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Article

One-Year Surveillance of the Chemical and Microbial Quality of Drinking Water Shuttled to the Eolian Islands

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Abstract: This work presents the chemical and biological characteristics of drinking water shuttled from the main land (Naples, Campania, Italy) to the Eolian islands (situated off the north-eastern coast of Sicily). The data obtained from a one year surveillance program, (January to December, 2012) indicate that the quality of the water delivered to the islands meets the drinking water quality standard year-round. During summer, when requests for drinking water increase with the increase of the islands population, the quality of the shipped water decreases, most likely due to the use of older vessels in addition to those used during the rest of the year. The results suggest an implementation of a monitoring program at the point-of-use in order to identify potential sources of contamination early in shipped drinking water and, therefore, to manage the potential risk of waterborne illness more effectively.

Keywords: shipped water; microbial and chemical contamination; public health

1. Introduction

A clean, constant supply of drinking water is essential to every human community. The possible sources of this commodity are ground or surface water, such as lakes, rivers and reservoirs. In some cases, these sources are close to the population; other times, drinking water suppliers get their water from sources many miles away. In the case of small islands where ground water is not only limited, but also does not meet drinking water standards, the removal of all contaminants and minerals would be extremely expensive. Therefore, in these cases, the preferred system is to shuttle drinking water by tankers. It is worth noting that in this case, drinking water that is not properly treated or disinfected or that travels through an improperly maintained distribution system may pose some health risks [1–4]. In order to avoid contamination, tankships need to be properly designed for the water trade. Likewise, the risk of waterborne-disease outbreaks mainly depends on the quality of water and on the maintenance of the tanker fleet.

It is well known that drinking water distribution systems are vulnerable to external contaminant entry if there is a loss of physical/hydraulic integrity. In their 2006 report on risk assessment and reduction for distribution systems, the Committee on Public Water Supply Distribution Systems of the National Research Council [5] defined a loss of physical integrity as when the system no longer acts as a barrier that prevents external contamination from deteriorating the internal drinking water supply. Associated pathways of contamination include water main breaks/repair sites, uncovered reservoirs or covered storage tanks with structural deficiencies, cross-connections with no, inappropriately installed or inadequately maintained backflow prevention devices and backflow or contaminant intrusion caused by low-pressure events [6].

The presence of contaminants in drinking water can result in both acute and chronic effects [7–10]. Acute effects occur within a few hours or days of the ingestion of high levels of contaminant and are mostly caused by human pathogens, such as viruses and bacteria. When high levels occur, they can cause illness and can be dangerous or deadly for those who are immune-compromised or vulnerable, like children or the elderly. The drinking water contaminants that can have chronic effects are chemicals, such as disinfection by-products, solvents and pesticides [11], and metals, such as arsenic [12–16].

Waterborne-disease outbreaks, associated with drinking water contaminated during shipping, are not easily detected. First, not all outbreaks are recognized, investigated or reported to health officials or local authorities. Second, the epidemiologic evidence must implicate water as the probable source of illness. However, in order to prevent waterborne outbreaks, the distribution system has to be frequently monitored for the early identification of a possible intrusion of contamination into the distribution system.

The current state of monitoring drinking water transport in Italy is regulated by Legislative Decree 31/2001 [17], to provide good practices for shipping and to minimize the risk. In this paper, the physico-chemical and microbiological characteristics of the water delivered from the Italian main land (Campania) to the Eolian Islands (Sicily) are reported. Twenty vessels were monitored multiple times through a one year distribution before the transport of water. To our knowledge, this is the first study that reports the microbial and physico-chemical quality of water shuttled to a small island.

