Possibility of eliminating organic pollutants from urban wastewater by filter planted with Calotropisprocera in an arid climate (case of the Djanet region)

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Abstract:Collected by the sewerage network, the wastewater contains many polluting elements, coming from the population, commercial, industrial and agricultural activities.These waters are collected and discharged into the natural environment and pollute it. Hence the need to transport them before discharge to a treatment plant to undergo several treatment phases. The objective of this study is to highlight the purification performance of the "Sodom apple tree" which is a very common shrub in the region of Djanet and Illizi in Algeria.As material, we used small buckets filled with sand with a gravel substrate.We sowed seeds that we let grow a few weeks.The water supply is under a horizontal flow regime under-ground. The urban wastewater used is preceded by preliminary treatment.The water obtained after purification is collected using a tap in a container placed under the seal. The comparison between the inlet and the outlet waters showed that the presence of the Sodom apple tree contributes to reducing their pollutant parameters with significant rates: 85.49% for Chemical Oxygen Demand, 87,52% for Biological Oxygen Demand, 81% for Suspended Matter , 70% for Nitrite, 64.70% for Nitrate and 69% for Phosphore. The majority of parameters at the filter output comply with Algerian irrigation standards

Keywords: wastewater;Calotropisprocera; Reuse;Purification;Irrigation;Djanet.

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1. Introduction

The Djanet region is experiencing urban development and agricultural dynamics, which increases the demand for water from the various user sectors, particularly agriculture. This results in significant discharges of wastewater, which without prior treatment constitutes an environmental and health threat. Wastewater is characterized by physicochemical and bacteriological parameters, which make it possible to determine its possible origin and to know the importance of its polluting load. They are collected and discharged into the natural environment.[1]

Before they are released into the natural environment and degrade it, it is imperative that they comply with established standards to protect the receiving environment from pollution.

Phyto-purification is a naturalprocess of filtration or depollution of wastewater, by plants. This combination of soil plants and micro-organismsmakesit possible to clean up wastewater by bacteriahidden in the root system of plants which are calledpurifiers.The purifying potential of plants was demonstrated by Seidel in 1946 to treat industrial effluents containing chemicals such as phenols, chlorophenols and heavy metals.Since then, this new extensive technology has been successfully exploited by several authors[2,3,4] for the treatment of several types of effluents..

The use of plantedfilters for wastewatertreatmentisincreasing all over the world. For example, there are about 8,000 installations in the United States, and about 5,000 in Germany [5]. In general, that planted systems are more efficient than those that are not planted [6, 7]. And have several advantages. They are less expensive to build and operate, can be built on the wastewater production site, require little mechanical equipment and are less sensitive to variations in pollutant loads. [4]

Thesesystems have thereforebecomeincreasinglypopular and currentlythey are the subject of intensive research, mainly in Europe, in order to optimizetheir basic design parameters[8,9]

The objective of thisstudyis to evaluate the effectiveness of filtersplantedwithCalotropisprocera for the elimination of pollutantsfromurbanwastewater in the city of Djanet located in an arid zone (southernAlgeria) and to be able to valorizethispurified water for irrigation.

2. Methodology

2.1 Study zone

The city of Djanet is located in the extreme south-east of Algeria, it is distant about 2200 km from the capital Algiers [10].It is located in the region of Tassilin'Ajjer with coordinates of 24 ° 33 'north latitude, and 9 ° 29' east longitude and an altitude of 1094 m. The Djanet region is bounded by the Libyan border to the east, the Nigerian border to the south, by the wilaya of Tamanrasset to the north, the commune of Bordj El Haoes and by the commune of Illizi to the southwest.(Figure1).

