Reuse of wastewater, treated by phytoremediation, for the irrigation of the Botanical Garden "le jardin Landon" (Biskra, Algeria). Sustainable solution for the preservation of a material heritage site

Reutilización de aguas residuales, tratadas por fitopurificación, para el riego del Jardín Botánico "le jardin Landon" (Biskra, Algeria). Solución sostenible para la preservación de un sitio de patrimonio material

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ABSTRACT

The green spaces of the city of Biskra (Algeria) resist the arid climate of the summer season and therefore suffer from water scarcity caused mainly by evaporation and transpiration of the plants. To remedy this problem, the study suggests to reuse the sewage for irrigation after being purified, using constructed wetlands with improved capacity by phytoremediation. As an example of a sustainable solution, it is proposed to apply this technique to the botanical garden of the city of Biskra (Algeria), «le jardin Landon». The design of a Constructed Wetland system is proposed. The Landon Garden was created in 1870 by Count Landon of Longueville, decorated with a variety of flora from the tropics and the Equatorial countries. It is currently considered as national material heritage.

KEYWORDS: Sustainable solution, Phytoremediation, Constructed wetlands, Irrigation, Material heritage.

RESUMEN

Los espacios verdes de la ciudad de Biskra resisten el clima árido de la temporada de verano y, por lo tanto, sufren de escasez de agua, causada principalmente por la evaporación y transpiración de las plantas. Para remediar este problema, el estudio sugiere reutilizar las aguas residuales para el riego después de ser purificadas, utilizando humedales construidos con capacidad mejorada por fitorremediación. Como ejemplo de una solución sostenible, se propone aplicar esta técnica al jardín botánico de la ciudad de Biskra (Algeria), «le jardin Landon». Se propone el diseño de un sistema de humedales construidos. El Landon Garden fue creado en 1870 por el conde Landon de Longueville, decorado con una variedad de flora de los trópicos y los países ecuatoriales. Actualmente se considera patrimonio material nacional.

PALABRAS CLAVE: Solución sostenible, Fitorremediación, Humedales construidos, Irrigación, Patrimonio material.

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Reaproveitamento de águas residuais, tratadas por fitopurificação, para a irrigação do jardim botânico "o jardim Landon" (Biskra, Argélia). Solução sustentável para preservação de patrimônio material

RESUMO

Os espaços verdes da cidade de Biskra (Argélia) resistem ao clima árido do verão e por isso sofrem com a escassez de água causada principalmente pela evaporação e transpiração das plantas. Para remediar esse problema, o estudo sugere o reaproveitamento do esgoto para irrigação após purificação, utilizando alagados construídos com capacidade melhorada por fitorremediação. Como exemplo de solução sustentável, propõe-se a aplicação desta técnica ao jardim botânico da cidade de Biskra (Argélia) «le jardin Landon». O projeto de um sistema de Wetland Construído é proposto. O Jardim Landon foi criado em 1870 pelo conde Landon de Longueville, decorado com uma variedade de flora dos trópicos e dos países equatoriais. Atualmente é considerado patrimônio material nacional.

PALAVRAS-CHAVE: Solução sustentável, Fitorremediação, Alagados construídos, Irrigação, Patrimônio material.

Réutilisation des eaux usées, traitées par phytopurification, pour l'irrigation du jardin botanique «le jardin Landon» (Biskra, Algérie). Solution durable pour la préservation d'un site patrimonial matériel

RÉSUMÉ

Les espaces verts de la ville de Biskra (Algérie) résistent au climat aride de la saison estivale et souffrent donc d'une pénurie d'eau causée principalement par l'évaporation et la transpiration des plantes. Pour remédier à ce problème, l'étude propose de réutiliser les eaux usées pour l'irrigation après avoir été épurées, en utilisant des zones humides construites avec une capacité améliorée par phytoremédiation. A titre d'exemple de solution durable, il est proposé d'appliquer cette technique au jardin botanique de la ville de Biskra (Algérie), «le jardin Landon». La conception d'un système de zones humides construites est proposée. Le jardin Landon a été créé en 1870 par le comte Landon de Longueville, décoré d'une flore variée des tropiques et des pays équatoriaux. Il est actuellement considéré comme patrimoine matériel national.

