PHYTOREMETIATION FOR ECOLOGICAL RESTAURATION AND INDUSTRIAL ECOLOGY*

Gianluigi Pirrera1**, Antonio Pluchino2

1Associazione Italiana per l’Ingegneria Naturalistica, + AIPIN, Via Scobar, 22, Palermo, Italy
2Freelance Engineer, Via Sant’Agostino, 3, Modica Italy

Abstract

Sometimes environmental sustainability needs are nullified by the lack of economic resources. This article proposes treatment systems connected with water ecosystems to get less economic resources. The case studies in Sicily, one in particular, include industrial ecology and circular economy as sustainable tools to achieve this goal. The 1st case is a depuration system involving filtering bags (put directly on the riverbed) which limits soil losses, permits river ecological depuration and the restoration of the suburban fluvial landscape. The 2nd case concerns the ecological restoration of a river mouth in the city of Catania. The river polluted waters are treated by phytoremediation and lagoon that increase the water areas before being subtracted by urban infrastructures. The 3rd case, the treatment of a mineral water factory, is more complex, because it had to protect the same groundwater from which the mineral water is pumped. The rain, the civil and the industry wastewater are so collected in large tanks, to remove them with vacuum truck. Costs were high and the landscape was of industrial use. The civil wastewater traditional phytoremediation plant has been changed in a two phase closed cycle-system, using two different species of plants (Phragmites and Typha), where the evapotranspiration represents the only output of water, eliminating the costs of waste disposal. A parametric security channel has been planted with Cyperus papyrus. This system interacts with the depuration systems of rain and industrial wastewater and, also, addressing in the papyrus channel, the phytoremediation. Other advanced landscaping methods will permit to expand water surfaces using elements of agricultural landscape. In particular, phyto-treatments and bio-ponds are planned, other than the method of fertigation on fruit trees such as olive trees, walnut trees and mulberry trees. The aim of obtaining natural depuration with less disposal costs and aquatic environmental improvement in industrial contexts so will be improved.

Keywords: circular economy, deep water safeguard, multifunction, sustainability

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** Corresponding author: e-mail: jl.mine@libero.it
1. Introduction

This paper deals with purification systems closely related to water ecosystems, the choice of plants, and the attention paid to the saving of economic and water resources, recalling some case studies already carried out in Sicily. All cases are multifunctional and include, in addition to the purifying function, also ecological restoration and circular economy principles (Amato et al., 2011). In the first case, the restoration of the river and suburban landscape of the Morello Valley (2008, Villarosa Enna) has been carried out in order to reclaim the natural landscape and the ecological depuration of the river through the use of “filtering bags” in the riverbed. Multifunctionality involves the retention of soil particles, the containment of soil loss, the consolidation of the shores and the ecological recovery. The plants used (Phragmites australis, Typha sp., Juncus sp.) were exclusively taken along the waterway and housed, both with the rhizome transplantation technique and that of ecocells transplantation (Lamouroux et al., 2015).

The second case (2015) is a true ecological urban restoration of the mouth of a river (Acquicella) within the city of Catania. Highly polluted river waters are treated by phytoremediation (Phragmites australis e Typha sp.) and lagoons that increase the lost aquatic surface for urban infrastructure. The plants used for the lagoons were exclusively picked up in the mouth area and settled by both rhizome transplantation (Phragmites australis, Typha sp., Juncus sp) and mixed ecocells pick up directly in the riverbed. The third case (2016), relating to the treatment of civil rain, rain and industrial wastewater of SI.A.M. (Sicil Acque Minerali s.r.l. Modica, Ragusa) adds elements of industrial ecology and circular economy (BenDor et al, 2015; Ghisellini et al., 2016). It is a technically complex case designed to safeguard the aquifer from which it is drawn from the water to be bottled. The discharging system (civilian, first rain and industrial washing) in tanks and subsequent disposal by high cost auto-offs has been replaced by three systems that interact with each other with benefits also for emergency management. Precisely: phytoremediation of dual-stage for civil discharges with two different species Phragmites australis, Typha sp.; a system of inground basin for first rain water and fertigation for washing waters. The effect of the evapotranspiration has reset the waste disposal costs, making the cycle closed. In a perimeter security channel has been used Cyperus papirus var. nana, aimed at increasing the landscaping and floristic value of the intervention and the experimental value since taxa belongs to those genera suitable for removing metals in aqueous solution (Juncus, Cyperus, Scirpus) (Cassetti, 2014; Latteo, 2012).

