RECLAMATION OF TREATED WASTEWATER IN THE APULIA REGION (ITALY): STATE OF THE ART AND FUTURE PERSPECTIVES

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Abstract

In Italy treated urban wastewaters, can be reclaimed for agricultural, civil and industrial purposes thanks to a recently approved Ministerial Decree, the n. 185/2003.

In the Apulia, a region in the south-east of Italy, due to the carsic nature of the soil and the consequent scarcity of water surface bodies, there have been built numerous urban wastewater treatment plants that discharge treated effluents in sea or in the subsoil.

Regional authorities, in the recently promulgated "Water Resources Protection and Management Master Plan", intended to stop this practice as soon as possible and stated that water reclamation must be implemented in the existing wastewater treatment plants.

The situation nowadays shows that in Apulia there are 197 urban wastewater treatment plants, 13 are currently eligible for reuse and 27 need additional improvements or are new constructions, to fulfil quality requirements of reclaimed water. This paper is aimed at qualitatively describing the state of the art of the wastewater reclamation in the Apulia region, the technologies actually utilizable to

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[1] This work is the result of the authors' commitment, starting from the idea and ending with its accomplishment. Particularly, each author contributed as follows: Giungato P.: 60%, Nardone E.: 30%, Notarnicola L.: 10%.

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adapt the existing treatment plants and also the economic aspects involved in the improvements of the existing facilities.

Among the technologies actually utilizable, some of them require high amount of electricity to work, others chemicals with the impacts related to its production.

From the economic point of view the adaptation costs depends on the size, on the quality parameters of the water to reach in the initial project of the plant and on the final use of the reclaimed water. Moreover concerns in farmers about the quality of reclaimed water for irrigation purposes impeded the diffusion of this new water source.

Riassunto

In Italia, le acque reflue urbane depurate possono essere riutilizzate per scopi agricoli, civili ed industriali grazie alla recente approvazione del Decreto Ministeriale n. 185/2003.

Nella Puglia, una regione nel sud-est dell'Italia, a causa della natura carsica del suolo e la conseguente scarsità di corpi idrici superficiali, sono stati costruiti negli anni numerosi impianti di depurazione delle acque reflue che scaricano gli effluenti trattati in mare e nel sottosuolo.

Le autorità regionali nel "Piano Regionale di Salvaguardia e Gestione delle Acque" recentemente approvato, intendono fermare tale pratica quanto prima e hanno stabilito di implementare negli impianti esistenti la pratica del riciclo delle acque trattate. La situazione odierna mostra che in Puglia vi sono 197 impianti di depurazione delle acque reflue urbane, 13 sono idonei al riuso e 27 necessitano di opere di miglioramento o sono nuove costruzioni, per soddisfare i requisiti di qualità dell'acqua per il riuso.

Scopo di questo lavoro è quello di descrivere qualitativamente lo stato dell'arte del riutilizzo delle acque reflue nella regione Puglia, le tecnologie realmente utilizzabili per adattare gli impianti di trattamento esistenti ed anche gli aspetti economici relativi al miglioramento degli impianti esistenti.

Tra le tecnologie effettivamente utilizzabili, alcune richiedono grandi quantità di energia elettrica per il loro funzionamento, altre composti chimici con l'impatto legato alla loro produzione. Dal punto di vista economico i costi di ristrutturazione dipendono dalle dimensioni, dai parametri di qualità delle acque da raggiungere nel progetto iniziale dell'impianto e dall'uso finale dell'acqua riciclata. Inoltre le perplessità degli agricoltori sulla qualità dell'acqua riciclata per scopi irrigui, scoraggiano la diffusione di questa nuova fonte idrica.

Keywords: Wastewater reclamation, Apulia, advanced tertiary treatment, disinfection.

Introduction

In the Mediterranean region large areas are affected by chronic water scarcity, due to the rapid development of local economy, the changes in traditional agriculture practices and land use, the groundwater over-exploitation with consequent sea water intrusion that worsens water quality, the climate changes.

