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New approach for evaluating the public health risk of living near a polluted river

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Key words

Sarno River basin • Chemical pollution • Microbiology • Airborne biological hazard

Summary

Chemical, physical and microbial analyses were conducted in the Sarno River basin to obtain a comprehensive description of the overall quality of the water bodies. The collection period lasted 12 months, between 2005 and 2006, with high frequency of sampling and analysis. More than 6,000 analytical determinations were performed on samples collected at six sampling points along the Sarno River and two points each on tributaries Solofrana and Cavaiola. The results indicated the presence of inorganic contaminants, which, in most cases, were below the Italian State water quality thresholds. The organic contamination showed an increasing trend, with respect to previous determinations, thus demonstrating the major contribution of untreated urban wastewater to the overall pollution of the river. Moreover, this study was designed to explore the correlation between the presence of microbial indicators of fecal contamination in Sarno River and their presumable presence in the aerosol surrounding the river, thus pointing to the possible environmental hazard associated with the presence of pathogens in the air.

Introduction

Pollution of the Sarno River is a long-standing problem that is still not well documented. It is commonly attributed to organic matter used in the tomato industry and to heavy metals from the leather tanneries. However, it is also affected by anthropogenic wastewaters, which have never been considered as a significant source of pollution. Although technical programs have been undertaken to reduce the environmental risk, the scientific data relative to the pollution of Sarno River basin are vague, fragmentary and incomplete. Many years after the Ministry of the Environment declared the area to be at high environmental risk [1] it emerges that adequate chemical and bacteriological data to support this claim are almost completely absent.

Moreover, there is a complete lack of epidemiological studies in the area, with which to assess cause-effect relationship between the pollution of the river and specific pathology, particularly carcinogenic, and which are needed to undertake an adequate sanitary program. Microbial contamination of water is responsible for numerous disease outbreaks [2-12]. Some of them can be documented, such as those involving acute gastrointestinal illness (GI) or deaths; however, many self-resolving and isolated cases go unreported to health officials.

Sarno River is quite a short watercourse of about 24 km that crosses a broad, populated area located south east of the volcano Vesuvio, in South Italy. The Sarno basin, with its tributaries Solofrana and Cavaiola, covers about 450 km^2. It has undergone rapid and uncontrolled urban expansion and now is populated by about one million people, concentrated in small towns. The population density, in some cases, is much higher than the national average (up to 2,200 inhabitants per km^2 along the coastal zones). The river and its tributaries are used extensively as a source of irrigation water for intensive agriculture in the basin. Therefore the pollution of river, for which the indiscriminate increase in pollution factors has made natural purification capacities insufficient, takes on a particular importance. The pollution of Sarno River has been studied in the past with particular emphasis on chemical and physical parameters, since it was believed that industries were the major polluters [13], and on the basis of geo-environmental aspects due to the high vulnerability of the basin [14, 15]. The most important industrial activities in this area are the production and processing of tomatoes (108 industries settled mainly along Sarno River) and the chemical processing of animal skin (184 leather tanneries principally along Solofrana tributary). Many other small and medium factories (e.g. producing paints, ceramics and food packaging) are also present in the area. The high density of population and the presence of industrial plants in this area, which are both sources of pollution, have caused a great deal of environmental concern.

It was therefore of particular interest to us to undertake an analytical monitoring program, through bacte-

rial and physico-chemical characterization, to evaluate the extent of water quality degradation and to assess a possible relationship with some disease outbreaks. These data are of great interest in providing a basis for comparison to further an understanding of the potential improvement in water quality, which certainly results in public health benefits. Microbiological quality of water was determined by searching traditional non-pathogenic micro-organisms as indicators of fecal pollution. However, monitoring surface waters for disease-causing micro-organisms and assessing a cause-effect relationship, if there is no direct contact with water, is not as straightforward as it would seem. Thus our idea was to determine the dispersion of micro-organisms from water to the surrounding air, which most likely determines an airborne biological hazard for people living near the river. Several have stated that aerosols containing micro-organisms can be generated from wastewater treatment plants (WWTP) [16-18] but, to our knowledge, there is no literature regarding aerosols from polluted rivers, which, as well as those from WWTP, could potentially carry pathogenic micro-organisms.

Materials and method

Sampling

Sampling took place every fortnight during one year between July 2005 and June 2006. Samples were collected and analyzed for chemical pollution and for the presence of fecal pollution indicator bacteria. Water samples were collected from six sites on the Sarno River and two sites each on the Cavaiola and Solofrana tributaries (as indicated in Figure 1). Moreover, an additional site was selected at the confluence between Cavaiola and Solofrana (AC).

