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Multi-Criteria Analysis to Choose the Suitable Technique of the Treatment of Rural Wastewater

Amal Kabbour[1]*, Latifa Mouhir[1], Mustapha El Hafidi[2], Laila Saafadi[1]

[1]Laboratory of Process Engineering & Environment, Faculty of Sciences & Techniques, Hassan II University of Casablanca, Mohammedia, Morocco
[2]National Office of Electricity and Potable Water (ONEE), Rabat, Morocco

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Abstract

In order to find a solution to the problem of liquid sanitation in small communities, especially in the rural area, which suffers from groundwater contamination, source of drinking water, due to the infiltration of raw sewage from uncontrolled latrines. Therefore, the aim of this work was to develop treatment scenarios in the Bouregreg pilot site, which are likely to mitigate the degradation of environmental quality and could serve as a model for the rural environment. Taking this into account, the objectives of the used approach in this work were: i) to develop a treatment processes database by carrying out a benchmarking of the main domestic wastewaters technical. ii) to define a multicriteria matrix of different treatments such as design, dimensioning, and the financial feasibility of each treatment through statistical analysis to select the appropriate variant for small communities. Indeed, vertical flow constructed wetland was selected as a suitable and sustainable solution for rural environment. Moreover, a pilot experimental setup was constructed to evaluate the potential of vetiveria zizanioides that was chosen for treating wastewater generated in campus wastewater outlet of ONEE-RABAT. Various water quality parameters such as Biological oxygen demand (BOD), Chemical oxygen demand (COD), and Solids matters (SM) were performed on the treated water and the overall results demonstrated that the applied system was able to remove 80 to 99 % of BOD, 71 to 90 % of COD, 93 to 99 % of SM and the parameters values of treated water are within the permissible limits for domestic (current legislation of morocco).

Keywords: Biological oxygen demand (BOD), Chemical oxygen demand (COD), Liquid sanitation, Multi-criteria, Solids matters (SM), Rural area, Vertical flow constructed wetland, Wastewater

1 Introduction

Water is a material that affects all aspects of human activities. As result, growing population and increasingly consumptive lifestyles leading to water scarcity. Wastewater treatment burning issue nowadays is considered a key solution when it comes to addressing the future issue of water shortage.

In recent year, Morocco has been putting efforts to invest the required fund in urban sanitation sector, is still one of the best way for the country's socio-economic development which was precondition for lasting peace. Morocco developed a national sanitation program (PNA), which is able to upgrade the sanitation sector in the horizon 2020, to achieve an 80% connection rate to urban public sewerage systems; to date we have been able to achieve this objective due to decades of experience and the close cooperation with professionals in both public and private sector. It also aims to reduce pollution to at least 60% of the effluent's pollutant load; currently the pollution reduction rate is 45% thanks to the treatment facilities (129 wastewater treatment plants).

Considering if the urban sector have benefited of some advance in the beginning of the action plan due to the flexibility of the decision makers, the rural population has not been left out, is also taken of the socio-economic aspect of these major development. On the other hand, in addition to investment, there are many obstacles to the development of rural sanitation such as: the unequal distribution of habitat and water resources, the lack of an institutional framework, and the culture of the rural population, which gives greater importance to income-generating activities. For this reason, the rural environment is really lagging behind; raw wastewater continues to be discharged into the receiving environment without previous treatment, which influence negatively on the environment and human health by contaminating groundwater. Considerable efforts are still needed to adjust this critical situation by improving rural health, environmental conditions and achieving equity between rural and urban areas. Conventional processes are expensive, inefficient; they use a huge amounts of chemicals products and could emit greenhouse gases, consequently not adapted to the rural environment due to the complexity of technical filed according to the national sanitation program (PNA). Therefore, the present trend is tending towards autonomous systems as alternative strategy for limiting negative environmental impacts by elimination of all forms of pollution while having minimal social, environmental and financial impacts.

The use of constructed wetland for wastewater treatment as sustainable and economical innovation could provide an adequate solution to this problem. The main uses of constructed wetlands have been reported to treat a wide kinds of wastewater, including domestic wastewater (3), hospital wastewater, industrial effluents (2) agricultural drainage (7), mine drainage-(18), stormwater runoff (5,20), and landfill

Corresponding author: Amal Kabbour, Laboratory of Process Engineering & Environment, Faculty of Sciences & Techniques, Hassan II University of Casablanca, Mohammedia, Morocco, E-mail: amal.kabbour-etu@etu.univh2c.ma

leachate (12). A large number beneficial of species can be used in constructed wetlands, depending on the type of filter, the mode of operation (continuous/discontinuous), the effluent flow and its characteristics, and the environmental conditions. Although the main characteristics of the selected species are fast growing, hyper-accumulation and high tolerance towards HMs toxicities. Vetiveria zizanioides (15) is a plant that meets these criteria. It will be the subject of this study.

