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An innovative coastal protection system: Quality characteristics and reuse options of drained sea water derived from its operation

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ABSTRACT

Coastal areas represent an important resource intrinsically linked to economics through the tourism industry. Nevertheless erosion along shorelines is becoming one of the growing serious environmental problems. For coastal defence, an innovative coastal protection system, the BMS (Beach Management System or RSA), was installed along a stretch of Italian coast. The technique is based on the principle of the artificial drainage of the beach to keep the water surface level low. After sea water drainage, pumps discharge the drained water back to the sea. Our proposal is to use the drained water as an option to its discharge into the sea. Therefore a study was carried out with the aim to verify if this proposal can be achievable. Analyses of both microbial parameters, such as bacterial indicators and *Salmonella*, and physico-chemical parameters were carried out for the evaluation of the hygienic characteristics of the drainage water at the outlet of the system. Results showed that a significant reduction (1–2 orders of magnitude) of the microbial loads was achieved after the transport of water through the sand and the coated-pipes of the system that work as an efficient mechanism of bacterial removal. Taking into consideration the obtained results, this new solution for the defence of shorelines could be used for making a productive reuse of good quality non-conventional water, such as sea water. Areas subject to coastal erosion could maximise benefits due to sustainable forms of coastal management with practices of water-saving and use the drained water for replenishment of marine swimming-pools, aquatic parks, aquariums and aquaculture pools or for the re-qualification of humid zones or for contrasting subsidence phenomena along the coasts.

Keywords: Bacteria; Beach management; Coastal protection; Erosion; Reuse; RSA system; Sea water

1. Introduction

Water supply is a finite resource and its available renewable quantity is diminishing as a result of unsustainable extraction and exploitation of resources [1]. Water scarcity is now viewed under the perspective of the quantities available for economic and social uses, as well as in relation to water requirements for natural and man-made ecosystems. Water scarcity can result from a range of phenomena that may be produced by natural causes, may be induced by human activities, or may result from the interaction of both. Weather changing, pollution and over-exploitation of resources, depletion of the groundwater level, intrusion of sea water into the aquifers, improved demand due to population growth, urbanization and

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agriculture and industrial expansions are among the main pressing issues.

To make concrete the principle of sustainable management of water resources it is mainly necessary to reduce the water demand and contemporaneously to enhance reuse capability [2].

Water reuse for beneficial purposes is an important element of the world's total water resources management. Its most obvious benefits are the provision of an alternative water resource and the conservation of freshwater supplies.

Coherently with this perspective, an innovative option for water's saving, to be evaluated according to requirements and specific purposes, can be represented by the use of non-conventional water, such as sea water. The supply of sea water is unlimited and for coastal areas its use may become competitive with prices of imported freshwater, especially if some non-potable but specific compatible uses are conceived.

In a scenario of global climate change, a specific attention to coastal dynamics and shoreline evolution should be paid. In this context, one of the growing environmental concerns faced by coastal communities is the coastal erosion. Several factors, including sea level rise, geology, and rapid coastal population growth accompanied by rapid increase of human activities that interfere with natural processes, have been linked to the problem.

There is increasing evidence that coastal erosion is an escalating environmental threat globally and a cause for concern [3]. In fact, over the past 100 years, about 70% of the world's sandy shorelines have been retreating and currently around 20% of the European coastline is eroding while at the same time the human population living in the coastal zone is strongly increasing. In our present culture, focusing on economic and social aspects, coastal erosion is considered as an unacceptable landward movement of the coastline [4].

