Some economic considerations on wastewater reclamation for irrigation, with reference to the Italian situation

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Abstract The purpose of this work is to check construction and operation costs for simplified post-treatment trains able to produce water displaying a quality suitable for different agricultural uses. Having in mind the quality of most of surface waters in Italy, the main parameters to control for a general purpose reclaimed water supply are microbial quality and TSS content. Therefore a contact filtration followed by disinfection is to be considered the minimum option, while the use of polishing ponds can be strictly limited in many Italian regions due to the area requirements and to the need to provide a full lining of bottom and levees. Some data referring to surface waters quality and to the Italian epidemiological situation are given. On the basis of the current Italian situation, the construction and operation cost increases due to a polishing section, downstream a standard municipal WWTP, are evaluated and the impact of different technical choices is shortly discussed (disinfection options, chemicals, etc.). Some considerations about the link existing in Italy between the cost of water for irrigation and the agricultural economy are made.

Keywords Quality standards; surface water quality; agricultural reuse; reclamation costs; treatment trains

Introduction

Quality and safety (on a continuous basis) are the main key-factors for an effective reclamation project, but its success is also related to the economic aspects, which are strongly influenced by quality standards.

Many questions can be put and the main ones can be summarised as follows.

- What is the average quality of water generally used for irrigation?
- Is this quality cause for documented risks?
- What are the uses of the reclaimed water?
- Are present quality standards for reclaimed water complying with these uses or only with some of them?

Quality standards are usually based on two different concepts: total safety – see for instance the provisional emergency standards set in Apulia (Bonomo *et al*. 1999), which take into account 52 different parameters, including many metals and organic compounds – or acceptable risks. Unrestricted or restricted uses can be separately considered, but in many situations (very common in Italy) this appears to be pretty theoretical. In fact a polishing plant could usually produce and distribute only one type of reclaimed water, which must clearly comply with the local most stringent requirements, being very difficult to check its final destination (it might be used both for crops to be raw-consumed or other crops, due to high estate subdivision). Quality standards (and therefore reclamation costs) are also affected by different irrigation options: for instance a lower microbiological quality can be accepted if spray irrigation is used only for crops not to be raw-consumed by humans, while in this situation no-contact irrigation (e.g. underground drip irrigation) has to be implemented for other crops. A risk analysis would be advisable to evaluate the impact of wastewater reclamation, when compared – for instance – with the quality of local surface waters used for irrigation. Moreover some regional standards set for surface water quality give MAC figures much looser than those provided by water reclamation standards:

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for instance Lombardy allowed – for unrestricted irrigation – the use of surface waters showing:

– T. Coli < 5,000 UFC 100 ml^{-1};
– F. Coli < 1,000 UFC 100 ml^{-1};
– F. Streptococci < 1,000 UFC 100 ml^{-1}.

Recent data about the microbiological quality of some rivers in Northern Italy are summarised in Figure 1, both for T. Coli and F. Coli; the rivers taken into account are extensively used for irrigation, even unrestricted. Po and Adige are the largest Italian rivers, while Ticino is a good quality important stream. The microbiological quality of Po and Adige can be considered pretty poor (even if some evolution toward better levels can be noticed, due to more effective treatment practices and to more stringent control on cattle-breeding farms): this situation is strictly linked to the first Italian Water Protection Act, which asked for disinfection only in the case of hygienical risks occurrence, following a specific request of local sanitary authorities (usually disinfection is considered as a reserve treatment step). The microbiological quality of Po and Adige appears to be worse than the one requested by Lombardy standards, while Ticino totally complies with them. The use of these waters for irrigation nearly throughout Northern Italy doesn't seem to lead to particular problems from an epidemiological point of view. In Figure 2, data referring to typhoid diseases distribution in Italy are given (Carbini *et al.*, 1997); the situation appears to be quite different in the four geographic areas considered: Northern Italy (N.I.), Central Italy (C.I.), Southern Italy (S.I.) and Insular Italy (I.I.). The overall national data (IT) are quite similar to European average figures and, with the only exception of Insular Italy, indicative of a diminishing trend.