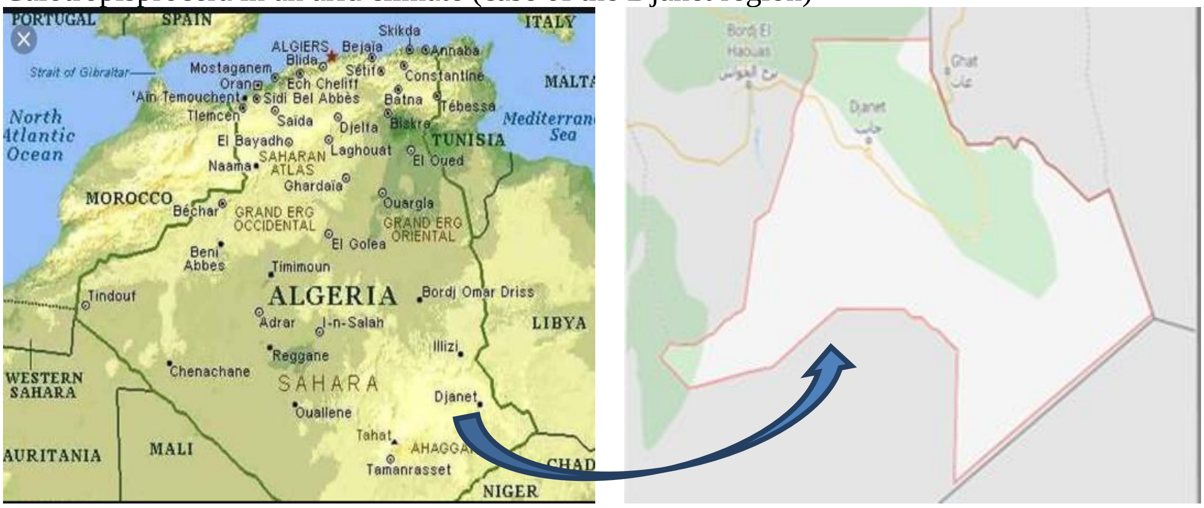

Figure 1. Location of Djanet [11]

The town of Djanet covers an area of around 56,103 km. It has a population of 1,200 to 1,500 inhabitants[12]

This region is characterized by a considerable agricultural area of 4,591 ha and of which only 477 ha are exploited [13]

The Tassilin'Ajjer, the Hoggar and their annexes are the only regions among the Saharan areas which receive precipitation slightly above normal and more regular. [14].In Djanet, the annual average is 19.2mm [15]

The temperatures in Djanet are regular. They range from 2.4 ° C in January the coldest month to 38.9 ° C in June the warmest month. They are rarely below 0 ° C or above 40 ° C.

Winds are more frequent during the day and especially during the hot period. The average wind speed varies from 0.9 m / s in December to 2.8 m / s in July. [16] Sandstorms are quite rare: they are around 9.1 days per year on average for an average duration of 13 hours. They come from the south, and their maximum frequency is in April and May [16]

Very low air humidity. The annual average is 29%. The wettest month is May with 39%.[16]

2.2.**Calotropisprocera**

The plant usedis The "Sodomappletree", scientificname"Calotropisprocera", a verycommonshrubaridregions of Africa[17] and the Middle East, especially in the wadisIn Algeria, itis in abundancebetween Illizi and Djanet.It is a Sahelian species that prefers sandy soils[18]

Its height varies between 2 and 6 meters,the trunk generally simple, without lower branches, covered with a cracked greyish brown bark. All parts of the plant exude white latex[19, 20] The leaves are large and can reach up to 30 centimeters. The hermaphrodite flowers, pentameters, grouped in cymes with the appearance of umbels. The corolla has 5 generally white lobes with purple or purple pointed ends. Pollinationtakes place thanks to insects[21]. The fruit isovoidwiththick pulp, green to yellowish in color, up to 10 cm or more. The interior is fibrous. Fiber envelops many seeds. This shrub is found on degraded soils, especially old crops and pastures gained by the sand. It isdroughtresistant and salttolerant[22]. Calotropisprocera is used as a coagulant in cheese making by herders, especially in Benin and Nigeria[23].According to [24], the macerated roots of Calotropisprocera can be used for the treatment of water polluted with Zn(II). .(Figure 2a).

Figure 2a. Calotropisprocera in Djanet
(Photography OULHACI D)

Figure 2b. Grainesplantées
(Photography OULHACI D)

To allow good development of the plant, the plantedseeds are first irrigatedwithdrinking water. As soon as the first leavesappear (figure 2b), sothat the plant adapts to used water, we graduallyadd the latter to the irrigation water (10, 20, ...100%).Wethenwash the plant, and place it in cylindrical tanks (40cm in diameter) filled to adepth of 80 cm of washedgravel.

The supply of water subjected to a vertical flow regime underground is made exclusively by urban wastewater and this with a regular frequency of once a week. The water of percolation obtained after purification is recovered by means of a tap in a container placed under each basin.

The experimenttook place from the beginning of autumn to the end of summerwiththree (3) repetitions. The urban wastewater used is preceded by a preliminary treatment (screening).

All the analyzes and measures necessary to quantify organic pollutants are standardized according to Algerian standards according to the techniques recommended by [25] . Given the organic charge of the wastewater and its fairly rapid biodegradation, the physicochemical parameters likely to be altered such as the temperature, salinity and electrical conductivity of the water, were measured in situ using a multi-parameter analyzer and the pH using a pH meter.

The other parameters were carried out in the laboratory, taking care to comply beforehand with all the rules for preserving samples during transport.