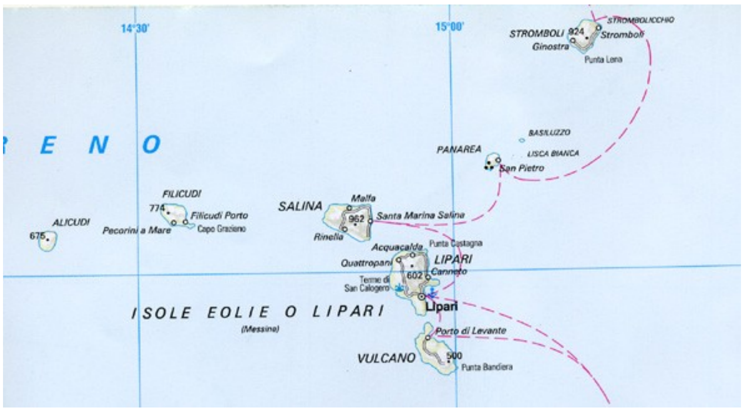
2. Materials and Methods

2.1. Sample Collection

Twenty vessels (twelve aged less than ten years and eight aged more than 30 years) were monitored for a single year before the transport of water. In Figure 1, a map of the distribution network is shown.

Figure 1. Map of Italy (**a**) Zoom on the Eolian Islands (**b**); The transport route is represented by the arrow.

(**a**)



(**b**)

Microbiological determinations were conducted each time the vessels left from the port of Naples, where they get water, whereas for physical and chemical parameters, water samples were collected once a month on each vessel, during January and December 2012, using the sampling method No. 1030, published by APAT (Agenzia per la protezione dell'Ambiente e per i servizi tecnici) [18]. Water was sampled when it was already stored in the tanks of vessels immediately before transport. The samples were kept at 4 °C, either in low-density polyethylene or Pyrex-glass containers, and were delivered to the laboratory within 4 h. In total, 111 physico-chemical and 207 microbiological determinations were performed. For microbiological determination, the samples were collected in pre-sterilized glass bottles, containing sodium thiosulfate, and shipped on ice to the laboratory for analysis. 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 model HI 9625.

2.2. Physico-Chemical Analyses

Inorganic anions (bromates, chlorides, fluorides, nitrites and nitrates) were determined using a Dionex DX 120 ion chromatograph, equipped with an ion Pac AS14 column (4 mm × 250 mm) and an ion Pac AG14 (4 mm × 50 mm) guard column, and detected by suppressed conductivity. The 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 (aluminum, arsenic, cadmium, chromium, copper, lead, iron, manganese and sodium) 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).

The determination of benzene, epichlorohydrin and trihalomethanes (THMs) was performed on an HP 5890 Series II gas chromatograph equipped with an HP 5921A atomic emission detector and a capillary column (HP 624 30 m × 0.32 mm I.D. (internal diameter), 1.8 µm film thickness).

2.3. Microbiological Analyses

Microbiological monitoring was conducted by analyzing 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 [19–23]. Therefore, water samples were analyzed for heterotrophic plate count (HPC; number of colonies in 1 mL of sample) and for total Coliform, *E. coli* and *Enterococcus* (the number of colonies in 100 mL of the sample), following the procedure described in the APAT CNR-IRSA (Consiglio Nazionale delle Ricerche—Istituto di Ricerca sulle Acque) guidelines, volume 3 (microbiological methods).

3. Results and Discussions

Table 1 summarizes the chemical and physical results, as mean values, of the analysis. The table shows that the overall quality of the water is acceptable, the physical and chemical parameters being below the regulatory level. All the results obtained over the entire period of monitoring meet the standards, as reported for Legislative Decree 31/2001 [17].

It is worth noting that, due to the increasing request for drinking water from the islands during the summer, additional vessels were used from May to September. These tankships are older and/or not specifically built to transport drinking water. An additional eight vessels were added to the winter fleet (12 ships). The chemical and physical determination performed on these vessels, once a month, showed a deterioration of the overall water quality, as can be observed from Figures 2–4, where a comparison of chloride content, conductivity and pH is reported.