Another representative item of the overall hygienical situation is here shortly reported: Hepatitis A (as shown in Figure 3); data appear to be similar or better than those recorded in other countries: for instance, in 1992, the USA figure for Hepatitis A was 9 cases/100,000

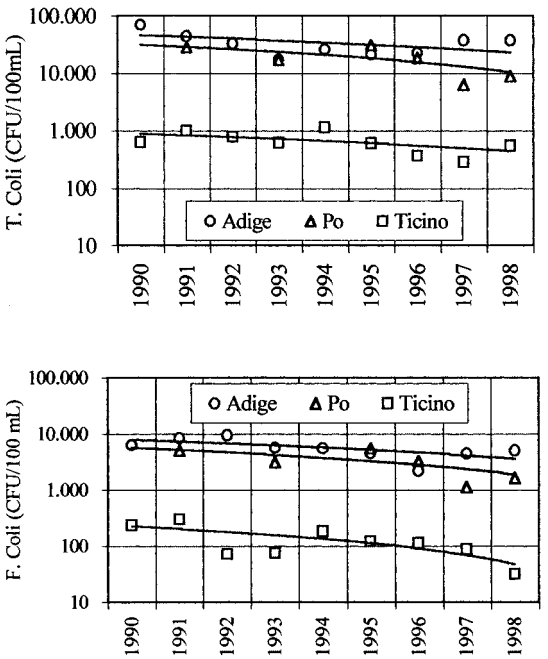

Figure 1 Yearly averages for T. Coli and F. Coli counts in some important Italian rivers. Samples were taken at the following distances before outlet: Po ≈ 90 kms; Adige ≈ 120 kms; Ticino ≈ 60 kms

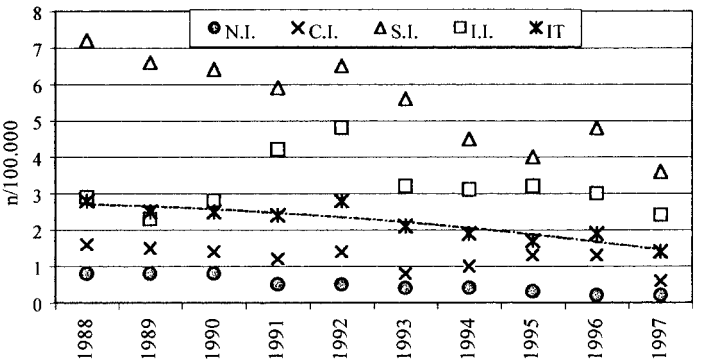

Figure 2 Evolution of typhoid diseases cases /100,000 inhabitants in different Italian geographical areas and for whole Italy (derived from Carbini *et al*., 1997)
Northern Italy (N.I.), Central Italy (C.I.), Southern Italy (S.I.), Insular Italy (I.I.) and Italy (IT)

inhabitants (Korff, 1995). The critical situation displayed for 1997 derives from local outbreaks in Southern and Insular Italy; in fact the 1997 incidence of Hepatitis A was in those areas 8 times greater than the average values of the decade, while for Northern and Central Italy the figure was in the average (4 cases/100,000 inhabitants).

The incidence of water among possible infectious pathways, appears to be in Italy quite low (see data summarised in Figure 4, referring to average figures during 1986–96), while the main cause is related to shellfish raw consumption (traditional in all seaside regions of Southern Italy), followed by the risks coming from travels to hygienically dangerous areas.

Economic considerations

The influence of water on production costs is not enough focused in Italy – both in the case of natural or reclaimed waters – in spite of its influence. The majority of water distributors are public authorities and water fees are usually not based on consumption, but on the farm's irrigable surface: for instance in a large irrigation district, supplied by Ticino river, the farmers are charged with an irrigation fee of about 100 € ha^{-1} per year (for spray irrigation, which is the most common practice), regardless of the volume of water effectively used. Fees for farmers are mainly due to O&M costs for water distribution: in fact, the

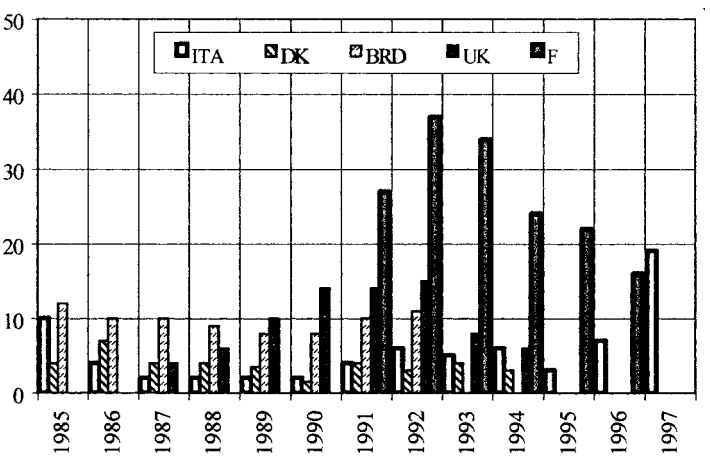

Figure 3 Hepatitis A cases/100,000 inhabitants in some EU countries (Nordenfelt, 1997; Zanetti, 1997; Flahault *et al*., 1997; SEIEVA, 1998)