Moreover the volume of urban wastewater is increasing with population and economic activities, so large areas may be supplied with reclaimed wastewater which may be used for different purposes depending on the local demand.

The interest for wastewater reuse is particularly addressed to agricultural and landscape irrigation with the aim of both enhancing the local economy, mostly based on agriculture, and saving good quality water resources for drinking purposes.

Referring to the Apulia region in the south-east of Italy, it has many analogies with other areas affected by frequent water shortage problems and water reuse could permit significant savings in water resources.

In Italy, an overall annual water rainfall of about 300 Gm^3 generates an utilizable inflow around 155 Gm^3 , feeding lakes, rivers and groundwater, the other part, about 145 Gm^3 is lost in the deep groundwater runoff or by evapotranspiration (the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere).

The utilizable flow yields only 52 Gm^3 of resources actually utilizable (1).

Because of the geographically uneven rainfalls distribution, in southern regions (like Apulia, Sicily and Sardinia) such figures drastically decrease as rainfalls result much lower (660 mm/y) than the national average (980 mm/y) (2-3).

Apulia, a region extended for about 19,400 km^2, with 834 km of coasts and a population of 4.6 million inhabitants, have an annual rainfall of about 13 Gm^3 but only part (15–20%) of these scarce water resources are actually available mainly because of the carsic nature of the subsoil, which generates an intense water infiltration with the subsequent scarcity of surface water bodies.

For these reasons, Apulia owns one of the smallest amount (136 m^3/capita/y) of potentially available water resources in the south of Italy, although most of the Apulian land is used for agricultural purposes (15,250 km^2), but only 3,650 km^2 of the cultivated area is irrigated.

Nevertheless, the economy of the region, mainly based on two water demanding activities, agriculture and tourism, is ranked as one of the best in the south. This is possible thanks to the efforts of the Apulian water agency (AQP) that imports water from bordering regions such as Campania, Lucania and Molise.

AQP manages the largest European aqueduct, a complex multi-reservoirs system with about 20,000 km of water networks (that distributes, net of leakages, about 300 Mm^3 of drinking water per year) and 10,000 km of wastewater collecting networks (4).

The agricultural sector is served by large irrigation-water distribution consortia, but a negative gap of about 700 Mm^3 is filled by farmers with water collected from local aquifers. It has been estimated that farmers have drilled about 140,000 wells whose extensive exploitation has caused the progressive salinization and depletion of relevant portions of the local aquifers.

In order to manage such a situation, regional authorities, in addition to drastically restrict water wells drilling, have also planned a strategic reuse, in agriculture as well as in industry, of treated municipal wastewater in the recently approved "Water Resources Protection and Management Master Plan".

The regional plan provides general provisions for protecting water resources from pollution, and, in particular, imposes that wastewater discharge into subsoil, a rather frequent practice in Apulia, has to be stopped as soon as possible, indicating the reuse of treated wastewater as an alternative (5).

At the national level wastewater reclamation is mainly based on two national laws, the Legislative Decree 152/2006 and the Ministerial Decree n.185/03 (6-7). In the latter, for the first time, have been clearly fixed the qualitative standards for wastewater agricultural and civil reuse giving to each region the possibility to modify only some parameters.

In Table 1 are reported some selected concentration limits for treated urban wastewater discharge in surface water bodies or in soil and for reclaimed water.

As it can be seen most of the concentration limits are lower for the discharge in soil than into surface water bodies, thus indicating that wastewater treatment plants initially devoted for discharge in soil have a more complex treatment line so the implementation of an advanced tertiary treatment would be easier and cheaper.