2. Objectives

The objective is to highlight the effectiveness of phytoremediation (civilian, rainwater and industrial wastewater) also for environmental restoration and circular economy. In order to optimize the use of plants for water purification and ecological recovery, a database has been devised which contains biotechnical characteristics of the most used and usable plants. The choice of species must depend on the depurative needs but also on the compatibility with the surrounding landscape, especially in protected areas, where it is appropriate to identify local and suitable taxa. For example, Typha sp., has a rapid growth and a wide tolerance for metals, with penetration in the soil up to 0.3-0.4 m; Phragmites australis has wide tolerance to climatic conditions, very rapid growth, 0.6 m radical penetration, high oxygen transfer capacity from the air to the submerged parts that promotes nitrification. Thanks to phytoremediation, standards of natural landscape improvement can be achieved even in industrial contexts and reduce the waste disposal costs. In the most complex case of the mineral water industry, the purification objective will be so
implemented that the optimization planned with even more pushed landscaping criteria will allow to increase water surfaces. In the most complex case of the mineral water industry, the purification objective will be implemented so that the optimization with even more expansive landscaping criteria will allow to increase water surfaces with elements of the agrarian landscape, use new edible species and aim at productions energy from biomass produced and technosoils productions.

3. Outline of the work

For environmental recovery operations in the Morello Valley, purification systems were made of filtering bags anchored to the river banks filled with large boulders and gabbioni. The ecological restoration of the mouth of the river Acquicella in the city of Catania is derived from environmental compensation measures imposed by the national VIA Commission for harbor expansion work. Efforts have been made to restore nature, to the recovery of dunes, and to the purification of river waters, fertilization systems, laguning, and reverse tree-lined bundles have been used for purification.

The SIAM plant in Modica (Ragusa) for the treatment of civil, industrial and first-time waste water treatment plants includes 3 systems: 1) industrial water discharged for fertigation; 2) the first rainwater treated with a bathtub divided into four and subsequent subirrigations; 3) civil wastewater with double tank phytodepuration, which allows to work in series and in parallel with two different hydrophytes (Phragmites australis e Typha latifolia). This allows to operate at "total evaporation" allowing savings on waste disposal. In addition, a perimeter safety band was developed with Cyperus papyrus for the treatment of first rainwater for total evapotraspiration and biomass production. For 2018, design modifications have already been made (two bio-ponds and one plantation with fruit trees) in order to improve the profit of the plant.

4. Materials and method

4.1. Morello Valley – Villarosa (Enna)

Morello Valley Oasis (Fig. 1a-b) aims at the enjoyable recovery of a natural landscape, perfectly integrated with the agricultural one, in an area where archaeological and mining elements emerge with a lakeside landscape (Lake Villarosa to retrain for good ecological quality, though eutrophic and artificialized by the water drain) with historic infrastructures, such as a bridge of the municipal aqueduct, a symbol of dependence from outside territories. The project has interested the tributary valleys, in a disadvantaged area, only crossed by discharges, purified experimentally directly into the riverbed. Also spondal and anti-erosive works of bioengineering, elements for the enjoyment (footpaths, huts for birdwatching, billboards etc.), maintenance, communication, research and wildlife management (Floating islands, spondal brushes, sleepers, nests, etc.). The Morello Valley, located between 2 streams, needed better socio-economic development, polluted and degraded for the dry valleys Vanella and Mastrosilvestro, with the right bank of the Morello River, still unsuitable by cementitious practices, on which large, geologically unstable and tormented areas lie. Urban tributary waves, in a disadvantaged area, offended by insufficiently cleaned drains, have been the subject of phytoremediation, trying to take advantage of the opportunity to rebuild and reclaim two valleys.

