) canals, respectively.

		Al	**B**	**Cu**	**Ni**	**Zn**
				µg/L		
REN	Mean	28	95	8.2	3.9	110
	S.D	30	72	18	2.6	525
	Max	170	267	109	16	3469
	Min	0.06	6.2	0.11	0.56	0.48
SAM	Mean	25	247	8.2	9.0	73.68
	S.D	39	128	13	5.2	306
	Max	212	542	70	20	1659
	Min	0.48	6.4	0.63	3.1	0.48
DOS	Mean	42	228	124	16	39
	S.D	91	174	863	8.5	33
	Max	495	860	6349	44	116
	Min	0.14	6.44	0.2	3.72	0.48
AcB	Mean	118	270	148	9.4	70
	S.D	314	157	642	4.8	357
	Max	1602	593	3345	29	2623
	Min	0.06	6.4	0.5	3.1	0.48

The matrix of data processing does not consider As, Cd, Co, Cr, Pb because just in some samples and just in some monitoring stations were found higher values above the instrumental detection limit (DL) which is 0.01, 0.01, 0.02, 0.03, 0.01 μg L^{-1}, respectively. Table 3 shows the summary statistics of some trace elements.

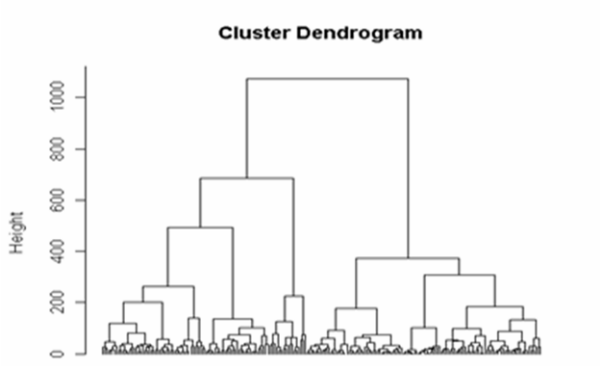

Figure 2

Dendrogram obtained by physiochemical and nutrients parameters concentration in Reno river, Samoggia stream and the network of artificial canals during the three years of water quality monitoring.

The Cluster Analysis (CA) showed the dendrogram that is depicted in Fig. 3. The cluster n° 6 has identified a difference between artificial and natural water bodies and between the sampling time. In effect the cluster n°1 is represented by stations of Reno and Samoggia while the cluster n°2 represents all the sites that flow together, through the Forcelli's water-pumping plant, in the Samoggia stream: Ghironda and Lavino streams, Martignoncello and Sanguinetola canals. The custer n°3 is formed by DOS and AcB stations. It is possible do a further division of the groups and identify Dosolo and Low Waters stations before and after the wastewater treatment plants.

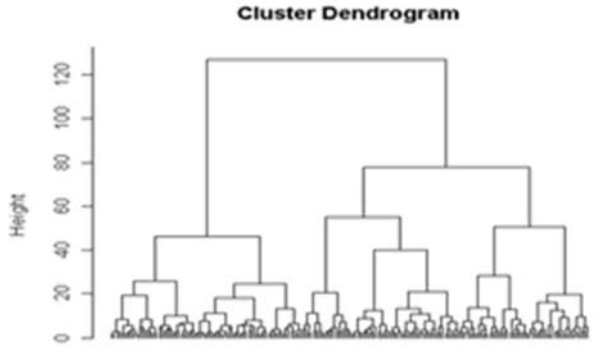

Figure 3

Dendrogram obtained by major and trace elements concentration in Reno river, Samoggia stream and the network of artificial canals during the three years of water quality monitoring.

Discussion and Conclusion

The average values of TP in the Reno river are lower than those of Samoggia stream and network of artificial canals but they are higher than those found in the Po river (Camusso et al., 2000). Particularly, the concentrations of TP in the canals are equal to those determined in the 1980 in the Po river due to the use of

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detergents. These values can be caused by the inlet into the river of wastewater treatment plants and the presence of livestock. The higher concentrations of NH_4 in the canals bears out this hypothesis even if the values are lower than those find in the surface water bodies of Greece (Simenov et al., 2003) and in the Gomti river basin (Sing et al., 2005). The Electrical Conductivity is higher in artificial canals and in the Samoggia river than the Reno river, that can become a hazard during the irrigation season of crops. These difference of physicochemical parameters are showed by CA. In particular, a cluster format only from stations Dosolo presents higher values of Cl, TP, EC and NH_4. The processes of autopurification in the waters of the Dosolo canal can not be explicated because the upstream catchment area is heavily anthropized and during the current the water bodies have strong impacts due to livestock and agriculture. The concentration of the nutrient decreases from the upstream to the downstream in the Law Water canal. The concentrations of trace elements do not show anomalies and are comparable to those found in other basins (Singh et al., 2005). The CA identifies the highest values in the canal network waters. Indeed the highest values are found in the canals that flow together first in Lavino stream and then, through the water-pumping plant of Forcelli, in Samoggia stream. The low water quality of the Samoggia stream gets worse that of Reno river. The CA identifies like water very anthropized also the sampling station DOS1 and DOS2 and AcB1 AcB2, which receive the wastewater of the wastewater treatment plants. In conclusion we can say that in this territory there are different pollution sources of the canals that are not able to neutralize with the autodepuration processes. This leads to a deterioration of water quality in the Reno river which are not always suitable for irrigation. Besides, thanks to the multivariate statistical analysis and in particular to the CA, we were able to identifies the stations with greater pollution of surface water.

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