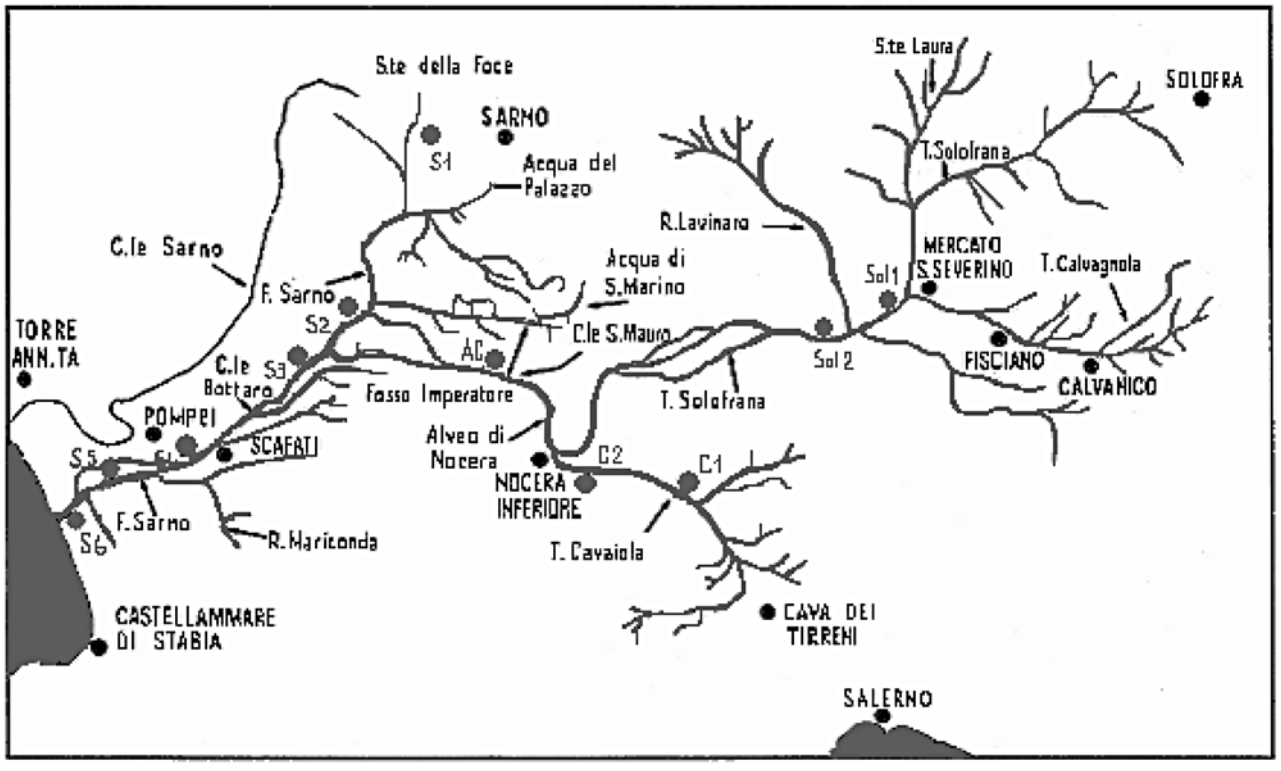
Physical and chemical analyses

Water samples were collected using the sampling method N° 1030 published by APAT (Italian Agency for Environmental Protection and Technical Services Report N°29/2003). The samples were kept at 4°C, either in low-density polyethylene or Pyrex-glass containers, and were delivered to the laboratory within 4 hours. Standard water-chemistry measurements and some physical properties, such as pH, electrical conductivity and water temperature were measured at the time of collection by means of a Hanna Instruments mod. HI 9625.

Settleable solids were determined by the Imhoff cones test; suspended solids by membrane filtration and weighing the filtered residue on evaporation at 105°C.

Chemical oxygen demand (COD) was determined with $K_2Cr_2O_7$ in H_2SO_4 1:1 by the open reflux method with $AgSO_4$ as a catalyst and $HgSO_4$ to remove Cl^- interfer-

Fig. 1. Locations of sampling sites in the Sarno River basin. Sites S1-S6 relate to the Sarno River, Sol1-Sol2 to the Solofrana, C1-C2 to the Cavaiola, and AC to the confluence between Solofrana and Cavaiola tributaries.



ence. Excess dichromate was titrated with Fe^{2+} using phenanthroline as an indicator.
The concentrations of $N\text{-}NO_2^-$ and $N\text{-}NH_4^+$ were determined spectrophotometrically (Perkin Elmer UV/Vis Lambda EZ 2209) using the sulphanilamide naphtylenediamine diamine reaction and the Nessler reagent (HgI_2 + KI), respectively.
Inorganic anions (bromides, chlorides, fluorides, acetates, sulphates, nitrates and phosphates) were determined using a Dionex DX 120 ion chromatograph, equipped with an ion Pac AS14 column (4 x 250 mm) and an ion Pac AG14 (4 x 50 mm) guard column and detected by suppressed conductivity. Eluent was 1.8 mM Na_2CO_3:1.6 mM $NaHCO_3$ at a flow rate of 2 mL min^{-1} at a pressure of 970 psi. The quality control was ensured by analyzing blank samples and international standards.
Metallic cations (cadmium, chromium, copper, lead and zinc) were determined by a Perkin Elmer model Analyst 100 atomic absorption spectrometer equipped with deuterium-arc background correction in acidic samples (pH below 2.0).