The phytoremediation was achieved by the creation of purifying filter systems (with filter bags anchored to the sides filled with large boulders and gabions), facilitating the lagging behind and the taking root of hydrophilic species, including rhizomes transplants, having phytoremediation functions (Fig.2a-b). The system, consolidating the shores,
implements basic technical functionality (purification) and at the same time it associates a naturalistic functionality (tending to the Minimum Vital Outflow), aesthetic-landscaping functionality and socio-economic functionality. It thus constitutes a multifunctional ecological corridor. For the works realized, the city of Villarosa obtained the City Prize for the Green 2009.

Fig. 1. Morello Valley – Villarosa (Enna)

Fig. 2. Filter ecosystem: (a) Filtering bags, (b) lagoons

4.2. Restoration of the mouth of the river Acquicella

This work collects in a small space various concepts of soil bioengineering, natural river hydraulics, phytoremediation with filter and dunes restoration ecosystems. The ecological restoration of the mouth of the river Acquicella in the city of Catania is derived from environmental compensation measures imposed by the national EIA Commission for harbor expansion work. The river crosses the city with full hydraulic on the coast, already busy with intense traffic with a roundabout in the mouth, waste and untreated wastewater.
The main object of natural re-opening of the river’s mouth was associated with the reconstruction of the totally disappeared dunes. In addition to the aforementioned interventions, a treatment of phytoremediation lagoon and inversed arborated buffer bands had to be added. Both systems avoid percolation of the sands and seeds of native species, thus finding better conditions for self-propagation and naturalistic recovery. In addition to purification, it should be considered that considerable solid transport of soil particles has forced to carry out heavy cleaning of the riverbed and waste removal. In other words, the job management tools, in addition to the activity purifying include at least four cleaning operations in a year.

Dune restoration (Fig. 3) has already produced propagation of *Ammophila arenaria*, the most important species for retaining the sand, and significant heights of the sandy mud. The restoration of the mouth of the river Acquicella is practically a real best practice for the city of Catania which needs some reflections. The first, as far as the river is concerned, is a phytoremediation activity that should affect the entire waterway and therefore the basin settlements. The second, with regard to the dunes, should be in line with the sandy coast to the mouth of the River Simeto. The outstanding launches of *Caretta caretta* of 2015 show that, despite intense bathing, species of natural interest (herons, geranium, sultan chicken) can resume populations. The ecological restoration of the mouth of the river Acquicella can thus be triggered by an ecological urban corridor (along the river) and coastal (up to the Simeto River Reserve). And if that were to happen the inevitable management costs for maintaining the natural environment they would not be frustrated by an inconsistent management practice with the effort of the Port Authority. For the landscaping objectives and conservation of the intervention realized, the hypothesis of a naturalistic fruition of the area is now practicable (Fig. 4).

![Fig. 3. Dunal restoration at the mouth of the river Acquicella](image)

![Fig. 4. Phytoremediation, lagoon and buffer bands hanging at the river Acquicella](image)
4.3. Water treatment plants SIAM in Modica (Ragusa)

4.3.1. Phytoremediation waste water

The plant is sub-surface horizontal flow (H-SFS) with upstream degreaser and organic pit type Imhoff (primary sedimentation treatment) and downstream a watertight reservoir with protection functions for accumulation of any spills (malfunction or intense rain). The passive protection of the groundwater from the wastewater is indispensable because it is from it that it comes to the bottling. It was made with 2 mm-long HDPE membrane and clay for 60 cm, rolled and compacted. The basin allows for the purification limits imposed even during extraordinary maintenance work (for example restoring the original permeability characteristics of the coverage medium) (Table 1).