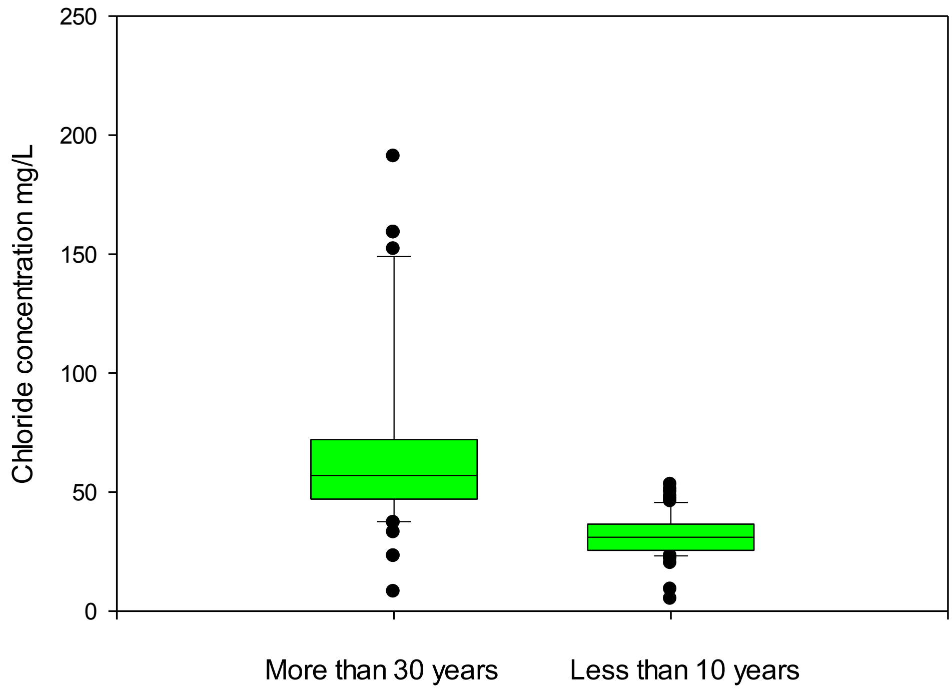
Table 1. Physical and chemical parameters relative to water samples collected in the tanks before shipping.

Parameter	Method	Unit	Mean	SD	Legislative Decree 31/01 *
Water Temperature	APAT CNR-IRSA 2100 MAN 29/2003	(°C)	13.2	0.8	-
Chemical Oxigen Demand (COD)	ISS.BEB.027 REV 00	(mg/L O_2)	0.1	0.01	5.0
Electric Conductivity	APAT CNR IRSA 2030 MAN 29/2003	(μS/cm)	812	342	2500
pH	APAT CNR IRSA 2060 MAN 29/2003	-	7.9	0.2	6.5–9.5
Total hardness	APAT CNR IRSA 2040 MAN 29/2003	(°F)	35.5	25.6	15–50
Fixed residue at 180 °C	ISS.BFA.032.REV 00	(mg/L)	350	35	1500
Ammonium	APAT CNR IRSA 4030 MAN 29/2003	(mg/L)	<0.02	-	0.50
Bromates	ISTISAN 03	(μg/L)	<1	-	10
Chlorides	APAT CNR IRSA 4020 MAN 29/2003	(mg/L)	52.68	37	250
Fluorides	APAT CNR-IRSA 4020 MAN 29/2003	(mg/L)	0.14	2.02	1.50
Nitrates	APAT CNR IRSA 4020 MAN 29/2003	(mg/L)	10	2.2	50
Nitrites	APAT CNR IRSA 4020 MAN 29/2003	(mg/L)	<0.02	-	0.50
Al	APAT CNR IRSA 3050 MAN 29/2003	(μg/L)	4	2.1	200
As	APAT CNR IRSA 3080 MAN 29/2003	(μg/L)	<1	-	10
Cd	APAT CNR-IRSA 3120 MAN 29/2003	(μg/L)	2.2	0.3	5.0
Cr	APAT CNR-IRSA 3150 MAN 29/2003	(μg/L)	<1	-	50
Cu	APAT CNR-IRSA 3250 MAN 29/2003	(mg/L)	0.01	0.8	1
Fe	APAT CNR IRSA 3160 MAN 29/2003	(μg/L)	3	0.8	200
Mn	APAT CNR IRSA 3190 MAN 29/2003	(μg/L)	1	0.1	50
Na	potentiometric	(mg/L)	15	2.4	200
Pb	APAT CNR-IRSA 3230 MAN 29/2003	(μg/L)	<1	-	10
Benzene	EPA-S021B	(μg/L)	<0.01	-	1.0
Epichlorohydrin	EPA-S260 B/96	(μg/L)	<0.01	-	0.1
THMs	EPA-S260 B/96	(μg/L)	<0.01	-	30