TABLE 1

CONCENTRATION LIMITS OF SELECTED PARAMETERS FOR TREATED URBAN WASTEWATER DISCHARGE IN SURFACE WATER BODIES OR IN SOIL AND FOR RECLAIMED WATER, IN ITALY

Pollutant		**Parameter**	**Unit**	**Treated urban wastewater discharge**		**Water reclamation**
				into surface water bodies[1]	**on soil**	**Irrigation and civil reuse**
Suspended solids		Total suspended solids	mg/L	35	25	10
Organic load		BOD_5	mg O_2/L	25	20	20
		COD	mg O_2/L	125	100	100
Macro-nutrients	N	Total N	mg N/L	NH_4 15 NO_2- 0.6 NO_3- 20	15	15
	P	Total P	mg P/L	10	2	2
Microbial Load		E. Coli	CFU/ 100 mL	5,000 [2]	5,000 [2]	10 [3]

(1) discharge in a no-heavily polluted area.
(2) Recommended but to be fixed according to environmental state of the surface water body.
(3) for 80% samples, none to exceed 100 CFU/100 mL.

State of the art of wastewater reclamation in Apulia

In Apulia there are 197 urban wastewater treatment plants, but only 186 are managed by AQP. Among the latter, 70 have capacity 2,000 – 9,999 person equivalent (p.e.), 94 have capacity 10,000 – 49,999 p.e. and 22 have capacity over 49,999 p.e. but only 40 have been located to the reuse of wastewater at the provincial level. Table 2 shows the status of the plants intended to the reuse of treated wastewater (8).

The reclamation capacity is actually around 150 Mm3/y, would cover about 20% of the negative gap in the irrigation needs.

Most of the sewage plants in Apulia works with a conventional system of activated sludge, with a primary, secondary and sometimes tertiary treatment. Quality of treated water fulfils the European Directive 91/271/CEE regarding the quality of secondary treatment discharges and, consequently, it is not yet suitable for reclamation.

Primary treatments generally consists of rough filtering with grilles or sieves sometimes followed by oil separation, while secondary treatment consists of biological activated sludge, in reactor or aerated tanks with blowing air or mechanic agitation, followed by secondary settling (Fig. 1).

From the technological point of view most of the tertiary treatment plants in the Apulia region have been designed or are running according to a series of physical or chemical treatments like flow equalization, coagulation, flocculation, sedimentation, filtration, and differs in the final disinfection step used to ensure minimum quality requirements of the effluents (Fig. 1).

The prevalent options are ferric chloride (as coagulant), anionic polyelectrolyte (as adjuvant of flocculation), sand and anthracite (as filtrations media).

Among disinfection techniques, hypochlorite, peracetic acid and UV are the most used, generally two different technologies in a serial arrangement. Ozone, chlorine dioxide and membranes are utilized only in some pilot plants.

The critical phase of the process, the disinfection, is finalized to the inactivation of pathogenic microorganisms (E. coli, Salmonella, coliforms) and is the critic step that need to be improved in most cases with the construction of an advanced tertiary treatment system.

In order to improve knowledge in this field regional authorities have financed a research project, whose acronym is "SIRPAR" (Integrated Strategies for Urban Wastewater Reclamation in the Apulia Region) in which there are water treatment companies as partners with the University, the Polytechnic of Bari and ENEA (Italian Agency for the New Technology, the Energy and the Environment). The general goal of the research project is to acquire the knowledge necessary to choose and manage the advanced tertiary treatment needed by the specific wastewater treatment plant to reach the quality requirements of the regional plan and to implement new and unexplored solutions (9). Nowadays in the Apulia region, from technical and economic considerations, only some advanced tertiary treatment system can be implemented in the existing plants.

