A proposal for multiple reuse of urban wastewater

Mario Maiolo and Daniela Pantusa

ABSTRACT

The present paper describes a proposal of multiple reuse of wastewater for the town of Camigliatello Silano, in the province of Cosenza, Italy. Camigliatello Silano is a locality devoted to agriculture and to both winter and summer tourism. There are several issues related to the management of water resources of the locality, including the lack of regularization of the discharge of urban wastewater with Italian and European regulations, poor availability of the resource for the irrigation sector, and necessary improvements in winter tourism. To solve these problems, this paper proposes a possible solution for the management of the water resources of the locality, through the reuse of wastewater. The proposed solution provides the reuse for agricultural purposes during the irrigation period and an innovative reuse for the production of artificial snow in the winter season. The reuse for irrigation allows the increase of water resources in agriculture, while the reuse for the production of artificial snow allows a longer skiing period. The proposed solution also solves the problem of regularization of wastewater discharge with positive effects on the environment and water resources.

Key words | multiple reuse, snowmaking

Mario Maiolo
Department of Environmental and Chemical Engineering,
University of Calabria,
Ponte P. Bucci,
I-87036 Arcavacata di Rende (CS),
Italy

Daniela Pantusa (corresponding author)
Innovation Engineering Department,
Ecotekne, University of Salento,
Via Monteroni,
I-73100 Lecce,
Italy
E-mail: *dpantusa@libero.it*

INTRODUCTION

The concept of sustainable development and the increasing pressure on water resources have led to the definition of projects and programs for the conservation of water resources. The sustainable management of water resources requires the identification of solutions to rationalize and optimize the use of available resources by improving the level of satisfaction of the demand and reducing the impact on the environment.

In this direction, important aspects are proper planning and management of water supply systems, the proper allocation of resources on a territory (Maiolo & Pantusa 2016) and the evaluation of the vulnerability of water systems and risk analysis of drinking water (Maiolo & Pantusa 2015). The increase in problems related to drought and water scarcity also require the identification of possible solutions of integration between different availability of water resources through, for example, the reuse of treated wastewater. The recovery and reuse of wastewater responds, in fact, to multiple objectives of water protection and optimization in the use of natural resources, such as:

- availability of additional water resources for productive sectors;
- quantitative and qualitative protection of water resources through the reduction in withdrawals from surface and ground water;
- reduction of impacts on receptor water bodies.

The possibility to reuse wastewater also implies, however, a series of problems concerning technical, economic and sanitary aspects that need to be suitably considered.

In this context, this paper describes a proposal of reuse of treated wastewater in agriculture and of the production of artificial snow that identifies, according to a rational and

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sustainable management of water resources, a possible solution to the various problems of the area under examination.

Agriculture is the sector with the greatest impact in terms of its pressure on water balances; it is estimated, in fact, that in the world, the water resource used for irrigation purposes is about 70% of that available (Alexandratos & Bruinsma 2012). The reuse of treated wastewater in the agricultural sector, is therefore, particularly interesting and various studies were conducted in several countries worldwide.

The reuse of wastewater in the agricultural sector leads to a number of possible advantages, but it also entails a series of problems related to ecological and sanitary aspects, which cannot be neglected. For agricultural land, treated wastewater represents a source of fertilizers, nutrients and macro elements. However, the discharge of wastewater into the soil also implies a number of negative aspects, related to the risks arising from the entry of substances that may be harmful to the soil and the crops, through the possibility of accumulation and passage of these substances into the food chain.

In literature there are now several experiments conducted on the reuse of wastewater for irrigation purposes which have obtained excellent results: irrigation of green areas (Chen *et al.* 2015), irrigation for agricultural purposes for the production of tomatoes, lettuce, eggplant with membrane treatments (Lopez *et al.* 2006), irrigation for the production of potatoes with treatment by sand and membranes filters (Forslund *et al.* 2010), irrigation for the production of watermelons with combined treatments by membrane and reverse osmosis (Oron *et al.* 2008).