MOTS-CLÉS: Solution durable, Phytoremédiation, Zones humides construites, Irrigation, Patrimoine matériel.

Riutilizzo delle acque reflue, trattate mediante fitopurificazione, per l'irrigazione del giardino botanico "Giardino Landon" (Biskra, Algeria). Soluzione sostenibile per la conservazione di un sito del patrimonio materiale

SOMMARIO

Gli spazi verdi della città di Biskra (Algeria) resistono al clima arido della stagione estiva e soffrono quindi della scarsità d'acqua causata principalmente dall'evaporazione e dalla traspirazione delle piante. Per ovviare a questo problema, lo studio suggerisce di riutilizzare le acque reflue per l'irrigazione dopo essere state purificate, utilizzando zone umide costruite con capacità migliorata mediante fitodepurazione. Come esempio di una soluzione sostenibile, si propone di applicare questa tecnica al giardino botanico della città di Biskra (Algeria) «le jardin Landon». Viene proposto il progetto di un sistema Constructed Wetland. Il giardino Landon è stato creato nel 1870 dal conte Landon de Longueville, decorato con una varietà di flora dei tropici e dei paesi equatoriali. Attualmente è considerato patrimonio materiale nazionale.

PAROLE CHIAVE: Soluzione sostenibile, Fitorisanamento, Zone umide costruite, Irrigazione, Patrimonio materiale.

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Introduction

Thanks to physic-chemical reactions and biological interactions undertaken by microorganisms and plants in aquatic systems, a natural process of self-depuration takes place within them. This ecological feature can be used as an alternative form of wastewater treatment. The latter is defined by the term phytoremediation. In addition, constructed wetlands are ecosystems that are artificially created to treat a wide range of wastewater, including municipal, industrial and agricultural effluents[1]. Among the types of constructed wetlands that use phytoremediation, one can find: the sub-superficial flow system SSFS, in which the basin is partially submerged in water to be purified; the superficial flow system SFS, in which the basin is permanently submerged in water to be purified, and the floating system FS, where the plants are supported by suitable floating structures, with free roots across the water flow to be purified. This water purification system is also used for the design of bio-pools[2].

The system of phytoremediation with sub-surface flow is considered to be the most developed. It is used in waterproof basins filled with a permeable and inert material (such as gravel), in which plants are planted. It can use horizontal or vertical flow. The act of purifying is carried out mainly by microorganisms that live in symbiosis with the plants. These microorganisms, either in aerobic or anaerobic form, sustain a series of chemical and physical reactions allowing the degradation of pollutants[3].The efficiency of microorganisms in the process of purification is mainly related to the degree of aeration and the level of organic matter load[4].

Particularly proliferating in wet environments, bacteria feed on waste materials and transform them into harmless molecules. The degradation of organic matter and denitrification of nitrogen in the root region of the plants, where treatment takes place, is due to microorganisms. The emission of oxygen by the roots of the macrophytes creates oxidized zones around the roots. Most of the organic wastewater decomposes into carbon dioxide[5]. Root tissues are probably niches more welcoming for microorganisms than inert mineral substrates. Several plants have been used in the process of phytoremediation, but the most widely used species are those that support excess water conditions developing along riversides, such as: *Phragmites australis,* species of the genera *Typha* (*latifolia, angustifolia, domingensis, orientalis and glauca*) and *Scirpus* (e.g. *lacustris, validus, californicus* and *acutus*)[6].

The technique of sewage treatment by plants appeared in Western Europe based on research by Seidel that began in the 1960's and by Kickuth in the late 1970's[7]. The successful use of this technology for the treatment of different types of domestic and urban effluents has been described by several researchers[8]. This technology is also in high demand in Central America, Eastern Europe and Asia. Artificial marshes were introduced in Quebec from the early 1990's. In Spain, the Center for New Water Technologies (CENTA) was created in 1994, focusing mainly on the technological support of wastewater treatment in small rural communities[9].