Microbial analyses

Samples were collected in pre-sterilized Teflon bottles and shipped on ice to the laboratory for analysis. Water samples were analyzed for heterotrophic plate count (HPC) bacteria by placing 1 mL of raw sample on an agar plate, and for total and fecal coliform (TC, FC), fecal streptococci (FS) and *E. coli*, employing the filtration membrane method (0.45 μm pore-size filters, Millipore). For these latter four 100-ml portions of the water sample were filtered and the filters were then placed on separate RODAC plates containing selective broth. Plates were incubated at 36°C and 22°C for HPC and examined after 24 and 72 hours, and at 36°C and 44°C for TC-FS and FC, respectively, and examined after 24 hours.
Water and air samples were collected concurrently at one selected site (S5) on the Sarno River and analyzed for traditional fecal indicators such as TC and FC. Air samples were collected (1000 L sampled at 180 L min^{-1}) by using a SAS (Surface Air System) mod. Super 180 apparatus (International pbi S.p.A. Milano) loaded with a 55-mm diameter contact plate with appropriate agar medium (the same as those used for water samples).
To mimic the biological aerosolizing process, we simulated experimentally the aerosolizing process in the laboratory by using an aerosol-making apparatus that produces particles ranging between 1.7 and 2.5 μm in size. Then, with the same air sample collector (SAS) equipped with a contact plate for fecal and total coliform, we collected air samples at different experimental conditions (10, 100, 1000 L min^{-1}). Plates were then incubated at 36°C and 44°C for TC and FC, respectively, and examined after 24 hours, counting the number of colonies growth.
Biological monitoring by EBI (Extended Biotic Index) or by the more recent IFF (Index of Fluvial functionality) was not carried out since, in all the stations except the head, there were no benthic macro-invertebrates because of heavy anoxic conditions.

Results and discussion

Summary results for chemical and physical analyses

The Sarno River exhibits two well-defined areas. In the first, lying between the headwater and the beginning of Sarno city (S1), the river has good characteristics and sustains trout and other delicate organisms. In the second, between Sarno city (S2) and the mouth (S6), the scenery changes completely, water quality declines and the river becomes gradually uncomfortable for the aquatic life, principally during summer. S1 could be considered as a reference location assumed to have a minimal human impact.
Tables I-III summarize the chemical and physical analyses, as average values, from the sampling sites on Sarno River S1, S3 and S6 (data relative to S2, S4 and S5 are not reported for the sake of brevity). The Tables show that physical and chemical parameters became worse on going from the headwater to the mouth of the river. Water temperature, as expected, presents a rather constant value (being 12.7 and 13.9 °C the minimum and maximum, respectively) at the head (S1), whereas at all other sample sites a great difference between minimum and maximum values are observed, with the average values becoming rather higher with respect to S1. The average pH of the river is 7.5 with small differences between sampling site and season. This homogeneity lead us to believe that no acid or alkaline substances have been discharged into the river.
The dissolved oxygen constantly decreases, on average, from the head to the mouth showing extremely low minimum values toward the mouth. These data are three to five times lower than those relative to the solubility of oxygen in water at the same temperatures. Bacterial respiration from the organic load evidently contributed to these anoxic conditions. Given the low level of oxygen, the determination of biological oxygen demand (BOD) was not conducted because it would have been meaningless. At the same time the chemical oxygen demand (COD) shows an increasing trend, reaching very high values toward the mouth. The highest COD values were observed in August with peaks at sites S5 and S6 (200 and 300 mg/L, respectively). Electrical conductivity (EC) varied seasonally, but homogeneously, at all sites, from 0.85 to 1.15 mS/cm. High electrical conductivity indicates high con-