Regarding wastewater reuse for snowmaking, it is an innovative approach. The water for snowmaking is, in fact, drawn generally from the waters of streams and rivers, from springs, from groundwater, from natural or artificial lakes and sometimes from water networks, or through conduits of the hydroelectric plants. Thinking of melting snow, which effectively produces irrigation of the slopes, wastewater reuse for snowmaking can be reasonably considered as a type of reuse for irrigation of green areas, or for recreational and sporting activities.

An important aspect to consider in wastewater reuse is the high bacterial load; subjecting, however, the waters to tertiary treatments and tertiary pushed, the bacterial load can be reduced to values even lower than those present in the waters generally used for snowmaking (Lopez *et al.* 2006).

A recent study conducted in seven parks in Beijing, to evaluate the effects of irrigation with the reuse of waste water (Chen *et al.* 2015), showed an increase of nutrients in the soil, such as nitrogen and phosphorus, with an increase of the organic substance of 6–17%, without significant pH changes. It had already been observed, in fact, that the organic carbon present in the recycled water can stimulate the activity of soil microorganisms (Ramirez-Fuentes *et al.* 2002).

The reuse of wastewater for snowmaking would provide a greater amount of nutrients at the disposal of vegetation on the ski run, which can assume about 19 g/hab/d of organic substance, 8 g/hab/d of N_{tot}, 2.8 g/hab/d of P_2O_5, 5 g/hab/d of K_2O (Masotti 2011); considering that the turf suffers damage during the winter season with skiing, and with slope preparation by snow groomers, a subsequent lawn hydroseeding could be hypothesized, which would benefit the greater contribution of nutrients contained in the water of melting artificial snow (Cernusca & Tappeiner 1990; Rixen *et al.* 2004).

STUDY AREA AND CURRENT WATER SUPPLY SYSTEM

Camigliatello Silano is a mountain highland situated 1,300 m above sea level. The local economy is based mainly on tourism and agriculture.

Located in the National Park of Sila, Camigliatello Silano is a tourist destination for nature activities such as hiking, mountain biking, fishing and walking along the shore of the Cecita lake. Due to snow falling in the winter months, this highland is a great center of attraction for snow sports, and there is a popular ski resort.

The current water supply system is fed by three intake structures on the Tasso stream (Figure 1):

- the first intake structure feeds the water distribution systems of the locality;
- the second intake structure feeds the existing snowmaking system;
- the third intake structure feeds the irrigation system.

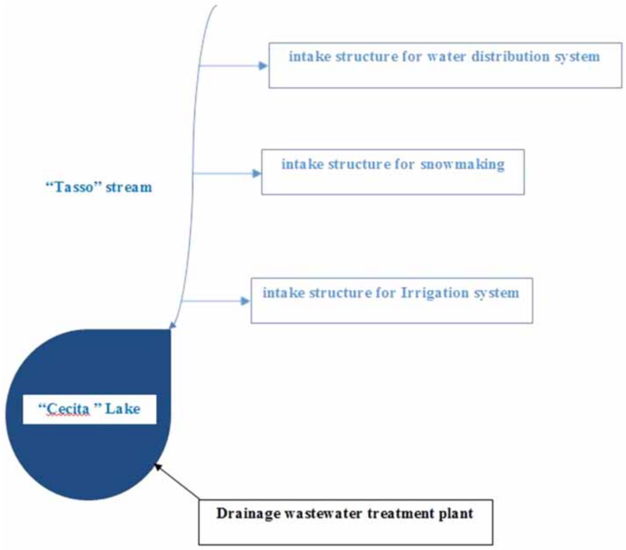

Figure 1 | Functional scheme of current water system.

Figure 2 | Scheme of the ski runs of Camigliatello Silano.

Regarding the water distribution system of Camigliatello Silano, it is possible to satisfy the user demand; however, the wastewater treatment plant serving the town discharges into a ditch which, in turn, flows into the artificial Cecita lake. This condition forced the competent authority not to authorize the discharge, according to current Italian and European legislation.

The ski resort of Camigliatello Silano consists of an 8-seater cableway and two ski runs, one blue and one red in difficulty, with a total length of 4,270 m and an extension of 88,478 m^2 (Figure 2).