TABLE 2

WASTEWATER TREATMENT PLANTS IN APULIA INTENDED TO THE REUSE, DIVIDED BY PROVINCE

Province	p.e.	Reclamation capacity (m^3/day)	Wastewater treatment capacity (m^3/day)	Situation
BARI				
Andria	130,000	12,960	25,992	to improve
Bari Est	541,261	78,000	108,264	completed
Bari Ovest	295,683	25,920	59,136	completed
Castellana Grotte	18,500	1,320	3,696	to improve
Conversano	24,037	6,000	4,800	completed
Molfetta	63,945	10,992	12,792	to improve
Putignano	28,097	5,616	5,616	new construction
Ruvo - Terlizzi	52,866	11,400	10,584	to improve
Barletta	92,305	35,520	18,456	new construction
BRINDISI				
Ceglie Messapico	29,450	5,880	5,880	to improve
Fasano Forc.	43,845	3,504	8,760	completed
Mesagne	81,413	13,992	16,272	completed
Ostuni	32,810	5,496	6,552	completed
San Donaci	7,700	1,536	1,536	to improve
S. Pancrazio Sal.	10,527	2,112	2,112	to improve
FOGGIA				
Carapelle	7,000	1,392	1,392	to improve
Cerignola	83,200	8,040	16,632	to improve
Foggia	187,200	30,000	37,440	completed
Isole Tremiti	5,000	1,008	1,008	completed
Lucera	37,620	4,512	7,536	to improve
Margherita di Sav.	19,800	3,000	3,960	to improve
San Severo	88,000	6,960	17,592	to improve
Trinitapoli	14,447	2,880	2,880	to improve
Vieste	22,133	4,416	4,416	completed
LECCE				
Carpignano Sal.	13,475	2,496	2,688	new construction
Casarano	41,902	3,504	8,376	new construction
Corsano	15,391	2,520	3,072	new construction
Gallipoli	80,000	12,000	16,008	new construction
Lecce	98,208	19,992	19,632	completed
Maglie	59,827	12,000	11,976	new construction
Novoli	10,932	2,184	2,184	to improve
Presicce	15,872	3,168	3,168	to improve
Tricase	17,751	1,968	3,552	new construction

TARANTO				
Avetrana	8,400	1,680	1,680	to improve
Castellaneta	17,860	3,576	3,576	completed
Lizzano	24,696	3,312	4,944	completed
Maruggio	18,000	3,600	3,600	to improve
Massafra	31,148	7,992	6,240	completed
Taranto Bellavista	132,723	16,000	16,000	to improve
Taranto Gennarini	100,000	30,000	30,000	to improve
Total	2,603,024	408,448	520,000	

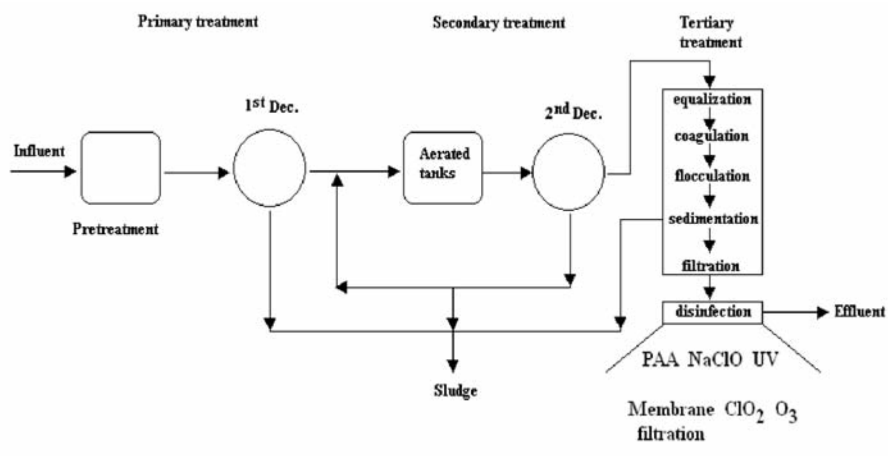

Fig. 1 - Scheme of the wastewater treatment plants in Apulia.

