Ecological Indicators 84 (2018) 244–253

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Combined statistical techniques for the water quality analysis of a natural wetland and evaluation of the potential implementation of a FWS for the area restoration: the Torre Flavia case study, Italy

Gianpaolo Sabia[a,*], Luigi Petta[a], Filippo Moretti[b], Riccardo Ceccarelli[c]

[a] Italian National Agency for New Technologies, Energy and Sustainable Economic Development, ENEA, Waste and Wastewaters Laboratory USER-R4R, Via Martiri di Monte Sole 4, 40129, BO, Italy

[b] Italian National Agency for New Technologies, Energy and Sustainable Economic Development, ENEA, Agrifood Sustainability, Quality and Safety Laboratory BIOAG-SOQUAS, Via Anguillarese 301, 00123 Santa Maria di Galeria (RM) Italy

[c] Via di Monte Pendola 3-00061 Anguillara S., RM, Italy

ARTICLE INFO

Keywords:
Chemometric analysis
Modelling
Pollutant removal
Process modelling
Water quality index
Area restoration

ABSTRACT

The paper focussed on the analysis of the environmental status of a natural wetland and the assessment of potential solutions to preserve the area, the related ecosystem services and natural equilibria. Data on water quality parameters and on climatic conditions were derived from a yearly monitoring campaign and web sources respectively. Chemometric techniques and a water quality index (WQI) were applied in order to assemble the obtained information and define an exhaustive overview of the wetland status. Data processing allowed to estimate the system water balance and to evaluate spatial and temporal variations of water quality. A water deficit as well as a major wetland sensitivity respect to pollution loads was verified during the warmer season (June-September). Local criticalities and environmental pressure were assessed and possible solutions to properly manage and restore the natural system were evaluated. The use of the wetland as a free water system (FWS) receiving treated wastewater from a local UWWTP was considered in the view of using local resources and restoring the water balance, avoiding environmental impacts and excessive management costs. Wetland auto-depurative capacity was assessed through common empirical plug flow models which revealed the ammonia nitrogen loads during the winter season as the limiting conditions. By deriving the maximum capacity of the system to receive pollutants, the study showed how water balance restorations as well as environmental and economic savings are achievable. Additional benefits have to be associated to ecosystem services and the possibility for recreational, cultural and educational activities.

1. Introduction

Wetlands are highly productive and biologically rich ecosystems (Carter et al., 1994; Chapman et al., 1996) able to guarantee a variety of ecosystem services, such as water purification, flood regulation, erosion control, coastline protection, and sediment and nutrient transport (Gosselink and Turner, 1978; de Groot et al., 2006; Keddy, 2000). Moreover, wetlands create aesthetically appealing spaces and wildlife habitats offering recreational, educational, and research opportunities (Fleming-Singer and Horne, 2006; Ghermandi et al., 2010; de Groot et al., 2006).

The hydrologic and water-quality functions of these systems depend on many factors such as climatic conditions, dominant vegetal species, soil/sediment characteristics, water regime and chemistry. The high rate of biological activity and the synergies among soil/sediment, plants and microorganisms promote processes able to remove pollutants from point and non-points source (i.e. runoff water, tributary effluents, agricultural activities etc.). Pollutants are removed through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption, assimilation by the plant tissue and microbial transformations (Kumar and Zhao, 2011). The water purification capability has pushed the development of artificial engineered systems, named constructed wetlands (CWs) which have been successfully implemented for secondary and tertiary treatment of domestic, agricultural wastewater, mine drainage and storm water (Gearheart, 1992; Mandi et al., 1998; Knight et al., 2000). These systems offer many advantages such as simplicity of design and low costs of installation, operation, and maintenance. Where suitable land is

* Corresponding author.
E-mail address: gianpaolo.sabia@enea.it (G. Sabia).

http://dx.doi.org/10.1016/j.ecolind.2017.08.065
Received 14 June 2017; Received in revised form 26 August 2017; Accepted 29 August 2017
Available online 25 September 2017
1470-160X/

Fig. 1. Aerial view of Torre Flavia site.

available at a reasonable cost, CWs have shown to be effective alternatives respect to conventional wastewater treatment plants (Langergraber et al., 2009; Siracusa and La Rosa, 2006). The basic engineered system developed for constructed wetlands refers to free water surface systems (FWS), similar to natural marsh with water surface directly exposed to the atmosphere and emerging plants. FWS closely resemble natural wetlands in appearance because they contain free floating or rooted plants. Effectively, most natural wetlands are considerable as FWS and have been directly used for the wastewater treatment.