Note: * Limit established in Legislative Decree 31/2001 by the Italian Parliament.

Figure 2 shows a comparison of the concentration of chloride ion in water samples collected from vessels aged more than thirty years and less than ten years. It can be observed that in the older vessels, the maximum concentration of chloride ion almost reaches the Maximum Contaminant Level (250 mg/L). The Maximum Contaminant Level is the maximum permissible level of a contaminant in water delivered to users of a public water system, to ensure safety and to provide high quality water. The chloride concentrations of the two experimental group vessels (more than 30 years and less than 10 years) are significantly different (Mann-Whitney test, N1 = 61, N2 = 61; $p < 0.001$).

Figure 2. Experimentally determined chloride concentration in vessels aged more than thirty years and less than ten years. The distribution is shown by a vertical box plot as the median (lines), 25th and 75th percentiles (boxes) and 90th and 10th percentiles (whiskers). Circles mark the outliers.



Different scenarios could explain the high levels of chloride ions. Firstly, one can suppose that water has been exposed to cracked, corroded or damaged tankers, secondly, that these latter have not been washed enough after being used to transport different liquids and, thirdly, that the tankers are not adequately sealed. This could allow the infiltration of marine water into the tanks and could reasonably also explain the higher conductivity values observed and the great variation of pH values.

As is shown in Figure 3, the conductivity values vary significantly between the two experimental groups (Mann-Whitney test, N1 = 19, N2 = 103, $p = 0.005$). The conductivity values are related to the higher concentration of chlorides that characterize the older vessels. The same trend was observed in the microbiological analysis, as will be discussed below.

The pH values measured in both types of vessels (more than 30 years old and less than 10 years old) were significantly different (Mann-Whitney test, N1 = 19, N2 = 103, $p = 0.047$).

Figure 3. Experimentally determined conductivities in vessels aged more than thirty years and less than ten years. The distribution is shown by a vertical box plot as the median (lines), 25th and 75th percentiles (boxes) and 90th and 10th percentiles (whiskers). Circles mark the outliers.