In coastal erosion risk management, the assessment methods have resulted in the predominance of engineering ''solutions'' (e.g., for resource exploitation, sea defense, and coastal protection) within a constantly changing dynamic system. There is an evidence that many responses in this area tend to solve erosion locally and very temporarily but tend to exacerbate coastal erosion problems in other locations. In many cases, this has led to catastrophic consequences for the resilience capacity of coastlines to respond to the stresses and shocks of environmental change and perform their socioecological functions [5]. Coastal environmental damages can be repaired and managed through the realization of defence structures that, however, can modify natural coastal dynamics and, in some cases, can represent an inadequate and economically unsustainable solution. In fact, current methods and means for preventing and minimizing shoreline erosion can include the installation of breakwaters, groins, revetments, sedimentation polders and jetties. Sand replenishment is often used in conjunction with these systems when shorelines have to be extended or restored. These techniques, though often functional, are costly and can detract from the natural environment. In Table 1 the most common coastline erosion protection options, their characteristics, advantages/disadvantages are described.

The implementation of coastal defence projects should instead obey principles based on overall natural processes operating on the coast. Innovative technologies should therefore push towards the search of new solutions for the defence of shorelines.

Among the newest systems, technologies based on the artificial drainage of the beach have been developed taking into account that the beach is an effective means of wave energy dissipation [6].

One of the latest beach drainage technologies is the so-called RSA or *Beach Management System* (BMS), a softer method respect to other systems for coastal protection. The concept is based on the principle that sand will tend to accrete if the beach surface is permeable due to an artificially lowered water table. The system actively lowers the water table in the swash zone, thereby enhancing the wave absorption capacity of the beach, reducing sand fluidisation and encouraging sand deposition. The system has no visual impact: perforated plastic drain pipes with a geotextile sleeve are laid into excavated trenches within the high tide swash zone. The coated-pipes run parallel to the shoreline, buried at a depth of approximately two metres below the beach surface and the geotextile sleeve serves to filter sand from the sea water collected in the drains. The pipes are connected to a submersible pump and to a discharge system. Sea water is fed by gravity to a sump whence it is removed using the pump. In this way, after drainage through the sandy means and the coated-pipes, water is discharged into the sea. The cost of the system installation depends on the length of the coast subjected to restoration. Comparing with the maintenance of other techniques, the beach drainage system is less costly on the long term [7].

It is well known that sand filtration is typically cited as being the first ''engineered'' process in water treatment. In fact, water drainage through sand affects microrganisms, viruses and colloidal particles that are removed during transport from one side to the other of the filtration means. This mechanism allows retention of contaminants thus improving water characteristics [8–10]. In the specific circumstances, it can be

Table 1
Description of various coastline erosion protection options

Option	Description	Possible advantages	Possible disadvantages
Seawall	An engineered structure that can take many forms. Long history of use for protection of human assets/ structures behind the beach.	High certainty of asset protection if well designed.	Cost. Damaging to natural character. Will adversely affect the beach/ lower amenity value.
Revetment	Sloping hard structure designed to dissipate wave energy.	High certainty of asset protection if well designed.	Cost. Damaging to natural character. May adversely affect the beach/ lower amenity value.
Rock dumping	Often an emergency measure during or immediately following storm damage.	Cheaper than a seawall or revetment.	Damaging to natural character. Difficult to get approval to place. Will adversely affect the beach/ lower amenity value.
Groyne	A structure placed perpendicular to the coastline to capture/hold sand that may be available in the littoral zone.	Some certainty of asset/ amenity protection if well designed.	Cost. Only suitable for specific sites. Damaging to natural character. May adversely affect adjacent beaches.
Sand sausage	Sand filled fabric bag placed in the surf zone to 'trip' waves, reducing energy on the beach face	Low cost relative to other hard engineering solutions.	Damaging to natural character when visible. May lower amenity value (swimming safety?).
Artificial reef	Sand filled fabric bags placed before the surf zone to 'trip' waves. New concept with initial focus on improved surf amenity.	Reduction of wave energy on the beach. Improved amenity value. Low impact on visible natural character.	Cost. May adversely affect adjacent beaches. May only be suitable for sites that meet specific criteria (wave climate, tidal range, sea bottom profile, etc).
Nourishment	The placement of sand on the beach face or near to the shore to increase material in the littoral zone.	Improved amenity value. Low impact on natural character.	Cost. Suitable sand may be difficult to find. Uncertainty regarding design life for erosion protection.
Managed retreat	Allow landward migration of the coastline. Remove/relocate assets.	Potential improvements to natural character.	Local resistance. Financial, social/political costs.
Beach drainage	Increases upper beach width and therefore dune stability. Non-intrusive technique resulting in a wider, dried beach.	Low tidal ranges sand beach sites with a high amenity value, low to moderate wave energy.	Low to moderate cost; less costly on the long term.