BOD5 was measured with a MF120 / ISO5813 manometer, COD with a HACH, DR / 890 Colorimeter and dissolved oxygen with an Oximeter.The suspended Matter were measured by the filtration method and the mineral elements (NH4 +, NO2 – and PO4-3) with a Visible UV Spectrophotometer, JENWAY 6310

3. Results and Discussion

The results of the analyzes of the physico-chemical parameters for the comparison before and after purification are

3.1 Suspended Matter

The suspended matter represent all the mineral and organic particles contained in the wastewater. Generally, theirpresence in wastewateris not a disadvantage for the reuse of the latter and caneven help soilfertility.[26]

In engineered wetlands, suspended matter is removed primarily by physical processes such as sedimentation and filtration [27] followed by aerobic or anaerobic microbial degradation within the substrate [28].These processes are obtained when wastewater passes through the system at a low speed due to the presence of vegetation and substrate [27]. Water treated with Calotropisprocera undergoes a significant reduction in concentrations from (120÷280) mg / l to (19÷69) mg / l, with 81,06% elimination rate.(Figure 3).

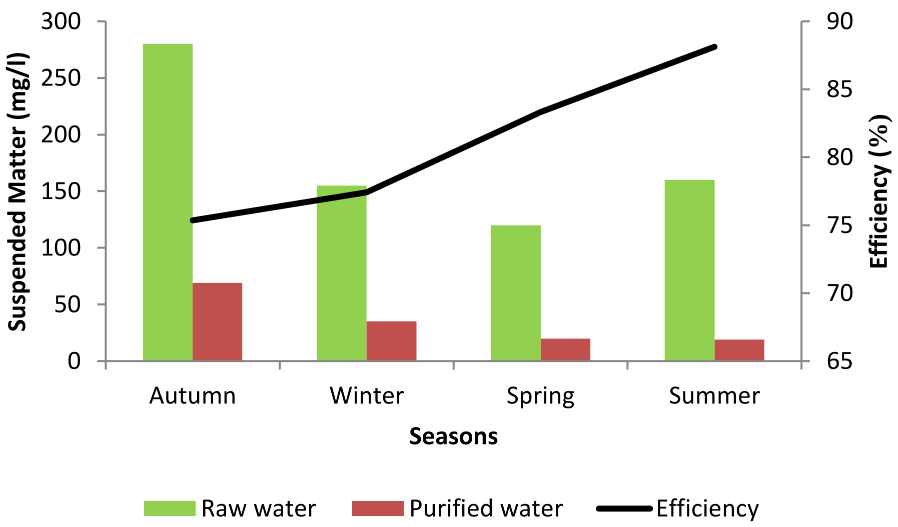

Figure 3. Seasonal variations of Suspended Matter at the inlet and outlet of the filter

It is noted that the concentration at the outlet is barely higher than 30 mg / l considered as limiting concentration of water intended for irrigation according to Algerian standards[29]. The low concentration of suspendedmatterobtained in the treated water provesthat the conditions required for good sedimentation and filtration have been achieved.

The overall clearance averages are similar to thosefound by otherauthors. For example, the resultsobtained by [27, 30] are between 81 and 95%.

3.2 Biological Oxygen Demand (BOD)

BOD_5 translates the amount of molecular oxygen used by the microorganisms during a 5days incubation period at 20 ° C and in the dark(oxidation of biodegradable organic matter by bacteria) to decompose the dissolved or suspended organic matter contained in one liter of water[31, 32, 33].

The studied waters underwent a reduction of (320÷250) mg O_2 / l to (27÷42)mg O_2/l with 87,52%elimination rate The average value is barely higher than the Algerian norms (BOD_5) is <30 mg O_2 / l).[29]..(Figure 4).