Sodium hypochlorite is one of the most prevalent option in tertiary treatment in Apulia, is used in solutions with concentrations ranging from 12.5 to 17% whose handling requires special design considerations because of its corrosiveness, the presence of chlorine fumes and gas binding in chemical feed lines.

Its use may originate chlorinated disinfection by-products in treated water in particular trihalomethanes (THMs) whose concentration, in some cases, did not comply with the new Italian law for direct agricultural reuse (10).

Peracetic acid (PAA) is also a strong oxidant and disinfectant, commercially available as an aqueous mixture containing acetic acid, hydrogen peroxide and water in equilibrium as follows:

$$CH_3COOH + H_2O_2 \rightarrow CH_3COOOH + H_2O \qquad (I)$$

PAA solutions have concentrations between 10% and 15% (primarily 12%), producing little toxic or mutagenic by-products after reaction with organic materials present in treated wastewater.

It has been observed the transformation of phenol to chlorophenol in water with high chlorine concentration (as occurs in seawater) through the generation of free halogen radicals, but the quantity and spectrum of these disinfection by-products are much less than those formed by chlorine (11).

PAA performs better than sodium hypochlorite against Vibrio cholerae and its activity improves at warmer climates, for this reason it has been implemented extensively in Italy (12).

One of the major drawbacks in the use of PAA disinfection is the increase of organic content in the effluent, and the potential microbial regrowth due to remaining acetic acid present in the disinfectant or resulting as a product of decomposition of PAA.

First used on high quality water supplies, UV light use as a reclaimed water disinfection agent evolved during the 1900s with the development of new lamps (13).

With the proper dosage, UV irradiation has proven to be an effective disinfectant for bacteria, protozoa, and viruses in reclaimed water, without formation of disinfection by-products as inactivation of microorganisms is based on photochemical reactions that modify DNA and RNA structures.

The germicidal portion of the UV radiation band is between 220 and 320 nm.

Ozone is chemically unstable as decomposes to oxygen very rapidly after generation and is generated onsite by electrical discharge in the disinfection of tap water and reclaimed water, using air, high-purified oxygen or oxygen-enriched air as raw materials.

The schematic flow diagram of an ozone disinfection system is reported in Fig. 2 (13).

Chlorine dioxide is produced in-situ by means of a reaction between sodium chlorite with hydrochloric acid (2):

$$5NaClO_2 + 4HCl \rightarrow 4ClO_2 + 5NaCl + 2H_2O \qquad (II)$$

Concern exists over the formation of by-products including chlorite (ClO_2-) and chlorate (ClO_3-) which may lead to hemolytic anemia at low levels of exposure, while higher levels of exposure may lead in an increase in methemoglobin (14).

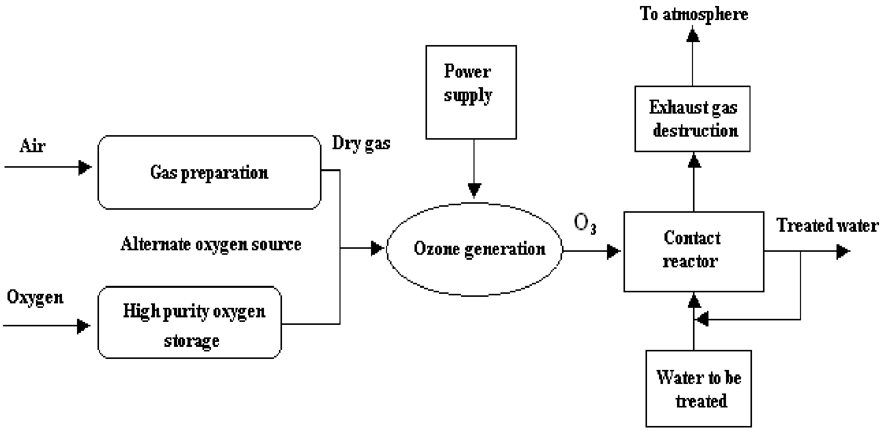

Fig. 2 - Schematic flow diagram of an ozone disinfection system (13).