Many studies have focused on the efficiency of this system to remove heavy metals contained in wastewater. Seghairi et al. (2014) studied the potential of *Tamarix* to purify industrial wastewater with concentrations of copper. The authors highlighted the potential of the genera *Tamarix* to purify the effluent of the industrial zone of Biskra (Algeria), with a reduction of copper of 75.96 % for a residence time of 15 days[10]. Gorelova & Frontasyeva (2017) investigated the possibility of using woody plants for biomonitoring and phytoremediation of environment anthropogenic pollution with heavy metals[11]. Other researchers[12] focused on the removal of pharmaceuticals by phytoremediation. They investigated the removal of 12 pharmaceuticals in a full scale constructed wetland processing hospital wastewaters in Eastern Ukraine. Their study observed an increase of removal efficiency for *androstenedione*, *carbamazepine*, *caffeine*, *diclofenac*, *estrone*, *ibuprofen*, *paracetamol*, *propranolol* and *triclosan*.

As an example of a sustainable development solution, this paper aims to study the reuse of wastewater, purified by phytoremediation, for the irrigation of the botanical garden "Le jardin Landon" of the city of Biskra (Algeria). Two main advantages are expected through the use of this technique: the first one is to purify the wastewater of the neighbourhood, and the second one is to ensure the permanent irrigation of the green areas while integrating with the landscape.

1. Hammer, 1989, 856.
2. Lajo & Luther, 2007, 234.
3. Brix & Arias, 2005.
4. Adrados et al., 2014; Butterwortha et al., 2016.
5. Brix, 1987.

6. Vymazal, 2011.
7. EPA, 1993, 2-1.
8. EPA, 1999; Vymazal, 2010; Healy, 2007; Brix & Arias, 2005.
9. García et al., 2013, 1.
10. Seghairi et al., 2014.
11. Gorelova & Frontasyeva, 2017.
12. Vystavna et al., 2017.

Brief overview of the Landon garden ("Le jardin Landon")

The Landon garden (Figure 1) was created in 1872 by Count Landon of Longueville.

This garden, called Garden of Allah by the English novelist Robert Hitchens, is a haven of peace and a place of daydreams for the artists and writers who visited this place, such as *Karl Marx*, *André Gide*, *Francis James*, etc.

The Landon garden or Villa Benevent encompasses a large number of tropical species, high-priced trees as well as a set of palm trees, which are ornamental ones for the most part. In fact, many plant species that are implanted there have been imported from all over the world and acclimated to the climate of the region. It occupies an area of around 4 hectares. At the beginning of its creation, it contained more than 200 species, but currently it remains about 54 species. The water requirements of the plants, as well as their irrigation regime, are evaluated based on the phenomenon of evapotranspiration.

Figure 1. The Landon garden

Source: Google maps.

Material and method

Based on mathematical models designed with data of existing stations, researchers have developed several possibilities for sizing constructed wetlands. We will discuss in the following the equations adopted for this purpose.

As mentioned above, the process of wastewater treatment, mediated by phytoremediation, is carried out according to a set of physic-chemical and biological reactions performed by micro-organisms and plants on the pollutants present in these waters.

According to the bibliography, there are different possibilities for the sizing of constructed wetlands. The sizing is based essentially on the elimination of a maximum of polluting load, to obtain at the end effluents of optimal quality. Mathematical models have been established, based on the kinetics of elimination of major pollutants, using semi-empirical coefficients, with data from existing stations.

For the size of the horizontal sub-surface flow basin, three parameters were considered for the biological elimination of pollutants: BOD5, ammoniacal nitrogen and nitric nitrogen[13]. The proposed equations are as follows:

$$ln\left(C_i \mid C_o\right) = tK_T \qquad (1)$$

$$\text{with } t = A_s ny / Q \qquad (2)$$

$$\text{and } K_T = K_R \theta_R^{(T_w - T_R)} \qquad (3)$$

C_i: concentration of pollution at the entrance of the station (after any possible primary treatment (in mg/l).

C_o: fixed effluent concentration, according to the desired purification objective (in mg/l).

t: hydraulic retention time (in days).

K_T: kinetic constant at temperature T_w (in days^{-1}).

A_s: filtering basin surface (m³).

n: medium porosity (in %).

y: depth in the middle of the wetland (m).

Q: average daily hydraulic flow (in m³/days).