Tab. I. Statistical analysis (on 24 determinations) for physical and chemical parameters relative to water samples collected at sampling site S1.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	13.2	0.45	0.21	12.70	13.60	13.30
Dissolved Oxygen	(ppm)	6.24	0.74	0.55	5.40	6.82	6.50
Electric Conductivity	(mS/cm)	0.74	0.02	0.00	0.73	0.77	0.74
pH		7.34	0.15	0.02	7.17	7.48	7.38
COD	(mg O_2/L)	-	-	-	-	-	-
Settleable solids	(mL/L)	-	-	-	-	-	-
Suspended solids	(mg/L)	-	-	-	-	-	-
Fixed residue at 180 °C	(mg/L)	466.66	20.81	433.33	450.00	490.00	460.00
Ammonium	(mg/L)	0.33	0.41	0.17	0.09	0.81	0.10
Fluorides	(mg/L)	0.57	0.02	0.00	0.54	0.59	0.59
Acetates	(mg/L)	-	-	-	-	-	-
Chlorides	(mg/L)	53.23	6.88	47.34	45.54	58.80	55.36
Nitrites	(mg/L)	-	-	-	-	-	-
Bromides	(mg/L)	0.05	0.08	0.00	0.01	0.15	0.01
Nitrates	(mg/L)	4.63	0.76	0.58	3.80	5.30	4.80
Phosphates	(mg/L)	0.06	0.11	0.01	0.00	0.20	0.00
Sulphates	(mg/L)	8.22	0.20	0.04	8.00	8.39	8.29
Cd	(µg/L)	0.2	0.34	0.12	0.00	0.60	0.00
Cr	(µg/L)	1	0.62	0.39	0.30	1.50	1.20
Pb	(µg/L)	0.33	0.57	0.33	0.00	1.00	0.00
Zn	(µg/L)	1.2	1.08	1.17	0.00	2.10	1.50
Cu	(µg/L)	1.4	0.87	0.76	0.00	1.60	1.40

Tab. II. Statistical analysis (on 24 determinations) for physical and chemical parameters relative to water samples collected at sampling site S3.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	16.06	3.43	11.81	8.90	20.90	16.80
Dissolved Oxygen	(ppm)	2.41	1.19	1.43	0.78	5.31	2.34
Electric Conductivity	(mS/cm)	0.98	0.09	0.0088	0.84	1.19	0.96
pH		7.53	0.14	0.02	7.22	7.78	7.56
COD	(mg O_2/L)	73.62	74.07	5487.04	0.00	300.00	40.00
Settleable solids	(mL/L)	1.15	0.92	0.84	0.20	3.00	0.85
Suspended solids	(mg/L)	51.55	44.14	1948.77	8.00	150.00	48.00
Fixed residue at 180 °C	(mg/L)	726.66	207.62	43105.88	140.00	1010.00	770.00
Ammonium	(mg/L)	10.24	38.52	1484.28	0.26	173.80	1.24
Fluorides	(mg/L)	0.58	0.22	0.05	0.08	0.81	0.64
Acetates	(mg/L)	1.43	1.80	3.24	0.45	4.13	0.58
Chlorides	(mg/L)	84.00	14.62	213.80	55.24	108.38	85.39
Nitrites	(mg/L)	0.85	0.59	0.35	0.01	2.26	0.84
Bromides	(mg/L)	0.24	0.08	0.0069	0.016	0.34	0.25
Nitrates	(mg/L)	7.97	4.86	23.63	0.61	17.70	9.39
Phosphates	(mg/L)	43.77	73.91	5463.19	0.00	183.86	1.75
Sulphates	(mg/L)	34.15	23.25	540.73	18.90	85.62	22.95
Cd	(µg/L)	0.67	1.62	2.63	0.10	5.00	0.13
Cr	(µg/L)	5.19	3.72	13.87	0.40	12.60	4.55
Pb	(µg/L)	1.66	1.45	2.11	0.20	4.60	1.20
Zn	(µg/L)	4.46	3.14	9.90	1.30	11.30	3.20
Cu	(µg/L)	5.40	6.037	36.45	0.40	22.30	3.05

Tab. III. Statistical analysis (on 24 determinations) for physical and chemical parameters relative to water samples collected at sampling site S6.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	18.37	4.06	16.56	10.30	23.20	19.85
Dissolved Oxygen	(ppm)	1.41	1.22	1.49	0.002	4.71	1.03
Electric Conductivity	(mS/cm)	1.17	0.14	0.02	0.95	1.453	1.14
pH		7.38	0.10	0.01	7.13	7.56	7.39
COD	(mg O_2/L)	76.19	54.95	3019.96	16.00	240.00	60.00
Settleable solids	(mL/L)	4.28	2.19	4.80	0.2	7.00	4.00
Suspended solids	(mg/L)	198.05	148.50	22054.90	7.5	524.00	200.00
Fixed residue at 180 °C	(mg/L)	888.88	177.19	31398.69	510.00	1110.00	935.00
Ammonium	(mg/L)	4.22	4.86	23.66	0.21	20.50	3.01
Fluorides	(mg/L)	0.94	0.18	0.03	0.75	1.41	0.92
Acetates	(mg/L)	1.35	1.07	1.15	0.54	3.22	1.03
Chlorides	(mg/L)	101.80	19.95	398.08	61.56	141.80	99.28
Nitrites	(mg/L)	1.24	0.97	0.95	0.01	3.21	1.28
Bromides	(mg/L)	0.47	0.18	0.03	0.03	0.84	0.47
Nitrates	(mg/L)	16.63	11.52	132.85	0.35	45.09	17.00
Phosphates	(mg/L)	58.23	102.97	10603.20	0.01	250.86	1.84
Sulphates	(mg/L)	52.82	41.89	1755.57	0.62	141.07	36.58
Cd	(µg/L)	1.09	2.66	7.11	0.05	8.20	0.20
Cr	(µg/L)	4.29	2.88	8.30	0.40	8.70	4.40
Pb	(µg/L)	4.85	3.84	14.75	0.30	14.80	4.05
Zn	(µg/L)	6.84	3.25	10.58	0.30	12.50	6.82
Cu	(µg/L)	8.48	7.48	55.97	2.10	25.70	4.40