considered that the operation of the RSA system acts as a natural water treatment process by inducing the sea water at the waterline to flow downward through the sand and into the horizontal pipes.

Based upon this principle and bearing in mind that a sustainable management of water resources implies also to take a look at alternative sources, we propose use of the drained water as an option to its discharge into the sea.

Therefore a study was carried out with the aim to verify if this proposal can be achievable. In the light of this chance, sea water and drained water at the outlet of the RSA system were analyzed and compared and their hygienic characteristics were evaluated. Data were gathered by a monitoring program carried out along the Italian coasts of the Tyrrhenian Sea, in the central Mediterranean coastal area. The investigation, conducted over approximately one year and half, was aimed at obtaining a quantitative picture of significant microbial parameters in order to determine the quality of the discharged sea water and consequently to identify the more appropriate options for its reuse.

2. Materials and methods

2.1. Study area

The investigation was carried out along the central coast of the Tyrrhenian Sea, near Rome, Italy. The site (Latitude 41°44′N, Longitude 12°16′E) is a sandy coastal area, degrading slowly and with a bathymetry of 5 m at a distance of 10 m from the beach and located at the mouth of Tiber river. The river flows through Rome and then it runs through small urban areas used mainly for agriculture and livestock breeding. The prevailing contamination sources for the river are urban, industrial and livestock farm wastewater. The contamination of river waters entering into the Tyrrhenian Sea can directly affects the water quality along the coast.

In the last 25 years, a severe erosion process has been taking place along this shoreline, probably caused by a progressive reduction in river input. At this site, with the aim to improve the beach's equilibrium and to restore the beach profile, the GECO Group, the Italian company that is the owner of the patent, installed the RSA system along about 2 km of coast.

2.2. Sample collection

A total of 32 samples was taken monthly for sixteen months. Two sampling points were selected at the site. Therefore, during each sampling day, both raw sea water samples, at 1 m from the waterline, at a depth of about 50 cm from the surface of the water of the public beach, and water samples after drainage, at the outlet of the RSA system, were collected. Contemporaneously, temperature and salinity were measured *in situ*.

All the collected samples were transported to the laboratory within 3 h of sampling and processed immediately. Analyses were performed for microbiological parameters and total suspended solid.

2.3. Microbiological analyses

One hundred and twenty eight microbiological determinations were carried out by investigating both the bacterial indicators of faecal contamination (*Escherichia coli* and Enterococci) and the marine Heterotrophic Plate Count (HPC). As a strict pathogen, *Salmonella* was determined in both kinds of samples.

In this context it is worth mentioning that in the EU Directive 2006/7/EC [11] bathing waters have to be classified, in accordance with certain specific criteria and limit values for Enterococci and *E. coli*, in one of four quality levels: poor, sufficient, good or excellent. This bathing water classification is based upon a percentile evaluation and on different limit values for inland and coastal waters. For coastal bathing water, in relation to the four quality levels, the classification foresees concentration values ranging between >500 and 250 CFU/100 ml for *E. coli* and between >185 and 100 CFU/100 ml for Enterococci.

The analyses were performed in duplicate both on sea water samples and on water after drainage.

The following analytical methods were used.