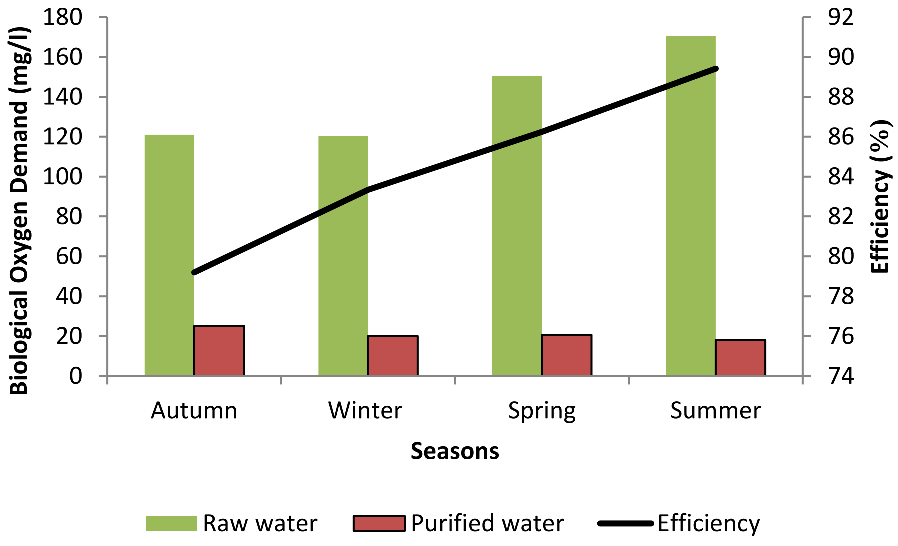

Figure 4. Seasonal variations of DOB at the inlet and outlet of the filter

3.3 Chemical Oxygen Demand

The COD allows assessing the concentration of organic or inorganic matter, dissolved or suspended in water, through the amount of oxygen necessary for their total chemical oxidation. The studied waters underwent a reduction of (670÷589) mg O_2 / l to (88÷95) mg O_2/l .Like the results of BOD, the averageoverallefficiency of COD isveryhigh (more than 85.49%) (Figure 5). The filterplantedwithCalotropisprocerawas effective in the treatment of usedwastewater. Theseresults are in agreement withthose of severalauthors [34, 9,35]. According to Algerian release standards[29]., purified water intended for irrigation must have COD less than 90 mg / l, and Calotropisprocera-treated water has a COD average value of 90,75 mg / l. These waters are therefore in the norms.

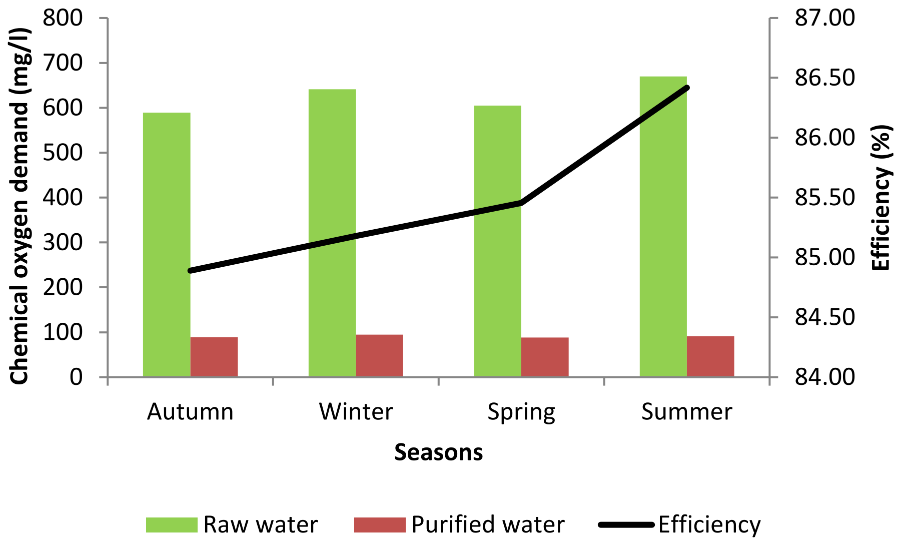

Figure 5. Seasonal variations of DOB at the inlet and outlet of the filter

The COD/BOD5 ratio value makesit possible to roughlyestimate the biodegradability of organicmatter in a given effluent. The COD/BOD5 ratios varybetween 2 and 2.3. Sincethese ratios are lessthan 2.5, itcanbeconcludedthatitispredominantlydomesticrawwastewater and easilybiodegradable[36, 37, 38] .

3.4 **Nitrate**

Nitrates are the final oxidizedform of nitrogen. Theirpresence in the water attests to good recovery in the event of organic pollution. Humanactivityisunmistakable as soon as concentrations exceeding 12 mg/l are observed[39]. The values recordedfrom the figure 6reveal a reductionbetweenraw water s (4.7÷7.6) mg/l and purified water (1.9÷2.1)mg/l ,with 64.70% elimination rate. Nitrate removalissatisfactory in the filterplantedwithCalotropisprocerawhichisprobably due, in part, to good nitrification; resultconfirmed by the work of [34, 35].