centration of salts, which can be presumably attributed to anthropogenic discharges. The high anthropic contribution is also confirmed by the high concentrations of settleable solids at all sampling sites, except the head, with values often exceeding the regulatory level of 0.5 mL/L [19]. Peaks of 4 mL/L (S5) and 7 mL/L (S6) were observed in autumn. Suspended solid concentrations were more heterogeneous than the settleable fraction: values at site S6 were from two- to six-fold higher than values fixed by Italian environmental legislation [19] for wastewaters to be discharged in superficial waters.

Anionic determinations looked at fluorine, chlorine, bromine, nitrite, nitrate, phosphate, sulphate and acetate ions. For the latter, no intervention limits for contaminated streams are yet established in Italy by current environmental legislation. Fluorine ion concentration was constantly low and mostly lower than the minimum value predicted for wastewaters to be discharged in superficial waters [19]. Chlorine ion concentration became appreciably higher starting from S3 sampling site located below the confluence with Solofrana tributary, downstream from a wastewater treatment plant. Concentrations of chlorides are in the range 35-120 mg/L. The results relative to the Solofrana and Cavaiola tributaries will be reported in the following. Regarding the sulphate ion very low levels were detected for most of the determinations but, at some sites toward the mouth, the values become appreciably higher (peaks of 140 mg/L at S5 and S6). Nitrite and nitrate anions are present in low concentrations. The former are either nonexistent or at trace levels, the latter show higher values but still below the limits predicted for superficial waters to be used for drinking water [19].

Concentrations of NH_4^+ were low if compared with the water quality standard of 15 mg/L and average values varied between 3.4 (S5) and 10.2 (S3). However, very high values, exceeding the regulatory limit, were observed at C1 and C2 sampling sites.

Over the entire period (values not reported for the sake of brevity), we note a seasonal variation in the overall anion concentrations that appears particularly evident for phosphates. This latter is almost absent for the entire period of determination except for three sampling dates between November and December, probably after stream water was enriched by surface runoff.

The same analytical determinations were carried out on samples collected along the Solofrana and Cavaiola tributaries and at their confluence (AC). The results are reported in Tables IV-VI as average values over the entire period of determination (data relative to

Tab. IV. Statistical analysis (on 24 determinations) for physical and chemical parameters relative to water samples collected at sampling site Sol2.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	15.92	4.05	16.42	10.2	21.20	16.40
Dissolved Oxygen	(ppm)	7.04	2.60	6.78	1.07	9.36	8.06
Electric Conductivity	(mS/cm)	2.76	0.38	0.14	2.12	3.56	2.71
pH		7.78	0.14	0.02	7.59	8.04	7.77
COD	(mg O_2/L)	81.00	43.33	1877.71	20.00	144.00	72.00
Settleable solids	(mL/L)	2.33	0.57	0.33	2.00	3.00	2.00
Suspended solids	(mg/L)	8.66	1.15	1.33	8.00	10.00	8.00
Fixed residue at 180 °C	(mg/L)	1810.13	829.54	688151.90	21.10	2530.00	2030.00
Ammonium	(mg/L)	1.49	1.87	3.49	0.18	4.78	1.00
Fluorides	(mg/L)	0.57	0.28	0.08	0.30	1.05	0.45
Acetates	(mg/L)	2.66	3.24	10.49	0.14	8.13	1.51
Chlorides	(mg/L)	652.12	96.89	9389.12	491.80	790.36	655.80
Nitrites	(mg/L)	9.90	14.76	217.98	0.04	33.55	0.40
Bromides	(mg/L)	0.45	0.18	0.03	0.30	0.75	0.40
Nitrates	(mg/L)	39.95	13.18	173.75	17.78	56.85	41.15
Phosphates	(mg/L)	319.32	542.11	293887.40	0.81	1161.86	2.85
Sulphates	(mg/L)	154.83	33.93	1151.33	113.90	197.30	152.42
Cd	(µg/L)	6.64	14.28	204.18	0.10	32.20	0.30
Cr	(µg/L)	44.64	26.82	719.67	2.90	72.10	56.60
Pb	(µg/L)	5.69	7.09	50.36	0.05	17.10	1.90
Zn	(µg/L)	7.88	3.54	12.58	5.00	13.40	6.05
Cu	(µg/L)	4.2	2.84	8.09	1.10	8.90	3.80