- Marine Heterotrophic Plate Count: Spread plate count on Marine Agar (75% marine water; Difco). Incubation at 22 ± 1 °C for 5 days. All colonies were counted.
- *E. coli*: Membrane filtration technique (0.45 μm pore size) on Tryptone Bile X-Glucuronide Agar (Biolife, Milan, Italy). Incubation at 44 ± 1 °C for 18–24 h. Green-blue and fluorescent colonies were counted.
- Enterococci: Membrane filtration technique (0.45 μm pore size) on Slanetz-Bartley Agar (Difco). Incubation at 36 ± 1 °C for 48 h. Confirmation on Esculin Iron Agar for the esculin hydrolysis, 2 h at 42 ± 1 °C. Pink to red colonies with black halos in the back side of the membrane were counted.
- *Salmonella* spp.: Presence–Absence Test through a pre-enrichment (Peptone Water, Oxoid) and an enrichment step (Rappaport-Vassiliadis Enrichment Broth, Oxoid). Isolation on Hektoen Enteric Agar (Oxoid). Green-blue with and without black centre colonies were counted.

2.4. Physical analysis

In each water sample, determinations of physical parameters were carried out according to the following methods:

- Water Temperature, *in situ*: measurement of the temperature by Mercury-filled Celsius thermometer (scale 0–50 °C, div. 1/1);
- Salinity *in situ*: refractometer (Atago), the measure was expressed in ‰;
- Total Suspended Solid (TSS): according to the APHA Standard Methods [12].

2.5. Statistical analysis

Data were compared in pairs using the χ^2, with the Yates correction, to test whether difference existed between the counts obtained from raw sea water and water after drainage analysis. Verification of possible reciprocal correlations among the microbial groups under investigation and the sea water temperature was

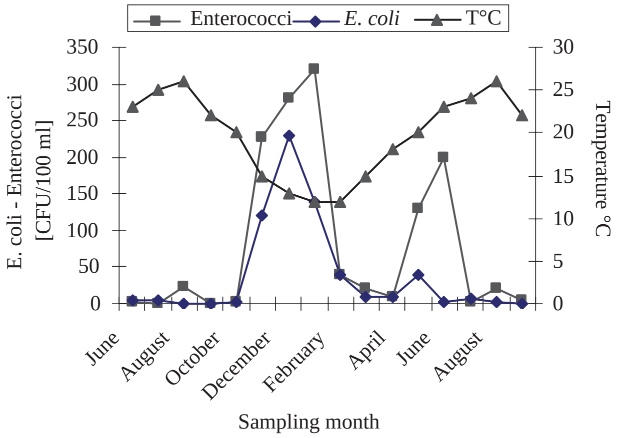

Fig. 1. *E. coli* and Enterococci concentrations recovered in raw sea water. The temperature values measured during the monitoring are also reported.

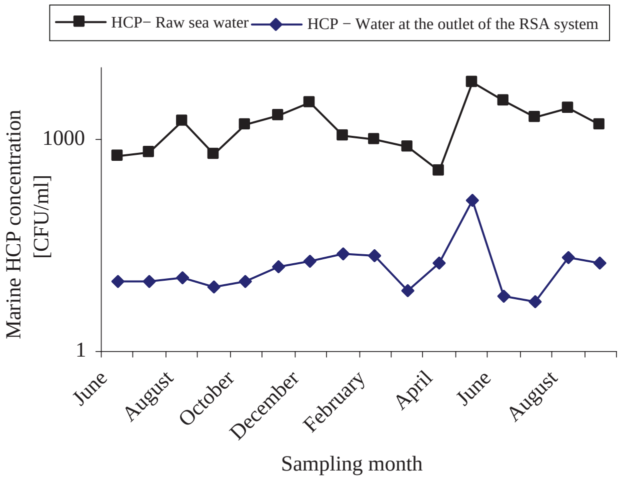

Fig. 2. Marine HPC concentrations in raw sea water and in water after drainage, at the outlet of the system.

determined by calculation of the regression coefficient. Furthermore, the effect of meteo-marine changes in the TTS values in both kinds of water was also examined (SPSS v. 15.0).