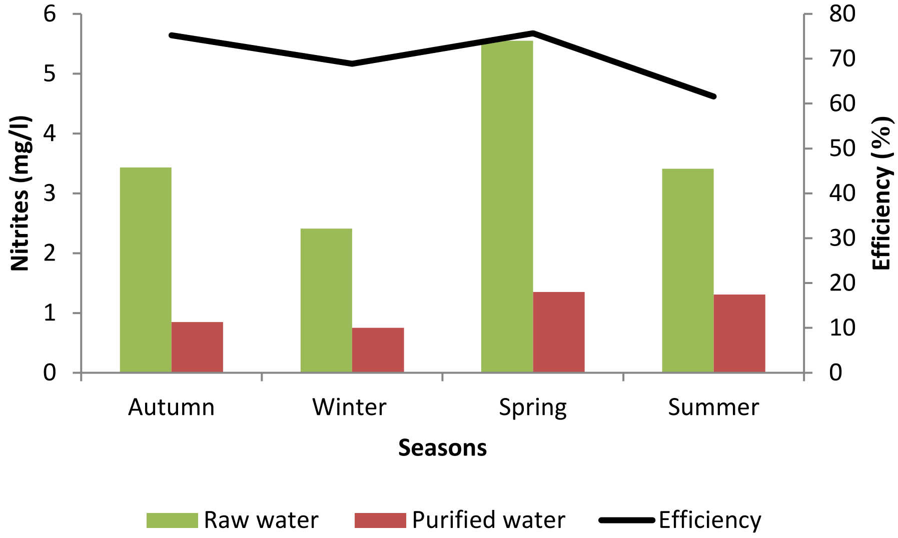

Figure 6. Seasonal variations of Nitrate at the inlet and outlet of the filter

3.5 Nitrite

Nitrites are the least oxygenated and least stable form of nitrogencompounds. Theirpresenceis due either to the bacterialoxidation of ammonia or to the reduction of nitrates [32].The values recorded reveal a significant reduction in Nitrites between raw water (5,5÷2.41)mg/l) and purified water (0.75÷1.35)mg/l , with 70% elimination rate.. This value is acceptable for irrigation according to Algerian release standards (1 mg / l) [29]..The significantelimination of (NO_2^-) in the planted filter is due to the presence of plants which have the property of absorbing oxygen from the air, it is transmitted by the leaves then the stems to the roots and rhizomes [40].(Figure 7).

This oxygenactivates the bacteriathatconvert nitrite (NO_2^-) to nitrate (NO_3^-) in the root zone. This processiscalled nitrification.

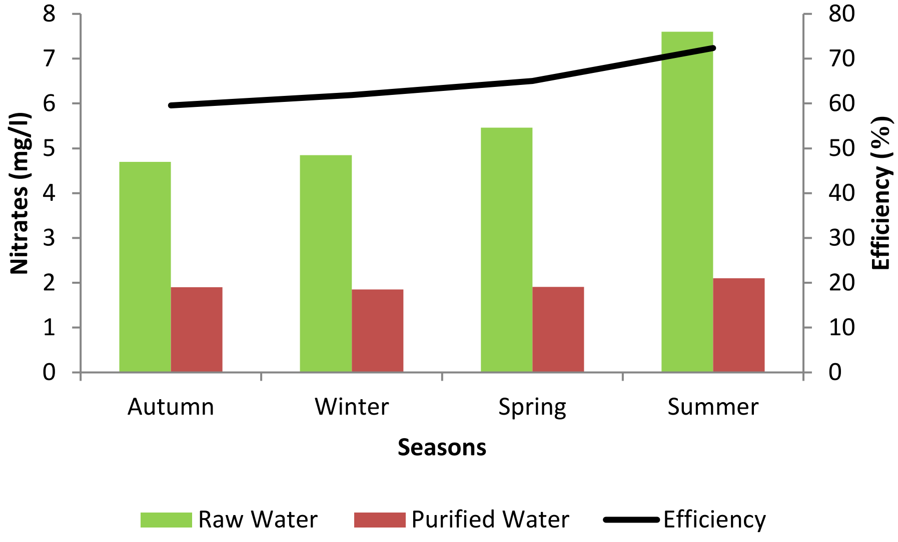

Figure 7. Seasonal variations of Nitrite at the inlet and outlet of the filter

3.6 Phosphore

Most organicphosphoruscomesfromdetergents, wasteproductsfromproteinmetabolism and itselimination as phosphates in the urine by humans[41].The values recordedfrom the figure 8 reveal a reductionbetweenraw water (6.4÷9.5) and purified water (1.9÷3.4) with 69% elimination rate..(Figure 8). This lowering of phosphorus concentration in the purified water iscaused by the adsorption of the substrate and the absorption by the plant for itsphysiological[42, 43].