To cope with the decreasing snowfall, some years ago the ski resort adopted a snowmaking system; this snowmaking system is constituted by the intake structure on the Tasso stream with a small storage capacity, and by an electric network with relative transformer cabin; along the edges of the ski runs wells with water and electricity outlets which are connected to the low-pressure type fan snow guns are positioned. This snowmaking system is subject to problems related to insufficient availability of water of the stream, which, during the peak demand of the snowmaking system, is in the lean period. This situation is further aggravated by poor snowfalls in recent years.

Considering the amount of water required for the first snowmaking, the small storage capacity of the existing snowmaking system and the flow rate of the Tasso stream, it was noted that an increase of about 22% of water availability would be necessary for the snowmaking system. Furthermore, the rapid emptying time of the tank (about 1 hour) does not allow for easy snowmaking.

Regarding the irrigation system of the study case, it is constituted by the intake structure on the Tasso stream, from which the water resource, by means of the pumping station, is sent to a small rectangular tank. From the tank, the water resource is sent to the Contrada Molarotta agricultural area which has an area of about 200 ha (Figure 3).

The irrigation system of the Sila highlands was built in the early 1900s and was designed for an extensive type of agriculture; as the agricultural sector over the years evolved into an intensive system, today, the infrastructure and available water resources are no longer adequate to meet the current demand of the agricultural sector. It has been estimated that about 30% of farmers are forced to draw water from the Cecita lake, to satisfy their own needs. Reduced rainfall and increased droughts contribute to aggravating the situation.

There are, therefore, several problems related to the management of water resources in the area, the solution of which would have positive effects on the economy of the

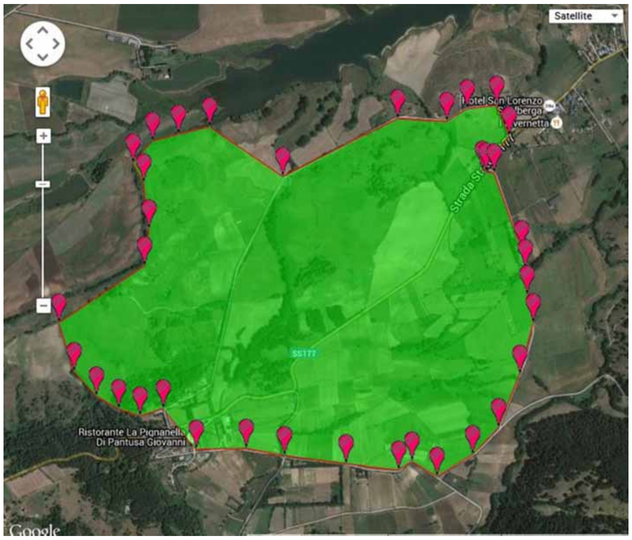

Figure 3 | Contrada Molarotta irrigated area.

territory, on the environment and on water resources themselves.

The solution proposed in this paper provides:

- a reuse for irrigation in the period from April to October that allows the increase of water resources in agriculture and limits the negative effects of water scarcity in the sector;
- an innovative reuse for the production of artificial snow in the period from November to March, that would allow a longer skiing period, being able even to meet the needs of the entire ski season.

The proposed solution also solves the problem of regularization of the discharge with positive effects on the environment and water resources.

DESCRIPTION OF THE PROPOSAL FOR MULTIPLE REUSE OF URBAN WASTEWATER

As mentioned above, the proposal for multiple reuse provides the reuse of urban wastewater for irrigation purposes and for snowmaking.

Proposal of reuse of wastewater for snowmaking

To produce artificial snow, tiny droplets of water must be sprayed in the winter cold air. A part of the water evaporates, subtracting heat from the environment, and consequently the remaining droplets are cooled, frozen and fall to the ground in the form of crystals and pieces of ice, forming the artificial snow. This process works effectively with air temperatures below $-4\,^{\circ}$C, with a humidity lower than 80% and a water temperature of $2\,^{\circ}$C max (Hahn 2004); this process takes place, like for natural snow, usually around the particles called condensation cores (suspended salts, pollens, dusts) that have an average diameter of 1 mm (Zeni 2010). If the air temperature rises above $3\,^{\circ}$C, snowmaking becomes uneconomical. To produce snow artificially, water, air and energy are needed. Today, the artificial snow is produced with air guns (high pressure systems) or with propeller guns (low pressure installations). All systems have advantages and disadvantages and each type is more or less adjusted to suit the local conditions (conformation of the territory, infrastructures, estimated size of the facility, etc.).