Tab. V. Statistical analysis (on 24 determinations) for physical and chemical parameters relative to water samples collected at sampling site C2.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	12.21	4.79	23.03	5.30	18.50	12.20
Dissolved Oxygen	(ppm)	6.56	1.87	3.51	3.03	9.57	6.64
Electric Conductivity	(mS/cm)	0.84	0.16	0.02	0.59	1.086	0.88
pH		8.07	0.21	0.04	7.59	8.32	8.10
COD	(mg O_2/L)	153.50	79.82	6372.28	48.00	280.00	130.00
Settleable solids	(mL/L)	0.97	1.35	1.82	0.30	3.00	0.30
Suspended solids	(mg/L)	43.33	25.16	633.33	20.00	70.00	40.00
Fixed residue at 180 °C	(mg/L)	683.75	156.92	24626.79	450.00	920.00	700.00
Ammonium	(mg/L)	11.07	7.77	60.46	0.40	20.35	10.14
Fluorides	(mg/L)	0.34	0.05	0.0031	0.28	0.47	0.34
Acetates	(mg/L)	3.76	7.06	49.90	0.03	19.70	0.44
Chlorides	(mg/L)	69.62	20.85	434.98	30.83	97.86	76.95
Nitrites	(mg/L)	2.49	1.60	2.56	0.21	4.81	1.92
Bromides	(mg/L)	0.14	0.03	0.0015	0.09	0.20	0.14
Nitrates	(mg/L)	3.25	2.76	7.62	0.38	7.58	2.18
Phosphates	(mg/L)	51.00	62.73	3935.45	0.33	140.89	2.63
Sulphates	(mg/L)	15.01	7.72	59.72	0.60	22.91	18.20
Cd	(µg/L)	0.06	0.05	0.0032	0.00069	0.10	0.10
Cr	(µg/L)	1.27	1.10	1.22	0.20	3.10	0.90
Pb	(µg/L)	12.07	19.05	363.08	0.20	40.20	3.95
Zn	(µg/L)	10.70	4.27	18.30	6.80	16.80	9.60
Cu	(µg/L)	11.30	5.00	25.09	7.00	16.80	10.10

Tab. VI. Statistical analysis (on 24 determinations) for physical and chemical parameters on water samples collected at sampling site AC.

Parameter		Average	St. dev.	Variance	Min.	Max.	Median
Water Temperature	(°C)	13.12	4.88	23.87	7.20	20.80	13.20
Dissolved Oxygen	(ppm)	7.54	1.03	1.06	6.31	9.48	7.30
Electric Conductivity	(mS/cm)	1.20	0.23	0.05	0.88	1.53	1.19
pH		8.10	0.09	0.0091	8.00	8.21	8.08
COD	(mg O_2/L)	78.66	30.63	938.66	32.00	120.00	80.00
Settleable solids	(mL/L)	0.95	0.52	0.27	0.45	1.50	0.90
Suspended solids	(mg/L)	28.23	1.66	2.76	26.70	30.00	28.00
Fixed residue at 180 °C	(mg/L)	870.00	235.03	55240.00	630.00	1250.00	775.00
Ammonium	(mg/L)	4.33	2.79	7.83	0.29	7.68	5.12
Fluorides	(mg/L)	0.48	0.15	0.02	0.31	0.74	0.40
Acetates	(mg/L)	0.37	0.63	0.40	0.001	1.78	0.10
Chlorides	(mg/L)	186.65	61.55	3788.73	124.59	292.46	160.86
Nitrites	(mg/L)	2.15	0.62	0.38	1.46	2.98	1.87
Bromides	(mg/L)	0.15	0.05	0.0028	0.11	0.24	0.13
Nitrates	(mg/L)	20.45	5.76	33.18	12.50	30.82	19.63
Phosphates	(mg/L)	106.41	184.37	33993.40	0.00	431.95	0.48
Sulphates	(mg/L)	45.36	17.81	317.32	34.17	76.72	37.67
Cd	(µg/L)	0.23	0.11	0.01	0.10	0.30	0.30
Cr	(µg/L)	14.6	11.09	123.14	3.40	35.90	15.90
Pb	(µg/L)	0.87	1.22	1.48	0.20	2.70	0.30
Zn	(µg/L)	5.65	3.36	11.29	0.30	9.40	5.90
Cu	(µg/L)	10.16	0.06	0.0033	10.10	10.20	10.20

Sol1 and C1 are not reported for the sake of brevity). From the data, the high contribution of the wastewater treatment plant (located between the sampling sites Sol1 and Sol2) is evident, which leads to a significant increase in the concentration of chlorine and sulphate ions (Cl^- peak of 790 mg/L and SO_4^{--} 190 mg/L at Sol2). After dilution along the river, high values of chlorine are still observed at AC and further on at sites S3-S6. The overall quality of water at C1, C2 and Sol1 sites is better than that relative to Sarno River. It is worth noting that the values of dissolved oxygen are roughly threefold those observed at Sarno River and that the electrical conductivity, suspended solids and fixed residue all present average values appreciably lower than those relative to Sarno River, thus showing that anthropogenic contamination have interested these water bodies to a lesser extent than at Sarno River. Anionic determinations reveal lower values with respect to Sarno River, except for Sol2 sampling site. At this latter, in fact, the highest average values of fixed residue, chlorides, nitrates, phosphates and sulphates have been detected. Not surprisingly these high concentrations could all derive from the WWTP effluent samples. Finally, acetate ions, mostly detected along the Cavaiola tributary, showed great seasonal variation.