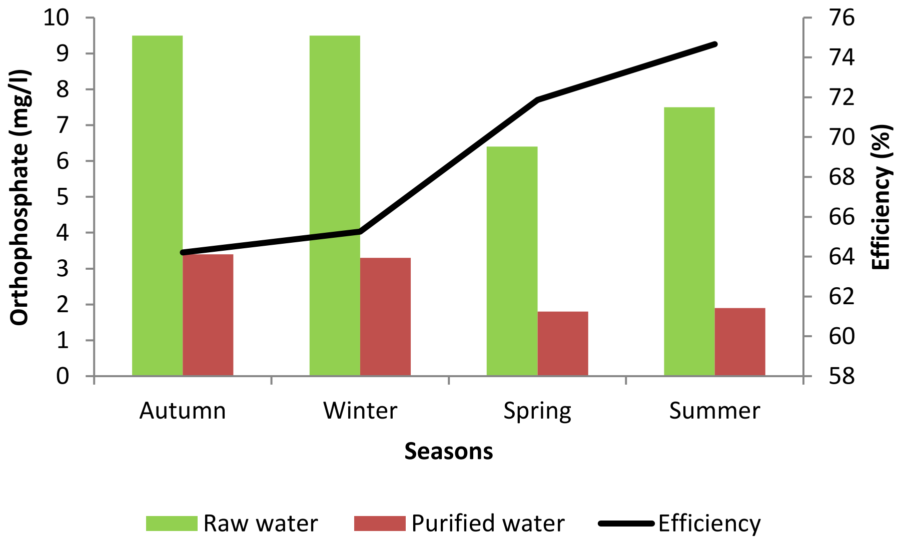

Figure 8. Seasonal variations of Phosphore at the inlet and outlet of the filter

This type of system isvery effective not only for the reduction of BOD, COD and SS, but also for nitrification [44, 45] becausethey are humidified by intermittencyallowing air to fill the pores of the substrate in the bed[46] and improving, in thisway, oxygentransferfrom the atmosphere to the system.It provides crystal clear water.

4. Conclusion

The objective of thisstudyis the evaluation of the different physico-chemicalqualityparameters of the purified water of the Djanet region by the apple tree of Sodom and the comparison with the Algerian standards of irrigation. The monitoring of the purification performance of the filterplantedwithappletree Sodome shows that the latter ensures a significantelimination of the organic load, i.e. 95% for MES, 81% COD and 84% for BOD, as well as 82% for NO-2 and 85 % for NO-3 and for phosphate. The dissolved oxygen content is 6.5 mg/l at the outlet, much higher than at the inlet (0.78).

The rate of pollutant removal in the planted filter appears to be dependent on climate and retention time. The results obtained revealed that the yield increased significantly during the vegetative period.The growth of plants and the development of the root system cause better oxygenation. Thanks to light radiation, plants produce oxygen which allows respiration and the development of bacterial colonies. Plants fix colonies of bacteria on the base of their stems, which improves the performance of the scavenger organisms. And absorb by their roots part of the mineral salts, nitrates and phosphates – resulting from the decomposition of the organic matter present in the Wastewater. The majority of the parameters of the purified water comply with the Algerian irrigation guidelines.

This processisvery simple, inexpensive, completelyecological. It iswithoutvisual, sound or olfactory nuisance for local residents and canevenbeveryaestheticbecauseitfitsperfectlyinto the landscape. This leads to the conclusion that purification withCalotropisprocerais effective and thatwastewatercanrepresent a renewable water resource to beexploited in irrigation. But thisreuse must of course be optimal, by adapting the irrigation systems to the quality of the water used and the cropsresistant to this water. This reuseis an economical option for Djanet, whichsuffersgreatlyfrom water shortage and environmentalproblems.

References

1. Baumont S, Camard J-P, Lefranc A, Franconie A, 2004- Réutilisation des eaux usées: risques sanitaires et faisabilité en Île-de-France. Rapport ORS, 9-32p.
2. Finlayson M, Chick A., 1983-Testing the potential of aquatic plants to treat abattoir effluent. Wat. Res., 17,(4), 415-422
3. BiddlestoneA.J,.Job G.D. 1991- .Treatment of dairy farm wastewaters in engineered reed bed systems. Process Biochemistry, 26 265- 268.

4. Brix H., 1993 - Macrophyte-mediated oxygen transfer in wetlands: Transport mechanisms and rates. Reprint from Constructed wetlands for water quality lmprovement (G. A. Moshiri, editor).Lewis Publishers .Boca Raton Ann Arbor. London, Tokyo,.
5. Vymazal, J., 2005a- Horizontal sub-surface flow and hybrid constructed wetland systems for wastewater treatment. Ecol. Eng. 25, 478–490.
6. Radoux M, Kemps D,1988 - Epurationcomparée des eauxuséesdomestiques par trois plantations hélophytiques et par un lagunage à macrophytes sous un mêmeclimattempéré. ActaOecologiaApplic., 9, (1),25-38.
7. Wathugala A.G., Suzuki T.,Kurihara Y. 1987- Removal of nitrogen, phosphorus and COD fromwastewaterusingsand filtration system withPhragmithesaustralis. Wat 21, (10), 1217-1224.
8. Wand, H., Vacca, G., Kuschk, P., Krüger, M., et Kästner, M., 2007- Removal of bacteria by filtration in planted and non-plantedsandcolumns. Water Res. 41, 159–167.
9. Brix, H., Arias, C. A. 2005-The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New danish guidelines. Ecological Engineering, 25, p.491-500.
10. Dubief J., 1999- L'Ajjer Sahara central, Ed. Karthala, Paris, 709 p Brid A. et Benhabirche A., 2004 - Carrefour du patrimoine matériel et immatérieldu monde touarg, Mém. Ing. Architecture, EPAU. El Harrach. Alger. 85p.
11. Ayoub A , 2000- Enthomofaune de trois stations cultivées à Djanet. Mémoire Ing. Agro., Inst. Nat. Agro., El Harrach, 94 p
12. Ozenda P., 2003- Flore et végétation du Sahara. Ed. CNRS, Paris, 662 p
13. Beddiaf Z, 2006- Caractérisation agro-morphologique de quelques populations locales de Vignaunguiculata (L.) Walp.dans la région de Djanet. Mém.Ing.Agro., Inst. Nat. Agro. El Harrach, 105 p
14. Abdoun F., 2002- Etude de la dynamiquespatio-temporelle des populations de Cupressusdupersiana A. Canus au Tassilin'Ajjer. Thèse de Doctorat, Université de droit, d'Economieet des Sciences d'Aix- Marseille III, Faculté des Sciences et Techniques de Saint-Jérôme, Marseille, 171 p.
15. Chopra I. C., Abrol B. K. et Handa K. L., 1960 - Les plantes médicinale des régions arides. UNESCO, Rennes, France, 99 p.
16. Arbonnier .;2002- Arbres, Arbustes et lianes des zones sèches d"Afrique de l"ouest, CIRAD, 2ème édition, 160-165
17. Dewan S., Saugraula H., Kumar VL., 2000- Preliminarystudies on the analgesicactivity of latexofCalotropisprocera.JournalofEthnopharmacology73 (1-2), 307-311
18. Benchelah A.C., Bouziane H., et Maka M., 2006-Arbres et arbustes du Sahara. Voyages au cœur de leurs usages. Ibis Press. Paris.239 p.