Normally, a snowmaking system consists of the following elements: collection system and water tank, pumps, pipes (water, electricity, compressed air), withdrawal points, sheds, compressors (for high pressure implants), fuel systems for electricity and underground cables, control system, refrigeration equipment (optional), small meteorological station and snow machines.

In snowmaking, the water resource plays a key role. With 1 m^3 of water, on average 2–2.5 m^3 of snow can be produced. For the snow base, about 30 cm of snow, a ski run of 1 ha requires at least a million liters, that is 1,000 m^3 of water, while the subsequent snowmaking requires, depending on the situation, a considerably higher water consumption. According to a study conducted in France during the 2002/03 season, in the snowmaking of 1 ha of ski slopes, approximately 4,000 m^3 of water were used (Hahn 2004).

It is in relation to this last point, namely the large quantities of water resources necessary for the production of artificial snow, that the possibility of reusing wastewater as an alternative water supply source for snowmaking systems should be concretely assessed.

Table 1 describes the amount of water required for the first and seasonal snowmaking for the Camigliatello Silano snowmaking system.

According to calculations made, a total of 10,617 m^3 of water is required for the first snowmaking with a layer of

Table 1 | Calculation of the needs of the water resource for the first and seasonal snowmaking

	Length (m)	Width (m)	Surface (m^2)	Surface (ha)	Volume (m^3)	Volume H_2O (m^3)	Snowmaking (h)	Snowmaking (d)
First snowmaking								
Blue ski run	2,220	16.4	36,408	3.6	10,922	4,369	279	5
Red ski run	2,050	25.4	52,070	5.2	15,621	6,248	400	7
Total						10,617		
Seasonal snowmaking								
Blue ski run	2,220	16.4	36,408	3.6	32,767	13,107	838	14
Red ski run	2,050	25.4	52,070	5.2	46,863	18,745	1,199	20
Total						31,852		

snow of 30 cm, and a consumption of about 1,200 m^3 per ha, and 31,852 m^3 of water for the entire season, considering a consumption of 3,600 m^3 per ha (Hahn 2004). The first snowmaking of the blue ski run requires 10,922 m^3 of snow and 5 days of snowmaking, while the red ski run requires 15,621 m^3 and 7 days of snowmaking, assuming the operation of six cannons for 10 hours at night. In order to have this volume of snow, 10,617 m^3 of wastewater are needed; since water from the municipal sewage treatment plant is about 530 m^3/day, 20 days are needed to accumulate this volume. A volume of about 31,852 m^3 would be left, therefore, to the Tasso stream, for the entire season. As stated previously, a supply of nutrients for the ski slopes would also be provided which could be useful for the ski slopes that have large areas with no grass cover, as shown in Figure 4.

Regarding regulations in Italy, the reuse of urban wastewater is regulated by Ministerial Decree Environment June 12, 2003 n. 185, implementation of Decree 04/03/2016 n.152 which, in turn, implements the European regulations 91/271/EEC, 91/676/EEC, 96/61/EC, 2000/60/EC. This Ministerial Decree provides for three permissible destinations for urban waste reuse: civil, industrial, and irrigation. The aforementioned legislation does not provide, therefore, specific regulations for snowmaking. The only specific legislation at the international level is that of the autonomous Province of Bolzano in Italy. The Autonomous Province of Bolzano, with Provincial Council Resolution n. 2691 of 25-07-2005 has established that in the province, for the production of artificial snow, only water for which there is a judgment of chemical and microbiological suitability can be used, which satisfies a series of quality requirements. In column 'A' of Table 2 the limit values of the parameters expected by the D.M. Environment June 12, 2003 n. 185 are described; in column 'B' the limit values of the Bolzano Provincial Council Resolution of 25-07-2005, n. 2691, in column 'C' the average values of the parameters measured by the manager output from the treatment plant, and in column 'D' the expected values following the intervention of the insertion of a wetland area as a tertiary treatment. The values in column 'D' were calculated by reducing the values of column 'C', according to the load removal efficiency obtained in pilot projects in the Mediterranean area (Masi & Martinuzzi 2007; Toscano *et al.* 2015). It also provides for an average reduction of fecal coliforms (FC) and fecal streptococci (FS) of about 3 log units (Hassen *et al.* 2000).