T_W: reference temperature in the wet zone (in °C).

T_R: reference temperature (in °C).

The sizing of horizontal filtering basin is based on the determination of the surface area as follows[14]:

$$A_s = Q \, ln\left(C_i \mid C_o\right) / \left(ynK \mid K_T\right) \qquad (4)$$

13. Reed, Middlebrooks & Crites, 1988; Reed & Brown, 1995.
14. Reed, Middlebrooks & Crites, 1988; Reed & Brown, 1995.

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The authors propose the values of Table 1 for the considered coefficients, according to the degree of pollution of the discharge considered.

The shape of a horizontal sub-surface flow system can be rectangular, while the slope of the bottom of the bed can vary from 1 to 5 %. The transverse area can be calculated using the Darcy relation, as follows:

$$Q = AK[dh/dL] \qquad (5)$$

A (m²) = l h: The cross-sectional area of the basin with h the water height and l the basin width.
Q (m³/d): average daily discharge rate.
K (m/d): hydraulic conductivity of the saturated material.
Dh/dL: hydraulic gradient corresponding to the slope of the water line to be obtained in operation from the inlet level filter surface to about 10 cm from the total height of the outlet (in m/m).
The ratio L / l must vary in the range 0.5 to 3[15].

Furthermore, for the design of vertical basins, the oxygen demand is calculated on the basis of 1 kg of O_2 per kg of BOD_5 to be removed, and of 4.3 kg of O_2 per kg of NH_3 to be oxidized[16]. The vertical bed is dimensioned by considering a surface aeration coefficient of Ka = 30 grams of O_2 per m² of surface area per day, and its height is taken equal to 0.9 m. The area obtained is increased by 25 %:

$$A = 1.25[DO/Ka] \qquad (6)$$
$$DO = C_{BOD5} \, Q$$

where:
DO = oxygen demand (in Kg / d).
Ka = surface aeration coefficient.
C_{BOD5} = Concentration in Biochemical Oxygen Demand (BOD) in 5 days (in Kg/m³).
Q = average flow of wastewater.

Sizing of the constructed wetlands

The sizing of the constructed wetlands is mainly based on the concentration of pollutants present in wastewater. Different processing steps are considered, namely: pretreatment, finishing filter and flow filtering basins.

For raw water, pretreatment consists of: screening, deoiling, grit removal and decanting. The decanting system can be a simple settling basin, a decanter / digester, an all-water septic tank or an Imhoff basin.

A septic tank is used for the collection, partial liquefaction of pollutants contained in wastewater and the retention of solids and floating waste. It receives all domestic wastewater. All the water in the pit must clear the effluent. It must also liquefy these retained materials by decanting and flotation.

Table 1. Reference parameters for the horizontal flow filtering basin

Parameter	BOD5	NH4-N	NO3-N	FC
		$1 < T_W < 10$		
T_R	20	10	10	20
C residue	6	0.2	0.2	-
K_R	1.104	K10	1.0	2.6
θ	1.06	1.15	1.15	1.15
		$T_W > 10$		
T_R	20	20	20	20
C residue	6	0.2	0.2	-
K_R	1.104	K_{NH}	1.0	-
θ	1.06	1.048	1.15	1.19

Source: Reed & Brown, 1995.

[15.] EPA, 1999.
[16.] Bulc, 2006.

For the macrophyte planted system, pretreatment requires an all-water septic tank for the purpose of decanting the coarse material with a retention time of 0.5 days.

- The useful volume of the pit, for an inlet flow rate Q = 105.15 l/s, is V = Q, ts = 52.58 m³. With: V = useful volume of the pit (in m³), ts = residence time (in days) and Q = average volume flow rate (in m³/d).
- For a depth of h = 1.5 m, the surface will be 35.05 m² (2x17 m²) with a length L = 6 m and a width l = 3 m.

Related to the second step, a box (or sewer manhole) with finishing filters (Figure 2) is placed immediately downstream of the all-water tank in order to trap all the fine particles that can be contained in the water coming from the septic tank. This device is generally used only in the case of a horizontal flow system.