There are several classes of treatment processes that uses membrane filtration: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) depending on the construction material of the membrane (cellulose acetate, polypropylene, aromatic polyamides and thin film composites), the nature of the driving force, the separation mechanisms and the nominal size of the separation achieved.

In the AQUATEC project, coordinated by the Institute for Water Research (IRSA) belonging to the National Research Council (CNR) in the Apulia region, have been studied various aspects of the process of membrane ultrafiltration by using a pilot plant (with maximum productivity of 0.7 m^3/hour) connected to the effluents of the wastewater treatment plant of Cerignola in the province of Foggia, a 50,000 inhabitants town in south-eastern Italy.

The system, with a filtering surface of 23.5 m^2, used hollow fiber membranes with a nominal pore diameter of 30 nm and delivered water used for irrigation of seasonal vegetables grown in a field adjacent to the waste water treatment plant (15-16).

One of the objectives of the investigation was the evaluation of agronomic results (features of soil and crops) of membrane filtered municipal wastewater versus conventional groundwater in drip irrigation of tomato, fennel and lettuce.

The results obtained after 2 years of experiments, clearly pointed out that concentrations of Cl^-, Na^+ and B were higher in membrane

filtered reclaimed water than that of conventional groundwater, whereas the other parameters were similar between the two water sources.
Moreover the microbial pollution of conventional groundwater was noticeable higher than that of filtered water, moreover microbial investigations revealed that plots irrigated with conventional groundwater resulted more polluted than those irrigated with filtered water and total coliforms were the only microorganisms found on the irrigated crops.

As the discharge into aquifers needs less stringent quality parameters (Table 1), plants that have been planned according to reach this quality index, have adaptation costs higher than those calculated for the plants initially devoted to discharge into soil.

Moreover, for the same reasons, the adaptation costs for wastewater reclamation depends on the quality index of the final use (industrial or irrigation) of the reclaimed water.

The wide variation in projected and real reuse costs, both function of treatment level and facility capacity, makes difficult to develop a correct planning of design and construction and the result is that the real costs of the projects are usually considerably higher than that estimated previously.

Most water prices are either subsidised or do not include the hidden costs of water determined by the environmental, social and economic impacts of the process.

These costs are composed of the direct costs of headworks, storage, treatment, distribution and also the externalities such as the impacts on public health, eutrophication, soil salinisation.

Some authors, in the case of advanced tertiary treatment adaptation with NaClO disinfection combined with UV treatment, estimate a cost in the range 0.10 - 1.2 €/m^3 (17) and stated that these costs depends on plant size.

The specific costs of reclamation are determined also by the volume of water delivered, as registered in the integrated plant with flocculation and chemical (NaClO) and physical (UV) disinfection systems located in Fasano Forcatella, in the province of Brindisi, from about 0.93 €/m^3 for 70,000 m^3/year delivered to 0.3 €/m^3/year for 700,000 m3/year delivered (18-19).

This observation suggests the importance of the scale economies in evaluating the construction and operation costs of an advanced tertiary treatment plant, an issue that stakeholders have to take into account in planning the construction or adaptation of an existing urban wastewater treatment plant intended to reclamation.

Future perspectives of wastewater reclamation in Apulia

Regional authorities have decided to finance the construction of new wastewater treatment plants including, in the initial project, the advanced tertiary treatment line for reclamation of water in order to reach the maximum reclamation capacity of the existing wastewater treatment system. One of the major drawbacks in planning these new treatment facilities and in improving the existing ones, is the choice of the disinfection system, which should include the most important relevant aspects from the economic and environmental point of view.

Among the various possibilities, some use chemicals, with the associated environmental concerns about formation of disinfection by-products, and others have higher electricity consumption or require production and disposal of UV lamps (containing mercury) or membranes.