Proposal of reuse in agriculture

In the area of the case study, the I.G.P. (Protected Geographical Indication) Potato 'Patata della Sila' is cultivated, which requires an amount of water equal to about 2,000 m^3/ha for the entire irrigation season (Taglioli 2007); using a spray irrigation system, the amount of water needed to cover the entire seasonal requirements is equal to approximately:

$$\text{Seasonal requirements of water resources:} \frac{200\ \text{ha} \times 2000\ \text{m}^3}{\text{ha} = 400,000\ \text{m}^3}$$

Calculations made regarding water availability and needs of the sector show a deficit of 31%. As mentioned previously,

Figure 4 | The final stretch of the ski runs.

this deficit forces farmers to draw water from Cecita lake, to satisfy their own needs.

Given that the annual volume of waste water produced by the municipal sewage treatment plant is about 195,000 m^3, and that of these 31,852 m^3 are reused for the snowmaking season of ski runs, a water volume of about 163,000 m^3 would remain for reuse in the agricultural sector; this value represents 41% of the needs of the considered irrigated area and would, therefore, cover the entire deficit of the sector.

Interventions to be implemented for the multiple reuse of urban wastewater

The interventions necessary to allow the multiple reuse of urban waste water of the local sewage treatment plant essentially consist of the realization of the works described below, represented in Figure 5 and through the simplified functional scheme of Figure 6.

- Construction of a pumping station (R1), at the exit from the wastewater treatment plant, from which the wastewater will be pumped to the phytoremediation basin (C);
- Construction of a pressurized pipeline (p1), about 1,100 m length, from the pumping station (R1) to the phytoremediation basin (C);
- Construction of phytoremediation basin type H-SSF as tertiary treatment, using and transforming the current accumulation tank of the irrigation system (C);
- Construction of a basin of accumulation, adjustment and refining (B) of 60,000 m^3, which will be used both for irrigation, and for the production of artificial snow; substantially it is a small lake, where the water is accumulated, regulated and refined after exiting the phytoremediation basin;
- Installation of a system of disinfection of the water using UV rays at the exit from the basin (B), before being sent to the reuse;
- Construction of a gravity pipeline (P2), about 2,200 m length, from the basin (B) to the pumping station (R2);

Table 2 | Comparison of limits

Parameter	Unit	Column A Limit source D.M.E. 12.06.03 n. 185	Column B Limit Souce B.P.C.R. 25.07.05 n. 2,691	Column C Average values measured by the manager	Column D expected values
pH		≥6.0 ≤ 9.5	≥6.5 ≤ 9.5	7.8	7.8
SAR		10	n.p.		–
Coarse materials		absent	n.p.	n.p.	–
Total suspended solids	mg/L	10	n.p.	29	3.48
BOD_5	mg/L	20	n.p.	26	9.62
COD	mg/L	100	n.p.	104	38.48
Total phosphorus	mg/L	10	n.p.	5.5	3.9
Total nitrogen	mg/L	35	n.p.	n.p.	–
Ammonia nitrogen	mg/L	2	n.p.	3.23	1.39
Specific electrical conductivity (20 °C)	μS/m	30	25	n.p.	–
Alluminio	mg/L	1	n.p.	n.p.	–
Antimony	μg/L	n.p.	5	n.p.	–
Arsenic	μg/L	20	10	n.p.	–
Barium	mg/L	10	n.p.	n.p.	–
Beryllium	mg/L	0.1	n.p.	n.p.	–
Boron	mg/L	1	n.p.	n.p.	–
Cadmium	mg/L	0.005	n.p.	n.p.	–
Cobalt	mg/L	0.05	n.p.	n.p.	–
Total chromium	mg/L	0.1	n.p.	n.p.	–
Chromium VI	mg/L	0.005	n.p.	n.p.	–
Iron	mg/L	2	0.2	n.p.	–
Manganese	mg/L	0.2	0.05	n.p.	–
Mercury	mg/L	0.001	n.p.	n.p.	–
Nickel	mg/L	0.2	n.p.	n.p.	–
Piombo	mg/L	0.1	n.p.	n.p.	–
Copper	mg/L	1	1	n.p.	–
Selenium	mg/L	10	10	n.p.	–
Pond	mg/L	3	n.p.	n.p.	–
Zinc	mg/L	0.5	n.p.	n.p.	–
Total cyanides	mg/L	0.05	n.p.	n.p.	–
Sulfides	mg/L	0.5	n.p.	n.p.	–
Sulfites	mg/L	0.5	n.p.	n.p.	–
Sulphate	mg/L	500	250	n.p.	–
Active chlorine	mg/L	0.2	n.p.	0.13	0.13
Chlorides	mg/L	250	250	n.p.	–
Fluorides	mg/L	1.5	n.p.	n.p.	–
Fats and oils animal / vegetable	mg/L	10	n.p.	n.p.	–