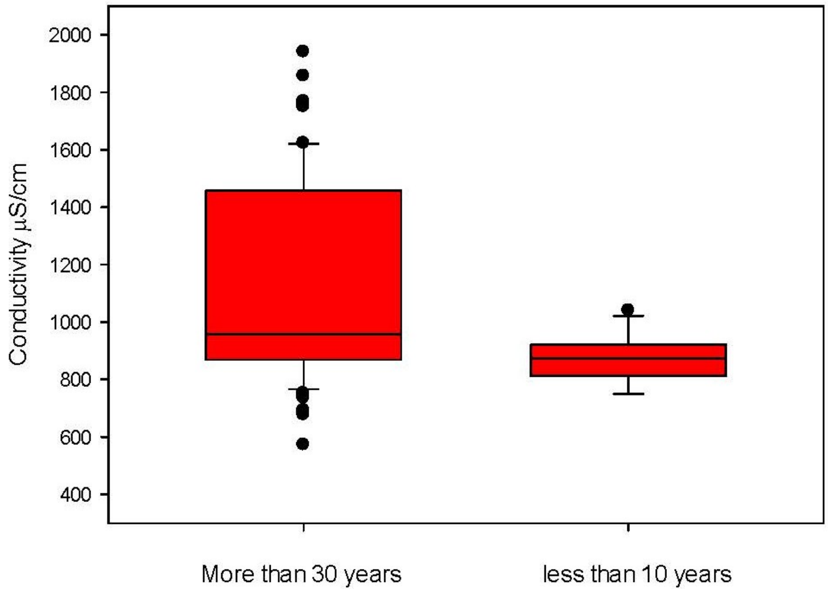


Figure 4. Experimentally determined pH values measured in vessel aged more than thirty years and less than ten years. The distribution is shown by a vertical box plot as the median (lines), 25th and 75th percentiles (boxes) and 90th and 10th percentiles (whiskers). Circles mark the outliers.

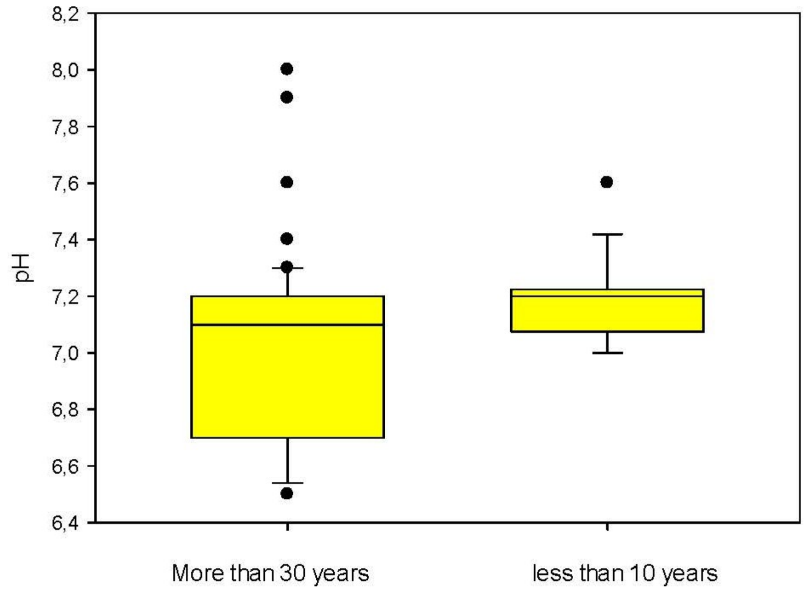
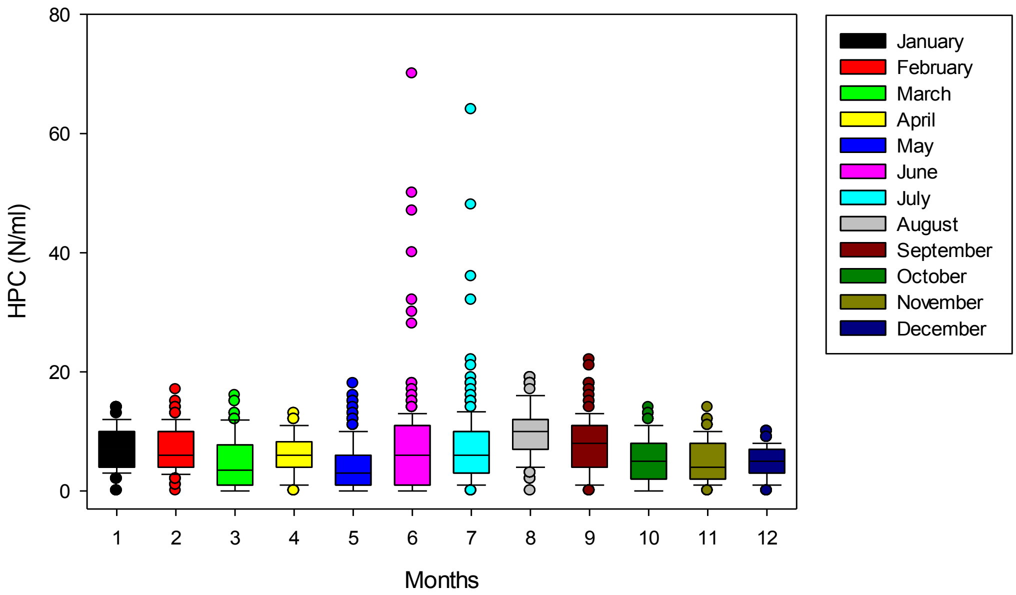