Concentrations of Cd, Cr, Cu, Pb and Zn were rather heterogeneous but within the regulatory limits for wastewater to be discharged in superficial waters. All the average concentrations are in the range of limits fixed by Legislative Decree 152/06 and only some maximum values exceed from the legal limits, most probably depending on uncontrolled release of polluting materials, thus suggesting that an occasional source was contributing to high contamination and emphasizing the importance of one-point discharges as the predominant source of chemical contamination.

Summary results for microbial analyses

Microbiological monitoring was conducted by analysing some indicators of fecal pollution, since it has been demonstrated that the presence of pathogens in aquatic environments is intermittent and their isolation is often complex, time-consuming and expensive [5, 6, 8, 9, 11].

Data are reported in Table VII for Sarno River and Table VIII for Solofrana and Cavaiola tributaries and their confluence (AC), respectively. For each determined parameter, the first line represents average concentrations and the second minimum and maximum values. At all stations along Sarno River, except the head, we found high levels of contamination. The level

Tab. VII. Statistical analysis for bacterial contamination at sampling points along Sarno River (S1-S6). For each site the first line represents average values and the second one minimum and maximum concentrations.

Sampling point	HPC (CFU/1 mL)	Total coliforms (CFU/100 mL)	Fecal coliforms (CFU/100 mL)	E. coli (CFU/100 mL)	F. streptococci (CFU/100 mL)
S1	15.00 0.00-20.00	–	–	–	–
S2	1.80E+06 2.0E+03 – 8.5E+06	8.50E+06 1.8E+03 – 8.0E+07	5.00E+06 1.5E+03 – 7.8E+06	4.50E+06 1.0E+05 – 7.0E+06	2.20E+06 0.8E+03 – 3.6E+06
S3	2.00E+06 7.0E+03 – 5E+07	6.10E+06 7.2E+03 – 3.5E+07	5.50E+06 6.0E+03 – 2.5E+07	4.20E+06 5.0E+05 – 9.0E+06	2.30E+06 3.2E+03 – 1.3E+07
S4	6.30E+06 1.0E+04 – 3.7E+07	1.70E+07 0.8E+04 – 3.0E+08	6.30E+06 0.5E+04 – 8.7E+07	4.30E+06 1.8E+06 – 2.7E+07	3.30E+06 0.2E+04 – 4.7E+07
S5	7.10E+06 3.5E+04 – 5.2E+07	3.40E+07 1.9E+04 – 4.2E+08	9.10E+06 3.5E+03 – 5.2E+07	5.80E+06 3.0E+05 – 4.2E+07	4.80E+06 1.5E+03 – 2.5E+07
S6	3.90E+06 1.00E+04 – 2.2E+07	4.10E+07 0.80E+04 – 2.0E+08	3.20E+07 0.60E+04 – 1.8E+08	1.90E+07 0.50E+06 – 8.5E+07	6.40E+06 0.30E+04 – 9.8E+07

Tab. VIII. Statistical analysis for bacterial contamination at sampling points along Cavaiola (C1, C2), Solofrana (Sol1, Sol2) and their confluence (AC). For each site, the first line represents average values and the second one minimum and maximum concentrations.

Sampling point	HPC (CFU/1 mL)	Total coliforms (CFU/100 mL)	Fecal coliforms (CFU/100 mL)	E. coli (CFU/100 mL)	F. streptococci (CFU/100 mL)
Sol1	1.20E+05 1.8E+04 – 3.5E+05	6.50E+05 1.8E+04 – 4.1E+06	5.00E+05 1.4E+03 – 7.8E+05	4.50E+05 1.0E+03 – 7.0E+05	2.10E+05 0.6E+03 – 3.6E+05
Sol2	2.00E+05 1.5E+04 – 5.0E+06	5.10E+04 6.2E+03 – 6.0E+06	4.50E+04 5.0E+03 – 1.5E+06	3.20E+04 3.0E+03 – 9.0E+05	2.40E+04 2.2E+03 – 1.3E+05
C1	6.00E+05 5.5E+04 – 4.7E+06	1.70E+06 8.0E+04 – 1.8E+07	1.30E+06 0.8E+04 – 0.7E+07	0.90E+06 7.8E+03 – 6.7E+06	0.30E+06 0.2E+04 – 4.7E+06
C2	5.10E+05 7.0E+04 – 5.2E+06	3.40E+06 1.2E+05 – 2.5E+07	8.10E+05 3.8E+03 – 5.2E+06	5.80E+05 3.0E+03 – 4.2E+06	4.30E+05 1.5E+03 – 2.4E+06
AC	3.90E+05 3.0E+04 – 1.2E+06	4.10E+05 6.0E+04 – 6.0E+06	3.20E+05 3.60E+04 – 1.7E+06	1.90E+05 0.90E+04 – 8.5E+05	1.40E+05 2.30E+04 – 9.8E+05