Table 1. Characteristics of purified (coming out of phytoremediation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measure unit</th>
<th>Value</th>
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<tbody>
<tr>
<td>Users</td>
<td>a.e.</td>
<td>21</td>
</tr>
<tr>
<td>Water flow</td>
<td>L/day</td>
<td>2950</td>
</tr>
<tr>
<td>BOD₅</td>
<td>mg/L O₂</td>
<td>20</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L O₂</td>
<td>120</td>
</tr>
<tr>
<td>Total solids in suspension</td>
<td>mg/L</td>
<td>60</td>
</tr>
</tbody>
</table>

The plant species (Phragmites australis and Typha latifolia) used were chosen for: good growth capacity under different climatic conditions and good resistance to high organic loads; the remarkable development of the radical and rhizomatic apparatus providing a wide contact surface with the waste; the large inner vessels for oxygen transport of the airborne parts to the roots and the rhizomes (submerged parts). The filtration medium, originally designed as gravelly has been put into operation with a calcarenic tout venant (Granulometry 10-16 mm.) because a porous material like this allows bacterial activities inside it useful to purification processes similar to those of "infiltration and percolation" systems.

4.3.2. Realization of the plant and improvements

4.3.2.1. Civil waste water treatment

The main improvement concerns recirculation upstream of purified waste (generally used in the percolators to increase the depurative efficiency) so as to compensate for the over-sized surface imposed. Thus, because of the modest wears, a total evaporation can be achieved which can dispose of all the effluent coming out of the plant. Altogether, the savings to date are around €12,000/year. Similarly, the perimeter security band of Cyperus papyrus var. Nana allows you to treat in part and dispose of (by evaporation) the washing waters while, saving on the management costs. In addition, the phytoremediation bed was divided into 2 units, separated by the realization of a wall without altering the overall surface and hence the sizing. A single bed of phytoremediation would have been complicated from a management point of view, because in times of extraordinary maintenance, such as the restoration of the original medium coverage permeability characteristics, the entire plant should have been interrupted. In normal operating conditions, the beds operate in parallel, however, given the presence of the lifting system downstream of the 2 beds (already for recirculation of sewage) is possible to predict its operation in series (Fig. 5a-b). Serial use is carried out in conditions of low flow rates of influent liquids, thus achieving even higher purification yields.
4.3.2.2. Water treatment of first rain

Given the process of the discharge of pollutants produced by the meteoric waters, they have a high content of contaminants, which are treated with a tank divided into 4 (of accumulation and gravity sedimentation of the organic and inert fraction) submerged in series and subsequent subirrigation.

4.3.3. Improvements (Next step 2018)

Two bio-ponds for the disposal of industrial waters (heavily contaminated by pH, phosphorus, nitrogen and sodium), and first rainwater are planned to equalize the flow rates and characteristics of contaminants. As for rainwater that can not be classified as rain water (“of second rain”), is advisable to convey them directly into the lagoon so that they can undergo pre-treatment before entering the soil. It is feared that, in view of the high movement of means which affects the yards of the establishment, also the second rainwater carries contaminants that can have an impact on the environment. In addition, in order to reduce the bleeding costs, it is expected to achieve lifting at the end of the tank, which conveys the waters to a bio-pond anaerobic, for the release of gaseous nitrogen by total evaporation.