Related to physic-chemical characteristics of district wastewater, the choice of the planted filter with horizontal or vertical flow is made according to the quantity of Biochemical Oxygen Demand (BOD5) or ammoniacal nitrogen NH_4^+ contained in wastewater. Wastewater analyzes show that both BOD5 (95mg/l) and NH_4^+ (25.68mg/l) are at the limit of poor quality. However, 12 % of the amount of NH_4^+ can be removed at the pretreatment stage.

Lastly, with regard to the concentrations of BOD (95 mg/l), COD (121.6 mg/l) and DO (0.8 kg/d), we opted for a hybrid system, composed of vertical water flow filtering basins followed by a set of horizontal water flow filtering basins (Table 2). The use of vertical filtering system allows a gain in surface area as well.

The water flow filtering basins will be buried, for ease of handling, gain of energy and integration into the landscape.

In order to ensure an integration of the purification system on the medium of the Landon Garden, a form has been adopted for the filtration basins that adapts to the flora of the environment (Figure 3).

Figure 2. Photographs showing the finishing filter, consisting of a filter holder and a sponge, before and after use
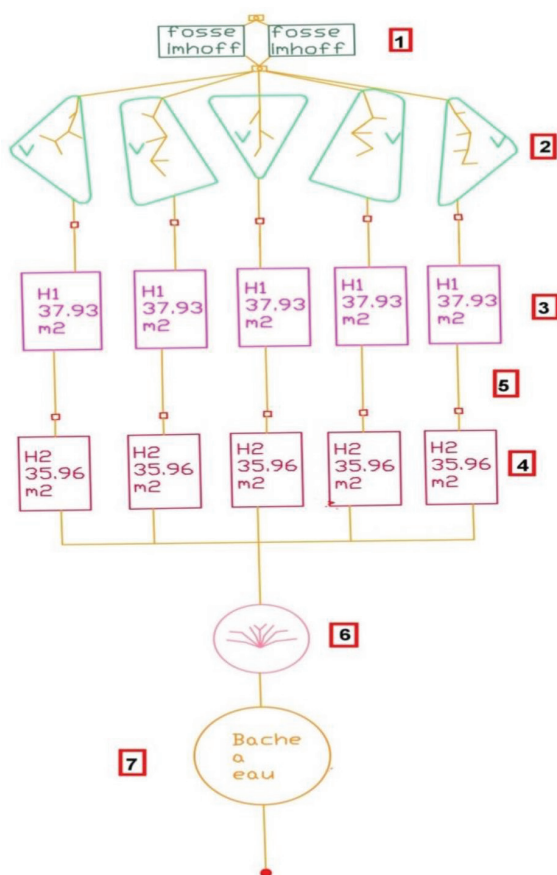

Source: authors.

Table 2. Sizing of the water flow filtering basins

	5 vertical water flow filtering basins (1st row)	5 Horizontal water flow filtering basins (2nd row)	5 Horizontal water flow filtering basins (3rd row)
Surface (m²)	33.33 m² (1basin)	37.93 m² (1basin)	35.96 m² (1basin)
Retention time (day)	12 hours (1basin)	12 hours (1basin)	12 hours (1basin)
Length (m)	8.33 m (1 basin)	10.02 m (1 basin)	10.02 m (1 basin)
Width (m)	4 m (1 basin)	3.79 m (1 basin)	3.59 m (1 basin)

Source: authors' own elaboration.

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Figure 3. Simplified diagram of phyto-purification installation.

Source: authors' own elaboration.

Conclusion

As an example of a sustainable development solution, the study aimed to design a constructed wetland system in a botanical garden of the city of Biskra (Algeria). The wastewater purified by phytoremediation will be used for the irrigation of a variety of tropical trees, existing in this garden since 1870.

A design of the wastewater circuit is carried out, namely: pretreatment, purification, accumulation and distribution. A septic tank was selected as a pretreatment process. Considering the concentrations of BOD and COD, a hybrid system was adopted, composed of vertical and horizontal water flow filtering basins. A form that adapts to the flora of the environment has been adopted for the filtration basins, in order to ensure an integration of the purification system on the medium of the Garden.

This system is mainly designed to purify the wastewaters of the district as well as to ensure the permanent irrigation of the green areas that suffer from water shortage, especially in summer season.

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