(*continued*)

Table 2 | continued

Parameter	Unit	Column A Limit source D.M.E. 12.06.03 n. 185	Column B Limit Souce B.P.C.R. 25.07.05 n. 2,691	Column C Average values measured by the manager	Column D expected values
Mineral oils	mg/L	0.05	n.p.	n.p.	–
Total phenols	mg/L	0.1	n.p.	n.p.	–
Total surfactants	mg/L	0.5	n.p.	n.p.	–
Nitrates expressed NO_3	mg/L	n.p.	50	n.p.	–
Nitrates expressed NO_2	mg/L	n.p.	0.5	n.p.	–
Ammonium expressed NH_4	mg/L	n.p.	0.5	n.p.	–
Escherichia coli	UFC/ 100 mL	200	200	1,500	90
Enterococchi	UFC/ 100 mL	n.p.	100	n.p.	–
Salmonella		absent	n.p.	n.p.	–
Oxidisability	mg/L O_2		5	n.p.	–
Total hardness	French degrees		X	n.p.	–

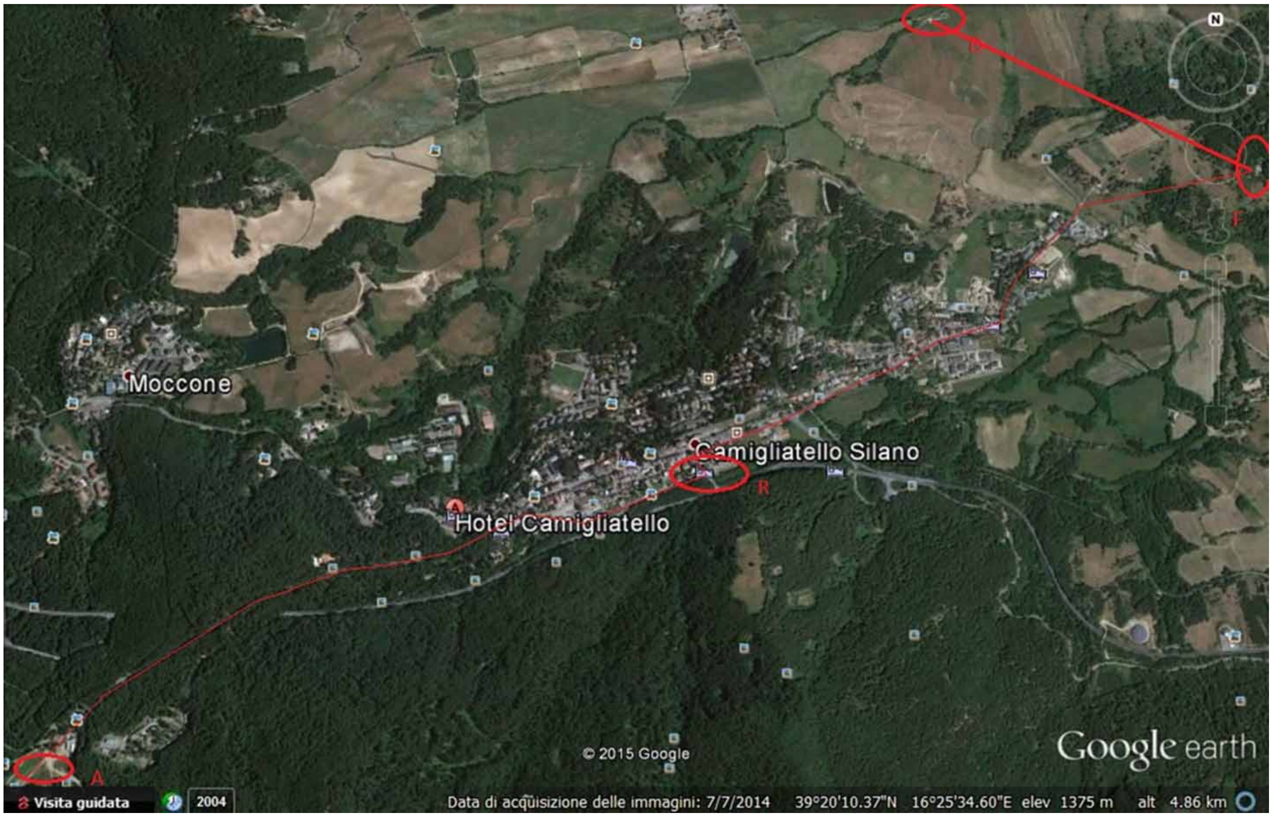

Figure 5 | Interventions to be implemented for the multiple reuse.

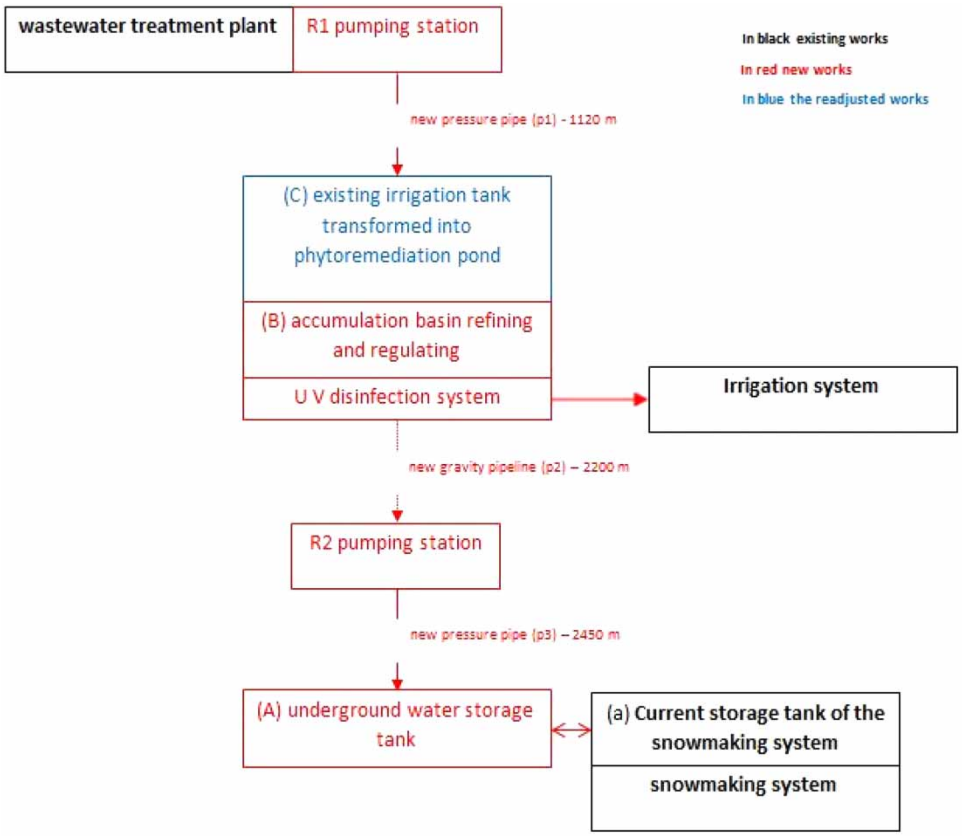

Figure 6 | Functional scheme.