19. Von Mayell H.J; 1990.- Arbres et arbustes du Sahel: leurs caractéristiqueset leurs utilisations. Scientifics Books, 191-192
20. Benchelah A.C., Bouziane H., Maka M. et Ouahes C., 2011-Fleurs du Sahara. Voyages ethnobotanique avec les Touaregs du Tassili. Ibis Press Paris. 255 p.
21. Dossou J., Hounzangbe A. S. et Soule H., 2006 - Production et transformation du lait frais en fromage peulh au bénin, Guide de bonnes pratiques 30 p.
22. Zenasni M A., Meroufel B., Amrouche A., Naar F. Z., Merzouka F., Difallah F Z., 2012 - Phytoremédiation de Zn (II) par les racines de Calotropisprocera (Bechar, Algérie). Science LibEditions Mersenne : Vol. 4, N ° 120304, 16 p.
23. Rodier J, Legube B, Merlet N, Brunet R, 2009- L'analyse de l'eau : eaux naturelles, eaux résiduaires, eaux de mer. 9eme Edition 1008-1043p.
24. F.A.O 2003; Food and Agriculture Organisation; - L'Irrigation avec des eaux usées traitées : Manuel d'utilisation, 73 p.
25. Cristina S.C. Calheiros, Vânia S. Bessa, Raquel B.R. Mesquita, Brix H, António O.S.S. Rangel, Paula M.L. Castro (2015):Constructedwetlandwitha polyculture of ornamental plants for wastewatertreatmentat a rural tourismfacility. Ecological Engineering Volume 79, June 2015,
26. Zurita, F., De Anda, J., et Belmont, M.A., 2006- Performance of laboratory-scalewetlandsplantedwith tropical ornamental plants to treatdomesticwastewater. Water Qual. Res. J. Can. 41, 410–417.
27. JORA ;2012. journal officiel de la république algérienne du 25 Chaâbane 1433 correspondant au 15juillet 2012 : Arreté interministériel du 8 Safar 1433 correspondant au 2 Janvier 2012 fixant les spécifications des eaux usées épurées à des fins agricoles..
28. Bensmina-Mimeche L, Benameur N, Bouziane T et DebabecheM . ;2010- Utilisation de filtres plantés de l'espèce Typha latofilia pour le traitement des eaux usées urbaines de la ville de Biskra, Algérie. Tunisian Journal of Medicinal Plants and Natural Products www.TJMPNP.comTJMPNP 4, 58-61.
29. Tradat, M.H. Chimie Des Eaux; 1991- Première, le Griffon D'argile Inc.: Sainte-Foy, QC, Canada, 537p.
30. Resjeck.F.,2002- Analyse des eaux, aspects réglementaires et techniques. Edition : SCERENE. p. 166-198
31. Clair, N.S.; Perry, L.M.; Gene, F.P. 2003- Chemistry for Environmental Engineering and Science, 5th ed.; McGraw-Hill Companies Inc.: New York, NY, USA,; 233p.
32. Vymazal,J.,2007- Removal of nutrients in various types of constructedwetland. Sci. Total Environ. 380, 48–65.
33. Bensmina-Mimeche, L. Debabeche, M. Seghairi, N. Benameur. N. 2013- Capacité de filtres plantés de macrophytes pour l'épuration des eaux usées dans le climat semi-aride. Courrier de savoir N°17.