3. Results

Analyses showed significant different hygienic characteristics of the two kinds of analyzed samples.

The raw sea water presented higher values not only for the classical indicators of faecal contamination but also for the marine heterotrophic flora. According to the EU bathing water Directive [11], at the investigated site, the calculation based on the 95 percentile criterion showed that this bathing water could be classified as ''excellent'' (limit values: Enterococci 100 CFU/100 ml and *E. coli* 250 CFU/100 ml). In fact, in the raw sea water samples *E. coli* ranged between 230 and 1 CFU/100 ml (mean 39 CFU/100 ml) and Enterococci between 320 and 0 CFU/100 ml (mean 80 CFU/100 ml; Fig. 1). Nevertheless, at the RSA outlet, a significant reduction ($p < 0.01$) of bacterial concentrations was observed all along the monitoring period (by one to two orders of magnitude). In confirmation of the retention capacity of the whole system, in 75% of water samples after drainage, bacterial indicators were not recovered, and in the remaining samples the concentration values ranged from 1 to 5 CFU/100 ml for both the parameters.

The HPC concentrations, a parameter not included in the EU Directive but helpful as a broader microbial indicator, similarly lowered in the water at the outlet of the system (maximum value: 135 CFU/ml, minimum value: 5 CFU/ml, mean: 21 CFU/ml), although much higher concentrations were observed in sea water (mean: 1796 CFU/ml; Fig. 2).

Salmonella spp. was present twice (January and June) in two raw sea water samples but the bacterium was never detected in the water after drainage, at the outlet of the system.

During the monitoring period, a remarkable fluctuation of bacterial concentrations was especially observed in sea water consistent with the water temperature that showed a range from 13 °C (January) to 26 °C (August; Fig. 1). The highest bacterial indicator concentrations were detected both at the top of the summer season and in the winter even if in these latter samples the values were 1.6 and 5.8 times higher than those observed during the summer, respectively for Enterococci and *E. coli*.

A negative reciprocal correlation was found between the bacterial indicators and sea water temperature ($p < 0.01$; Fig. 1). In Table 2 the mean values of water temperature and salinity measured in the two kinds of samples are reported.

Table 2
Average values of the water temperature and salinity measured at the sampling points

Kind of sample	Water temperature [°C]	Salinity [‰]
Raw sea water		
Average	20	37.5
Maximum	26	39
Minimum	13	34
Drained sea water		
Average	19	36.4
Maximum	24	38
Minimum	12	34

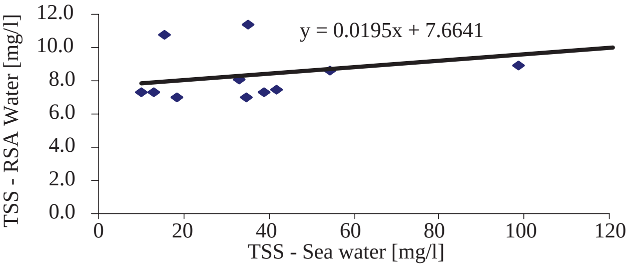

Fig. 3. Concentrations and trend of the TSS in sea water and in water after drainage.

Water temperature measured in the two kinds of samples remained nearly unchanged (about one degree lower in the water at the outlet) and the same occurred for salinity (1–2 ppt of difference). In a different way, the TTS concentration appeared to vary according to the meteo-marine conditions. In fact, in calm sea conditions (low turbidity, fine resuspended sediment), lower TSS values were measured in the sea water (mean: TSS 14 mg/l) respect to rough sea conditions (mean: TSS 57 mg/l), but in comparison a lower reduction of their concentrations (mean: TSS 8 mg/l) was observed in water after drainage (Fig. 3).