of *E. coli*, shown to be an appropriate bacterial indicator for predicting GI illness [12], ranged from 1.0E + 05 to 8.5E + 07 (CFU/100 mL). Fecal coliform ranged from 1.5E + 03 to 1.8E + 08 (CFU/100 mL) with a little seasonal variation. This high microbial contamination leads us to suppose that the stream is composed almost entirely of urban wastewaters.

Microbial contamination is responsible for numerous outbreaks of disease after contact with or ingestion of water. Numerous studies have associated the presence of microbial indicators (either in marine or freshwater) to health outcomes. The literature strongly suggests a dose-response relationship between fecal contamination and the risk of GI illness [12, 20] but, to our knowledge, did not examine the risk posed to human health by the dispersion of contaminants into the aerosols. *E. coli*, for example, has been recognized as a source of acute pulmonary illness.

Thus, a major challenge in assessing airborne biological hazards to surrounding communities posed by the outspread of contaminated water is searching appropriate indicators in the aerosols. Our objective was to explore the presence of indicator bacteria in aerosols, which provide a more reliable approach to determining the risk to human health, e.g. when water is used as an irrigation source for fruits and vegetables. With this aim we collected water and air samples concurrently at one selected site (S5); water sample was analyzed for total and fecal coliform showing the following values TC = 1.2E + 06, FC = 0.16E + 04, whereas, at first, no fecal contamination was found in air samples. These latter, however, showed contamination from heterotrophic bacteria. The process of aerosol spread has evident correlation with meteorological factors, such as temperature, relative humidity or wind intensity and direction, which interact with each other in

Tab. IX. Analysis for FC contamination of air samples obtained by aerosolizing process.

Volume Air collected (L min-1)	Fecal Coliforms (CFU)
10	5
100	50
1000	200

various ways depending upon local conditions [21, 22]. To overcome these factors and to further investigate this point we simulated an aerosolizing process in the laboratory by using an aerosol-making apparatus. Then, with the same air sample collector (SAS) equipped with a contact plate appropriate for fecal and total coliform, we collected air samples under different experimental conditions (10, 100, 1000 L min^{-1}). After 24 hours of incubation we were not able to count the number of colonies formed for total coliforms, since the surface of plates was completely invaded, whereas for fecal coliform a correlation was found between volumes of air collected and bacterial concentration, as reported in Table IX.

Although this laboratory test mimics rigorously the biological aerosolizing process, not all results obtained might necessarily also occur under real-life exposure conditions. However, exploring the transport of fecal pollution from the river to the air is of extreme importance in assessing risks to human health from any use of river water. Although these analyses have been only qualitative and the different volumes examined for aerosolized bacteria cannot allow us to appraise with accuracy the correlation with the bacterial concentration found in water, their presence in the air suggests that more dedicated studies are needed to address with greater accuracy the quantitative aspects of this association. Further work is in progress to explore the quantitative relationship between the concentrations of bacteria in water and in air with the aim of establishing the lower limit of concentration below which the aerosolizing process cannot provide an appreciable health risk. However, these findings allow us to emphasize that, by improving biological water quality using appropriate treatment before discharging urban wastewater into the river, the risk to public health can be reduced.

Conclusion

In comparison with previous studies conducted on Sarno River basin a substantial reduction in metal and inorganic ions is observed, which can be related to improved industrial wastewater treatments before discharging into the river. However, the results clearly show a great influx of untreated urban wastewater, with both the overall frequency of detection and the total concentration being greater in all the samples collected downstream than those collected at the reference station. Water quality degradation due to fecal bacteria has been increasing and, consequently, also the potential risk to human health. From the headwaters to the mouth our results indicate a continued and progressive degradation in river water quality. While our objective was not to examine the adverse health effect associated with the pollution of the river, the present article has shown that people living in this area may be exposed to micro-organisms not only by contacting or ingesting water but also in the air. The findings shown here indicate the usefulness of this approach in being able to predict, and thus potentially reduce, threats to human health from use of these waters, even when individuals do not consume or come into contact with the contaminated water. The results of this study allow us to evaluate qualitatively and provide information on the presence in surface waters and their aerosols of micro-organisms associated with pathogenicity in humans. We also suggest that improving the biological water quality, along with improved industrial wastewater treatments, which has led to a reduction in metal and inorganic ions, will certainly benefit public health.

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