34. Metcalf and Eddy, Inc. 1991- Wastewater Engineering: Treatment, Disposal, and Reuse. 3rd Edition, McGraw-Hill, Inc., Singapore.
35. Ashley, R.; Hvitved-Jacobsen, T.; Krajewski, J.L.B. 1999- Quo vadis sewer process modeling? Water Sci. Technol. , 39, 9–22.
36. Klimiuk, E.; Łebkowska, M. Biotechnologia w OchronieŚrodowiska; WydawnictwoNaukowe PWN: Warszawa, Poland, 2008. [Google Scholar]
37. Bremond R. et Perrodon C. (1979). Paramètres de la qualité des eaux, 2ème édition. Ministère de l'Environnement et du Cadre de Vie. 259p
38. Brix, H. 1994-."Function of Macrophytes in ConstructedWetlands." Wat.Sci. Tech. 29(4): pp 71-78
39. N'diaye A. D., OuldSid'ahmedOuldKankou M., Sarr A. D. et Lo B. 2011- Contribution de l'analyse en composantes principales à l'evaluation de la couleur des effluents de la ville de Nouakchott, Larhyss Journal, ISSN 1112-3680, n° 09, pp. 139-147..
40. Drizo A ., Comeau Y ., Forget C., Chapuis R.P., 2002- Phosphorus saturation potential : A parameter for estimating the longevity of constructedwetlandsystems . Env .Sci . Tech. 36, pp 4642-4648.
41. Molle P. 2003. Filtres plantés de roseaux : limites hydraulique et rétention du phosphore. Thèse de doctorat, Université Montpellier II, p 217
42. Arias, C.A., Brix, H., et Marti, E., 2005-. Recycling of treated effluents enhances removal of total nitrogen in vertical flow constructed wetlands. J. Environ. Sci. Health 40, p.1431–1443
43. Prochaska, C.A., Zouboulis, A.I., et Eskridge, K.M., 2007- Performance of pilot-scale vertical-flow constructedwetlands, as affected by season; substrate, hydraulicload and frequency of application of simulateurbansewage. ECOL. ENG. 31.p57–66.
44. Prochaska C.A. and A.I. Zouboulis 2006- Removal of phosphate by pilot vertical-flow constructedwetlandsusing a mixture of sand and dolomite as substrate. Ecol. Eng., 26, 293-303.
45. Hachem C., Abdessamed M.,Samia B.,Samir K. Mechanical performances and durability analysis of sand concrete modified with nano-silica. NeuroQuantology 21(7):420-431.DOI: 10.48047/nq.2023.21.7.nq23039
46. Samia B., Hachem C., Didi F.Thermal Performance and Environmental Analysis of a Brick Based on Traditional Gypsum Plaster Reinforced with Date Palm fibres. International Journal of Membrane Science and Technology 10(05):151-163. DOI: 10.15379/ijmst.v10i5.2445
47. Hachem C., et al. Performance Improvement of Dune Sand Asphalt Concrete With Two Different Types of Fillers. Tobacco Regulatory Science 9(1):2104-2114
48. Samia B., et al. Experimental characterization of design performance of sand-grained asphalt concrete for worn pavement. Tobacco Regulatory Science 9(1):2090-2103
49. Hachem C., et al. Contribution to study of influence of different additions on thermo-mechanical properties of Adobe based on El Hadjira clay . Journal of Critical Reviews 08(01):1005-1015 . DOI: 10.31838/jcr.08.01.112

50. Samir K. et al .The effect of using recycled materials (sand and fine powder) from demolished concrete waste in alluvial sand mortar. Research on Engineering Structures a DOI: 10.17515/resm2023.820ma0712
51. Hachem C., et al. Thermal Study of Traditional Gypsum Plaster Brick Prototypes: The Case of Ouargla. Selected Scientific Papers - Journal of Civil Engineering 17(1):1-13 DOI: 10.2478/sspjce-2022-0019
52. Abdessalam M. et al . Contribution to the study of the thermo mechanical properties of compressed earth brick (CEB) produced by waste red bricks. Journal of Critical Reviews 9(ISSUE 05, 2022):12DOI: 10.31838/jcr.09.05.16
53. Abdessalam M. et al . Influence of temperature on the prototypes made by earth bricks (raw and fired) reinforced with date palm fibers intended for constructions in the Saharan zone (Ouargla). Journal of Critical Reviews 08(02):1087-1101
54. Hachem C., et al. Thermal Study of Earth Bricks Reinforced by Date palm Fibers. Energy Procedia 74:919-925. DOI: 10.1016/j.egypro.2015.07.827
55. Hachem C., et al. Study of the Characteristics of Mud Bricks Reinforced with Plastic Polymer. International Journal of Advanced Research in Engineering & Technology 11(12):767-778. DOI: 10.34218/IJARET.11.12.2020.076