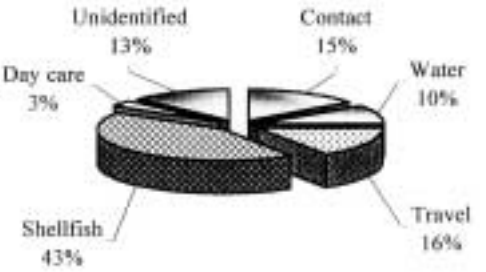

Figure 4 Main infectious risk factors for Hepatitis A in Italy (from SEIEVA, 1997)

charge asked by the State to withdraw public waters for irrigation purposes is very low (~ 36 € $year^{-1}$ at a 100 Ls^{-1} flow). The amount of water usually withdrawn during the irrigation season is 2,500–6,000 m^3ha^{-1} (thus giving for natural waters a 0.012–0.03 € m^{-3} range), depending on crop, climate and farmers' habits. In the case of corn, the cost of water will be roughly 8% of the average selling price for farmers: as a consequence the economic impact of water prices is to be taken into account, especially considering that the current EU agricultural policy will lead to reduce farmer's profits. Similar considerations can be made for reclaimed water, thus the control of polishing costs appears to be a primary target.

Coming to the main purpose of this paper, a simple treatment train, based on contact filtration followed by four different disinfection agents (ozone, chlorine, UV rays or peracetic acid) has been studied (see Figure 5) and the four different options have been analysed from the economic point of view.

Construction and operating costs have been estimated for the following microbiological quality standards:

A) T. Coli: ≤ 2.2 MPN 100 ml^{-1}
B) T. Coli: ≤ 23 MPN 100 ml^{-1}
C) T. Coli: ≤ 200 MPN 100 ml^{-1}
D) T. Coli: ≤ 1000 MPN 100 ml^{-1}

Scenarios A and B refer respectively to stringent standards for unrestricted and restricted irrigation (California's Title 22), while scenarios C and D refer to looser ones. The Italian standards (average results of a seven days long survey) – currently under revision, following the recent issue of a new Water Protection Act (May 29th, 1999) – were derived from the California's ones: 2 T. Coli MPN 100 ml^{-1}, for products to be eaten raw, and 20 T. Coli MPN 100 ml^{-1}, for pastures and products to be eaten cooked or processed (Delibera C.I.T.A.I., February 4th, 1977). Ozonation has here been taken into account only for scenarios A, B and C, while PAA has not been considered to be a feasible option for scenario

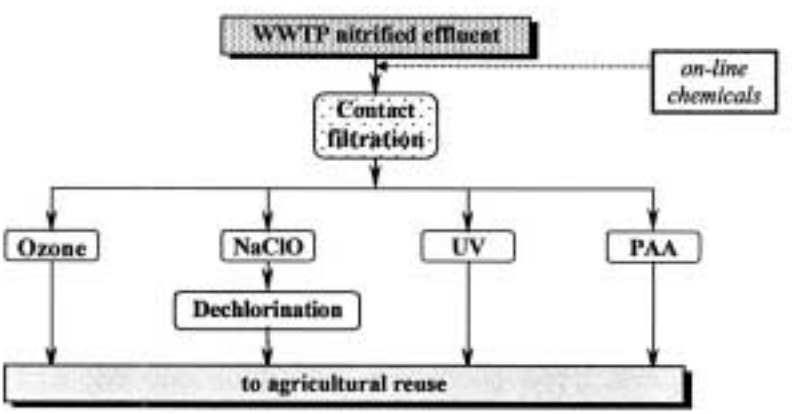

Figure 5 General layout of the polishing trains taken in consideration for costs evaluation

A, as very high doses would be necessary in this case, as evidenced for instance by Liberti & Notarnicola (1999); a further related problem is the possible BOD increase due to PAA decomposition products (mainly acetic acid), in case of high doses.