The choice of species will be strictly bound to the surrounding agrarian and natural landscape. For this reason, it is appropriate to add to the rainwater treatment system, a small lagoon basin (free-fresh water) [40mq*1m] as a treatment for refining such waters. With regard to industrial waters of 120 m³/week and currently destined for fertigation, it is proposed an anaerobic bio-pond with a belt of Cyperus papyrus, and to follow a plantation, with fruit species, such as (nuts, maltose, olive trees, etc.) to be fed with water from bio-pond. The use of fertigation with water from purifying treatments on olives for canteen, takes on particular experimental value as a fruit quality analysis is undertaken to ascertain any changes in organoleptic and health characteristics. Any excess water can be used for fertigation. For further protection of the territory, we propose the realization of a “roof hedge”, a vegetative barrier at different heights of the truck and deep depths, with the aim of intercepting any contaminants present in the first and second rain waters and immersed in the soil by sub-irrigation (Fig. 6).

For new tanks (bio-ponds, lagoons, etc.) waterproofing will with bentonite geocomposites, as a more versatile solution, with less impact as natural materials (clay) and a maximum guarantee. Finally, the addition of the lagoon basin and the vegetative barrier will further limit the contamination of the soil associated with such waters (Figs. 7-8).

5. Results and discussion

The results obtained with the phytoremediation interventions in the riverbed lead to the conclusion that it is possible to retrain degraded environments with systems that go both to consolidate the shores and to restore an ecological balance in the areas under examination. The adoption of industrial ecology elements allows agricultural landscaping also for
industrial plants and savings on waste disposal. The combined interaction between the different purification needs (waste water, rainwater and industrial water) eases to resolve emergency situations and also allows management savings. The exploitation of vegetated perimeter band, as well as improve the landscape, allows further purifying safety, total evapotranspiration and biomass production.

Fig. 6. Roof hedge

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<thead>
<tr>
<th>PHYTODEPURATION AND NATURAL TREATMENTS FOR RESTORATION ECOLOGY</th>
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<tr>
<td>CURRENT STATUS – 2017</td>
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<tr>
<td>I STEP – GOALS:</td>
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<tr>
<td>1. DEPURATION</td>
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<tr>
<td>2. REDUCTION OF DISPOSAL COSTS</td>
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![Diagram](image)

1: Industrial water volume = 120 m³/week. Part of it is directed to the papyrus pond
2: Part of rainwater is directed in the papyrus pond
3: Oversized pool that can collect both rainwater and industrial water

Fig 7. Current state (2017) of water treatment plants in Modica (Ragusa)
The perimeter security band with Papyrus also allows handling and dispensing (for total evapotranspiration and biomass production) the waters of first rain, saving on management costs. In addition, the industrial waters are in part used for phytoremediation of civil waste water treatment that is able to absorb contaminants (pH, P, N and Na) mainly derived from nitric acid and sodium hydroxide.

Experience has led to a great response from Papyrus and Phragmites, while Thypa needs time-controlled spills within the establishment and an equalization and pre-treatment with upstream plants. With the downstream plantation of edible species (mulberries, walnuts, olive trees etc.) fed for fertigation with purified waters, a search is made to verify the quality of the fruit and to evaluate assumptions of use for feeding. A further evolution of the criteria of industrial ecology is to go beyond purification alone. It is possible to move to a much wider concept from the point of view of resources and energy production. In fact, through the phytoremediation by aquatic macrophytes, after treating the stabilized organic fraction, there is a production of biomass that can be used for the production of green composted fertilizer for the production of technosoils. Technosoils, anthropogenic soils derived from the mixture of several components, can be used in soil bioengineering works and environmental restoration of dredged areas (Fig. 9).

6. Conclusions

Phytoremediation in the riverbed allows retraining degraded environments. The adoption of industrial ecology can also create landscapes for industrial plants and waste savings. Combined interaction between the different purification needs (wastewater, rainwater and industrial water) brings further benefits.
Experience shows on the one hand the phytoremediation of contaminants, on the other the use of several species including some edible. All this makes it possible to anticipate the possibility of exploitation even for the energy purposes of biomass produced, or, the production of green composted fertilizer for the production of technosols for the works of soil bioengineering and for the environmental restoration of degraded areas.

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**References**