Figure 5 shows the results of the microbial analysis performed on all the vessels used to deliver drinking water to the Eolian Islands, during one year shipping, each time the vessels starts its transport. Total and fecal Coliform bacteria were always below the detection limit, thus excluding human health risk. During each month, the absence of *E. coli*, Coliform and *Enterococcus* was observed, except in July, when one of the old vessels showed a weak contamination of Coliform and *Enterococcus*, always below the accepted limits (about three cells/100 mL of water). Regarding the heterotrophic plate count (HPC), which is an indicator of general water quality within a distribution system [24], the levels are rather low. A great variation from the mean value, a great difference between minimum and maximum, is only observed during the months of June and July, and the highest average values were in August, which correspond to the period of the major request for drinking water and, then, to the use of older vessels, sometimes improperly utilized for drinking water transport in addition to those regularly used during the year. To analyze the differences in the number of bacteria identified in the water in the 12 months, we used a Kruskal–Wallis One Way Analysis of Variance on Ranks. The results confirmed that there are significant differences among the months ($H_{(11)} = 266.176$; $p < 0.001$). For the pairwise comparisons, Dunn's method has been used. It suggests that the HPC values measured in the vessels during August are significantly different from the other values measured during all other months ($p < 0.05$).

Therefore, though shipped water meets state standards and is generally safe to drink year-round, the potential threats to safe drinking water increase in the summer season.

Figure 5. Heterotrophic plate count (HPC) bacteria measured at temperature T = 22°C during one year of monitoring of all the ships used to deliver drinking water from Naples to the Eolian Islands. The distribution is shown by the vertical box plot as the median (lines), 25th and 75th percentiles (boxes) and 90th and 10th percentiles (whiskers). Circles mark the outliers.



One more critical point that could add risk is the procedure adopted to deliver water from the ship to the island. Figure 6 is a picture of a vessel taken during the operation of water distribution at Filicudi, one of the Eolian Islands. It shows how water is transported through pipes partially immerged in sea water and/or lying on the harbor platform. These pipes are handled without detailed operating procedures, thereby producing potential for the ingress of contaminants. A greater level of cleanliness and hygiene should be adopted to mitigate these risks.

Figure 6. Picture of a vessel taken during the operation of water distribution at Filicudi, one of the Eolian Islands.

In this study, we did not evaluate any relation between water contamination after shipping and reported health concerns. However, we do provide some insight into the potential public health risks associated with the distribution systems from the main land to small islands. Nonetheless, we are convinced that a surveillance program would protect the imported drinking water and also assist in identifying system breakdowns, operator errors and other engineering-related activities that lead to outbreaks.

4. Conclusions

The results reported in this paper show that the drinking water quality is generally good; however, a systematic surveillance system is desirable to identify potential sources of contaminants in drinking water shipped to small islands early. Although monitoring does not necessarily suggest good operation conditions, it is crucial to ensure that clean and safe drinking water will be delivered to the islands. Water restrictions have demonstrated that the overall quality of drinking water changes, most probably due to the use of older vessels or vessels that are not specifically designed for water shipping. Since water contamination can occur during shipping and unloading, an implementation of the monitoring program at the point-of-use is suggested in order to identify potential sources of contamination in shipped drinking water early and, therefore, to manage the potential risk of waterborne illness more effectively.

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Conflicts of Interest

The authors declare no conflict of interest.

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