Cost estimation has been referred to a plant flow of 50,000 m^3d^{-1}, representative of an Italian medium size plant (capable to irrigate 1,000–3,000 ha, depending on crops and climate and assuming a specific weekly water demand in the range 120–350 m^3ha^{-1}). The polishing section – downstream a nitro-denitro WWTP showing a reference T. Coli content in the order of 10^5 MPN 100 ml^{-1} – is based on single media contact filtration, using ferric chloride or aluminium poly-chloride (provision for 1 mg l^{-1} polymer was also made), followed by disinfection performed by four alternative agents, as in the following Table 1.

Construction costs for the different units were derived from recent data (1999) referring to the Italian market (all appurtenances included), checked with those of similar plants in operation. The results of this survey can be summarised as follows: the increase of construction costs induced by a polishing section can be evaluated to be usually in the order of 12–14% of the capital cost requested for a standard nitro-denitro WWTP, when the contact filtration unit is followed by a disinfection step performed using NaClO (with subsequent dechlorination), UV irradiation or peracetic acid (PAA). The situation becomes different when the polishing train provides ozonation as disinfection step: in this case the cost increase can range from 25% (scenario C) to 35% (scenario A) of the construction cost for a nitro-denitro WWTP.

Operation costs have been evaluated on the basis of the 1999 prices for energy (~ 0.1 € kWh^{-1}), chemicals, sludge disposal (~ 50 € t^{-1}) and labour; maintenance has been evaluated as 0.5% of the building and 3% of the equipment costs (yearly basis).

Operation costs appear to be strongly influenced by different disinfection options and quality targets (reclaimed water distribution has not been considered here); the increase of operation costs induced by a reclamation section (expressed as percentage of the standard

Table 1 Main characteristics for the four different disinfection units

Disinfection agent	Main characteristics	Doses range (depending on quality target)
Ozone	Oxygen-fed generator; 15 minutes contact time; O_3 doses calculated by the Selleck *et al*. model, taking into account the initial ozone demand.	7–18 mg l^{-1}
Chlorine	30 minutes (as a minimum) plug-flow contact time (downstream a flash-mixing unit), followed by dechlorination (1:1 Sodium meta-bisulphite/ chlorine weight ratio); active chlorine was calculated with the previously cited model, taking into account the initial chlorine demand.	5–11 mg l^{-1}
PAA	Contact tank similar to that used for chlorination (same contact time). Doses derived from experimental data (Visconti, 1999).	4–14 mg l^{-1}
UV	Low pressure lamps; open channel (3.1–12.5 seconds contact time, depending on scenarios).	23–92 $mWs^{-1}cm^{-2}$

Table 2 Operation cost increases ($FeCl_3$ contact filtration) for different scenarios and disinfection agents, expressed as % of the ones for a standard nitro-denitro municipal WWTP (amortisation not included) (A = 2.2 T. Coli 100 ml^{-1}; B = 23 T. Coli 100 ml^{-1}; C = 100 T. Coli 100 ml^{-1}; D = 1,000 T. Coli 100 ml^{-1})

Scenario	Contact filtration NaClO	Contact filtration UV	Contact filtration PAA	Contact filtration O_3
A	18.2%	17.7%	N/A	60.6%
B	16.0%	15.4%	64.4%	41.6%
C	15.3%	14.1%	42.2%	33.1%
D	14.9%	13.7%	27.4%	N/A

N/A: not applicable

nitro-denitro WWTP operation cost) is given in Table 2 for $FeCl_3$ contact filtration followed by disinfection. The influence of amortisation per unit flow – not considered here – largely depends on the length of the irrigation season, which can widely vary in Italy. It must in any case be stressed that, the use of a final filtration step nowadays spreading in Italian plants (also when reclamation is not foreseen), the influence of amortisation on reclamation costs will be lower. Figure 6 summarises the specific operation costs for all situations here evaluated; the power curves, interpolating calculated data (amortisation not included), could be used in similar conditions to evaluate operation costs for other quality targets.