Several successful experiences have proved the efficiency of CWs in buffering and reducing pollutant loadings. Wu et al. (2017) have investigated long-term performance of a full-scale integrated CW system to treat sanitary and industrial mixed wastewater demonstrating the validity of such approach for advanced wastewater treatment to meet the more stringent discharge requirements. Kotti et al. (2010) have evaluated the wastewater treatment performance of FWS by operating 5 pilot-scale units assembled combining different plant species and substrate materials. The authors have verified the BOD_5, COD, TKN, ammonia (NH_4-N), *ortho*-phosphate (PO_4-P) and total phosphorus (TP) removal efficiency. Siracusa and La Rosa (2006) have carried out an emergency analysis on the monetary savings and benefits in the view of coupling a traditional municipal wastewater treatment plant with a FWS in a Sicilian town. They have found that the proposed design implied economical savings and the reduction of the pressures on local environment with the option of treated water reuse.

The maintenance of the wetland hydrologic and water-quality functions is of basilar importance to preserve these valuable areas and the related ecosystem services. In order to properly manage and preserve wetland areas from degradative phenomena and imbalances, a full knowledge of natural equilibria and the supporting processes is required. Site-specific environmental issues and criticalities need to be deeply addressed so as to establish suitable actions for wetland safeguarding: where human activities or natural processes are impairing system functionalities, countermeasures have to be taken in order to tackle the disturbances and restore their natural resistance and resilience to external factor pressures.

This paper is focussed on the analysis of the hydrologic and environmental status of a natural wetland located in Lazio region (Italy, Torre Flavia wetland area) assessing the potential benefits on the ecosystem services in terms of environmental impacts and economic benefits given by the implementation of a FWS system as a possible solution to preserve and manage the natural area. The survey regarded a preliminary site analysis aimed at investigating site-specific environmental conditions such as climate, water balance and quality, potential source of contaminations and local water sources. A water quality index WQI (Kannel et al., 2007; Kumar and Dua, 2009; Pesce and Wunderlin, 2000) and chemometric analysis (Kannel et al., 2007) were combined for the evaluation of the wetland water quality over space and time. Common plug flow kinetic models were employed to estimate the wetland auto-depurative capacity (Kadlec et al., 1996; Wetzel, 2000; Kadlec, 1997) in the view of using a local UWWTP treated effluent as a water input to regulate the wetland water balance. The study demonstrated the validity of the proposed approach in preserving the wetland natural equilibria and achieve environmental and economic savings.

2. Materials and methods

2.1. Historical background and general site characteristics

Torre Flavia wetland belongs to a natural site located in Lazio region, Italy (41°57.6′N, 12°2.9′ E), which represents the residual part of a wide system of marshland and salty ponds extended, at the beginning of the last century, for hundreds of hectares. In the last decades, erosion processes and land reclamations, mainly due to agriculture activities and expanding urbanisation, considerably reduced its extension. At present, the wetland has a 16 ha extension including a short strip of coastal land between sea and Cerveteri and Ladispoli municipalities (Fig. 1). The flooded area was declared as “Natural monument of Torre Flavia” by Regional Decree (DPGR. n. 613/97) and was furtherly classified as Site of Community Importance (SIC IT 6030020) belonging to Natura 2000 network.

The wetland can be subdivided in three main zones: a) the vegetated zone accounting for about the 62% of the total area which is characterized by a stable growth of the common reed (*Phragmites australis*) with a water depth of 40–60 cm and a plant density higher than 200 species stems per m^2; b) the central area, about 24% of the total area, where water depth increases up to 80–100 cm and the stems of *Phragmites australis* are less dense while floating species appear; c) the free water surfaces represented by the channel network, with a water depth varying from 100 to 140 cm, accounting for about the 14% of the total area. As a whole, the wet area is characterized by a series of small depressions in which water flows due to sea level rising, climate events contribution and inland canals runoffs. The natural process of wet-dry alternating conditions subjected the natural area to a progressive burying process due to the deposition of plant debris and organic residues. Up to 2007, appropriate managing actions executed by some local fish farming operators allowed an effective wetland water level control, thus avoiding the filling risks. After the closure of the productive activities (i.e. aquaculture), the controlling Authority (Rome Province) decided to keep the area flooded all year long instead of allowing the natural rotation of dry and wet periods in relation to seasons. This choice caused a modification of fish and bird biodiversity, facilitating the presence of permanent freshwater species. Currently, seeking to regulate the wetland water level, the controlling Authority provides a regular freshwater supply from the Tiber River which is ensured by the local Reclamation Consortium with a cost of about 6.000 euro/y.

2.2. Data acquisition and elaborations

Climate daily values (i.e., rainfall, humidity, temperature, potential