4. Discussion and conclusions

The sustainable use of water implies resource conservation, environmental friendliness, technological appropriateness, economic viability, and social acceptability of development issues. The adoption of these sustainability facets is a priority for using water in every human, economic and social activity – human and domestic consumption, agriculture, industry, energy production, recreational and leisure uses.

The perception that water is increasingly scarce gives to water management a great relevance. Water resources development anywhere requires the consideration of all options available [13]. In this context the use of non-conventional water resources, such as desalinized sea water and brackish water, runoff water, reclaimed wastewater, to complement or replace the use of usual sources of freshwater increases the availability of water supplies [14].

In our study, for improvement water status in the coastline environment, we propose to introduce new water resources such as drained sea water. As shown by results, a reduction in the microbial loads was achieved after the transport of sea water through the sand and the coated-pipes of the RSA system. A decrease of 1–2 orders of magnitude was observed for both faecal indicators and marine HPC; although recovered in only two samples in raw sea water, *Salmonella* was never detected in the discharged water. Water at the outlet of the system showed also a reduction of solid particulate material (TSS), with the advantage to decrease the visual turbidity. Furthermore, it is recognized that water turbidity correlates well with bacterial concentrations and water turbidity removal may be a useful tool for indicating the degree of pathogen removal [15,16].

During the investigation a great variability of bacterial concentrations was measured in the raw sea water samples. It is accepted that the survival of bacterial microflora in sea water is strongly influenced by abiotic (e.g., salinity, sunlight, and temperature) and biotic (predation and competition) factors. It is recognized that the biological tolerance of bacteria to physicochemical factors is complex and dynamic. Previous studies have shown that bacteria of enteric origin (e.g., Enterococci and *E. coli*) can vary seasonally in accordance with the change in water temperature [17] and cooler water temperatures increase the duration of *E. coli* survival in water and soil [18,19].

The present findings are consistent with this evidence. Higher counts of faecal indicators were recorded in the winter months even if slight increased counts also occurred during the summer. This should not surprise because environmental pressure from tourism along this coast, leading to increased nutrient inputs through wastewater, subsequently increases the bacterial concentration in coastal water. In contrast, inputs from tourists are expected to be comparatively low in winter, when only residents live on the coastal area.

Problems of water supply in coastal and tourist areas are becoming increasingly common and may be further increased by climate change and increasing demand from other sectors. Water use by tourists is often twice that of residents, and large volumes of water are also required for recreational facilities such as swimming pools and water parks. Use of non-conventional water, such as sea water, can be a possible choice, along the coastal areas. Wherever installed, the innovative RSA system could be a valid technology for a sustainable management of water resources.

In our investigation, the system, by means of the drainage of sea water, showed to be able to supply water with good quality characteristics. Furthermore, well known that sands can constitute a passive element in bioaccumulation and concentration of pollutants arising from neighbouring waters, analyses for the same microbiological parameters analyzed in the water samples were carried out on sands collected at the waterline of the beach where the system was installed. Results were compared with those obtained from the analyses of sands sampled on a beach out of this area. No difference in their hygienic characteristics emerged from the analyses (not published data).

In addition to advantages in term of protection and restoration of coasts and negligible environmental impact of the RSA system, results of this investigation could make actual the proposal of using sea water derived from its operation as an alternative option to its discharge into the sea. The consideration of one or more alternative uses could be appropriate if our results are compared with hygienic requirements for faecal indicators and HPC recommended by the World Health Organization [20] for the safety in swimming pools. As the hygienic characteristics of drained water to a great extent agree with those recommended for water in swimming pools, replenishment of marine swimming pools, aquatic parks, aquariums and aquaculture pools as well as re-qualification of humid zones or withdrawal subsidence phenomena along the coasts could be some alternative to drained water discharge. The implementation of these activities along coastal areas could reduce the costs for supplying and transporting freshwater; furthermore, areas subject to coastal erosion could thus maximise benefits due to sustainable forms of coastal management with practices of water-saving.

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