From Table 2 the economic impact of different disinfection agents is evident (the use of aluminium poly-chloride – here not taken into account – leads to higher operation costs) and the use of ozone appears to be limited to very peculiar situations (the situation will probably become less unfavourable with the spreading of new-generation ozonators); the PAA option is at the moment difficult to choose – PAA being a very expensive disinfectant (~ 0.75 € kg^{-1}, 1999), even if its price is decreasing (~ 0.5 € kg^{-1} less in the last two years) – and limited to looser water quality standards, when a low DBPs level is the main issue. Operation costs using NaClO or UV rays are very similar and pretty interesting; it must anyway be focused that scenario A quality levels are not easily reached, on a continuous basis, by UV rays following a standard single media contact filtration, in case of wide TSS influent fluctuations; another aspect to focus, referring to UV irradiation, is the influence of lamps disposal (related to lamps service time) on operation costs. In any case, the influence of quality targets on operation appears to be not so strong, when NaClO and UV are used.

Conclusions

The compliance with stringent microbiological standards significantly affects overall wastewater treatment costs. With reference to a standard nitro-denitro municipal WWTP, even a simplified polishing step (contact filtration followed by disinfection) can increase operation costs by 15–20%, for the more economically feasible polishing trains based on UV or NaClO disinfection. However both of them have to face some practical limitations: consequences of influent TSS fluctuations for UV rays and increasing concern – in some countries – for possible toxicity risks related to chlorination.

Construction cost increases are less significant (with the exception of ozone disinfection), but their influence on the final cost per unit flow can be important in case of a short

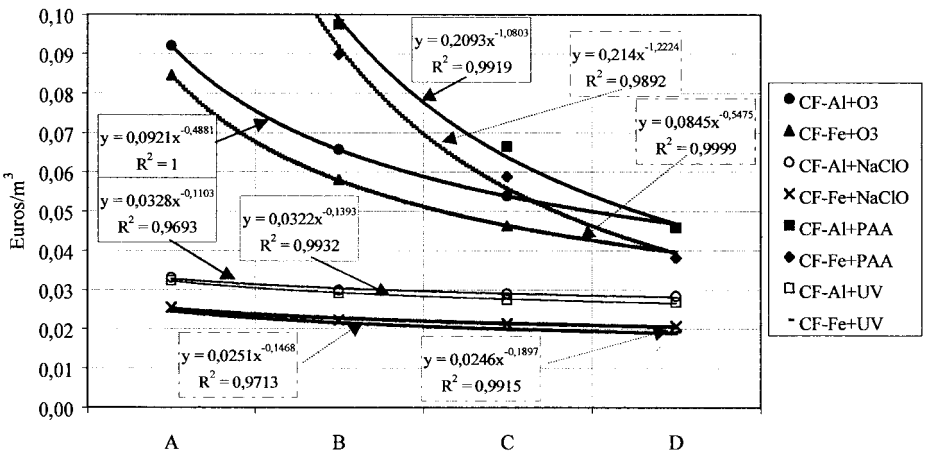

Figure 6 Operation costs (€/m^3, amortisation not included) for different microbiological targets, in a 200,000 EI polishing plant (contact filtration + disinfection) using different chemicals and disinfectants (A = 2.2 T. Coli 100 ml^{-1}; B = 23 T. Coli 100 ml^{-1}; C = 100 T. Coli 100 ml^{-1}; D = 1,000 T. Coli 100 ml^{-1})

irrigation season (corn or similar crops), if polishing units are operated for few months a year, strongly increasing the yearly amortisation rates per cubic metre.

Data previously reported can give a contribution to the debate, current in Italy like in other countries, about quality standards for wastewater reclamation.

A. The present microbiological quality of natural surface waters utilised in Italy for irrigation cannot be neglected: usually their T. Coli contents are close to scenario D figures or higher, without any direct evidence of related epidemiological risks.
B. The influence of different disinfection options on polishing costs is evident:
   – O_3 can nowadays be taken into account in Italy, if also other quality targets (removal of organic compounds, colour, etc.) must be provided;
   – PAA would be of some interest (but not for stringent quality levels), if its price will continue its lowering trend.
C. Therefore, if toxicity concerns for the use of chlorine will continue to grow and UV disinfection will not be able to reach on a continuous basis the most stringent standards, the economic outcomes can be very significant and able to affect the agricultural production costs.
D. As a consequence the widespread implementation of very stringent standards can lead to reduce, with the exception of arid areas, the interest in reclamation practices, particularly considering the difficult situation of agriculture related to the current policy in the European Union.

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