- Construction of a pumping station (R2), to raise the water from the gravity pipe (p2) to the underground tank (A), at the service of the production of artificial snow system;
- Construction of an underground water storage tank (A) placed in the final part of the ski slopes with a volume of 4,500 m^3, adjacent to the current accumulation tank (a) of about 50 m^3.

COST-BENEFIT ANALYSIS OF THE PROPOSED INTERVENTION

The cost-benefit analysis method carries out a comparative analysis of the advantages, in terms of collective welfare improvements, and cost, in terms of resource prices, concerning the various possible policy interventions.

Before proceeding with the cost-benefit analysis, it is necessary to make a brief consideration on the reasons for the implementation of interventions. The examined interventions are aimed at the resolution of the problem, previously described, of the lack of authorization to discharge of the Camigliatello Silano sewage treatment plant; this issue is, indeed, very serious as the municipal administration is subject annually to an administrative sanction from 6,000 € to 60,000 €, and the Region Calabria in turn is subject to an infringement procedure by the EU for matters of water depuration.

The possible solutions are:

1. the one proposed in this paper, which provides a multiple reuse of waste water;
2. the solution of catchment and discharge into the river Neto.

The costs of the planned works are summarized in Table 3; these costs were determined using the average prices, obtained taking into account regional price lists

Table 3 | Comparison of the costs for the two solutions

Reuse of wastewater	Cost €	Catchment and discharge into the river Neto	Cost €
Pumping station (R1)	11,780.00	Pumping station (R1)	11,780.00
Pressurized pipeline (p1)	167,074.40	Pressurized pipeline (p1)	167,074.40
Phytoremediation basin (C)	112,000.00	Gravity pipeline (P4)	160,454.00
Basin of accumulation, adjustment and refining (B)	226,400.00	Pumping station (R4)	11,780.00
System of disinfection of the water to UV rays	72,022.65	Pressurized pipeline (p5)	447,570.00
Gravity pipeline (P2)	252,263.49	Gravity pipeline (P6)	550,128.00
Pumping station (R2)	11,780.00		
Pressurized pipeline (p3)	371,686.50		
tTnk of in ground accumulation (A)	51,520.00		
Total	**1,285,927.04**		**1,348,786.40**

and those of the market. A lower cost for the solution of multiple reuse is to be highlighted.

The benefits were evaluated in terms of improvement of general well-being: for both solutions, an important benefit is to respond to regulatory compliances.

As for the solution of catchment and discharge into the river Neto, there are no other benefits, while in the case of multiple reuse of wastewater, the other benefits are:

- a lower environmental impact of waste water, in relation to the realization of a tertiary treatment of phytoremediation and a basin of accumulation, adjustment and refining;
- the realization of basin of accumulation, adjustment and refining useful for:
  - agricultural purposes;
  - snowmaking, and subsequent resolution also of the problem of the primary resource shortage in the winter months;
  - sporting purposes as a basin for fishing;
- saving of primary water resource, both for agricultural purposes, and for artificial snow. In fact, with the proposed solution, it is possible to cover the entire demand for artificial snow and 41% of the irrigation requirements, reducing withdrawals from the Tasso stream.

CONCLUSIONS

This paper describes a proposal of multiple reuse of urban wastewater in the tourist highland of Camigliatello Silano. Through this proposal a real opportunity to reuse wastewater was evaluated by performing an analysis of the distribution system, of the morphology of the territory and of the wastewater treatment system of the locality under consideration.

The aim of the proposal is, therefore, the identification of a more rational management of the water resources in order to solve the various problems of the area under consideration. In particular, through the reuse in agriculture and the innovative reuse for snowmaking, this proposal identifies, according to a rational and sustainable management of water resources, solutions for three different problems of the case study:

1. adjusting of the discharge of urban wastewater to meet the existing Italian and European regulations;
2. protection of primary water resources and increase of snowmaking capacity;
3. increase of the availability of water resources for the agricultural sector where production was significantly affected by the decrease of water resources over time.

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