The only assessment tool that can help stakeholders to make the correct choice could be the Life Cycle Assessment (LCA) in which is used an holistic approach (20) for environmental assessment, in which problem shifting is avoided, since impacts in different places and moments in time can be taken into account.

Under the SIRPAR project the different disinfection systems under investigation are analysed in their electrical, chemical and materials consumptions in the construction, use and final disposal phases, in order to establish the best environmental friendly technique to achieve quality parameter for reclaimed water.

From the calculations and data collected in the existing plants, emerges the need to take into account also the size of the plants in planning the construction of new wastewater treatment plants with an advanced tertiary treatment line for wastewater reclamation.

The scale economy suggests the construction of bigger plants and the collection of water from different small facilities as favourite options, as the disinfection costs decrease with the amount of delivered water.

Following these suggestions regional authorities are planning the construction of larger tertiary treatment plants in which to collect the water (subjected to a primary and secondary treatment) from more than one plant.

An interesting project is being developed in Taranto, a 200,000 inhabitants town of the Apulia region, for “Gennarini” and “Bellavista” wastewater treatment plants, in which reclamation of urban wastewater will serve the huge water needs of a steelmaking factory with 9 million tons of steel producing capacity per year.

In this case the water from the "Gennarini" plant is treated and then pumped to the "Bellavista" plant where is mixed with its treated water in an equalization basin. The water is then subjected to the tertiary treatment reaching the quality parameters needed for the steelmaking factory and thus avoiding freshwater collection from the local aquifers and rivers.

There have been highlighted some concerns among farmers in use of reclaimed water for irrigation purposes that impeded the diffusion of this practice. In order to overcome such a distrust in the use of reclaimed water regional authorities should strengthen the efforts in information and communication involving municipalities and academic institutions.

Conclusions

Wastewater reclamation is one of the most effective strategies to solve the problem of water shortage in a region characterized by an irrigation deficit as Apulia in Italy. Moreover the presence of a steelmaking factory, one of the biggest in the world, and a diffuse intensive agriculture with the associated water needs satisfied by large water draining-off by local aquifers, is a decisive driving force toward the realization of large advanced tertiary treatment plants for reclamation of urban wastewater for industrial and agricultural reuse.

Regional authorities have defined a "Water Resources Protection and Management Master Plan" in which the reuse of urban treated waste-water, plays a relevant role and imposes that wastewater discharge into subsoil, a rather frequent practice in Apulia, has to be stopped as soon as possible, clearly fixing the qualitative standards for wastewater reuse.

From the technological, infrastructural, logistic and economic standpoints, not all the wastewater treatment plants can be involved in the wastewater reuse, because some of them have a scarce capacity, or are very far from agricultural districts, or are equipped only with preliminary or primary treatment sections, without the secondary treatment, or cannot be connected to the wastewater distribution pipelines. Among the existing 197 urban wastewater treatment plants, 13 are currently eligible for reuse and 27 need additional improvements, in particular in the disinfection system, in order to achieve the quality parameters fixed by the plan.

Among different disinfection solutions chemical ones need production and transportation of chemical formulations with the associated environmental pollution and moreover adverse health effects in the use phase due to emissions of trace contaminants whereas UV, ozone and filtration, have higher electrical consumption and suffer the disposal of spent lamps and membranes, but have less problems in disinfection by-products generation.

The adaptation costs are strongly dependent on the construction characteristics of the facilities and the volume delivered. Calculations suggests that adaptation costs of the reuse plants are lesser for the plants initially devoted to soil discharge of the effluents and for bigger facilities. Moreover it has been verified that costs decrease with the volume of reclaimed water delivered, indicating as favoured the construction of larger tertiary treatment lines in which to collect the water (subjected to a primary and secondary treatment) from more small plants, as is being developed in Taranto for “Gennarini” and “Bellavista” urban wastewater treatment plants. In this case reclaimed water can satisfy the needs of a steelmaking factory.

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