2 Material and Methods

2.1 Statistical multi-criteria data analysis

In the present approach, selecting an optimal wastewater treatment system among others, adapted to the rural environment which was our priority based on implement decision support tools such as multi-criteria analysis that can provide a relevant and constructive contribution to the various issues, giving several possible options. In fact, no single criterion is sufficient to select a wastewater system; different criteria must be considered, such as: technical, urban, physical, environmental, financial and socio-economic order. The variables in question are sanitation techniques used to treat wastewater from rural area, and to evaluate each process in terms of the various criteria previously cited. The use of the multi-criteria matrix is strongly recommended to facilitate this analysis. It is created with the variants "Sanitation techniques" in column and the criteria are classified in rows (Tab.1); each cell of the matrix Cij (i line and j column), is completed as follows, we have assigned:

- 1 to the favorable impacts between each sanitation technique and the different criteria;
- 0 to neutral impacts (neither favorable nor unfavorable);
- -1 to unfavorable impacts.

The IBM SPSS STATISTICS software was used to facilitate this analysis as well as the management and selection of one or more of the most appropriate techniques. Among the functions included in the basic software, factorial analysis was divided into 2 types. In this case principal component analysis (PCA) was used since it meets our needs. The data from the multi-criteria matrix are then entered into the basic software.

2.2 Experimental set-up

The experimental device consisted of a physical microcosm model of raw wastewater treatment plant that was constructed within the domestic wastewater experimental pilot station, at upstream of the Bouregreg valley and downstream of the Sidi Mohamed Ben Abdallah, Northwest of Morocco (Between 4° 01′ 31″and 6° 50′ 10″), in Rabat City. The experimental set-up was conducted through a permeable bed of gravel from down upwards: 44 cm of 13/20 mm gravel to drain water passing through the filter means to an outlet point, and 25 cm of 2/4 mm gravel as filtration layer. The plastic tank measuring 1.14m in length × 0.9m in width × 0.64m in depth. The root reaches depth of more than 3 m but in this case is limited to the optimal depth of the tank. The experiment was carried out one month after the planting of the macrophytes and their adaptation period to the new environment. The initial raw wastewater characteristics were around 512, 144 mg/L and 297mg/L for Chemical Oxygen Demand (COD), Biological oxygen demand (BOD), and total suspended solids (SS) respectively. The flow rate of raw wastewater into the tank was 0,5 m^3/day while the hydraulic retention time between the inlet point and outlet point was 2 days. The lower hydraulic retention time of 2 days was selected as previously described by Maria et al. (9) and also approved by Magdi Ebrahim Khalifa (10), which showed that the lower hydraulic retention time enables constructed wetland to provide the highest pollutant removal efficiency.

2.3 Sampling of wastewater effluent

The sampling was carried out by taking samples at two points of the tank (inlet, and outlet); collected almost at the same time, every week, using plastic bottles, these samples are carefully mixed to make a homogeneous and representative sample. The experiment data consisted of 40 sampling.

2.4 Analytical methods: Physico-chemical analyses

Wastewater and treated water were analyzed for various parameters : BOD5 was determined by means of a measurement system OxiTop which measures the consumption in oxygen by biological way (1), Chemical oxygen demand COD was performed by oxidation with the dichromate of potassium $K_2Cr_2O_7$ with boiling in the presence of ions Ag^+ as catalysts of oxydation and having complexes ions Hg^{+2} as having complexes chlorides (1), and SS by centrifugation was executed by a filtration on filtering records (disks) of Whatman GF/C 1.2 microns as stipulated in the French standard procedure AFNOR (1).

3 Results and discussion

3.1 The multi-criteria matrix

The result of the multi-criteria analysis of the different purification techniques adapted to rural areas demonstrated an overall idea of the different variants as shown in the Table 1. Domestic wastewater faces several problems, such as treatment, disposal, and reuse. The improper discharge of wastewater provider negative impact on the receiving aquatic environment and soil structure. Also, it could subject toxic effects on the groundwater being discharged to the land. This necessitates prompt and adequate treatment of the wastewater before its disposal (12, 4). Wastewater are generally treated using biological methods such as activated sludge process, trickling filters, aerated and natural lagoons, bio-disc, and phytoremediation treatment (11). The treatment of rural wastewater using traditional wastewater treatment plants such as the activated sludge, trickling filters, aerated lagoons, and bio-disc is not feasible, as it will require high-energy rate to provide the required oxygen, requires more operation labor (administration labor cost, laboratory labor cost and unit process operation labor cost) and maintenance labor (16). However, all these treatments need sewage collectors, which are difficult to construct in rural areas because of their low economic status and rugged terrain because rural domestic wastewater has different characteristics to urban sewage; in particular, it has lower concentrations of pollutants (21). Additionally, it is always widely distributed, with as much as 90% of untreated wastewater indiscriminately discharged directly onto nearby surfaces (3). This causes groundwater to become polluted over time, which can endanger public sanitation and the health of rural residents. Constructed wetlands (CWs) are considered to be an effective and low-cost treatment system for reducing levels of chemicals and biological organisms in domestic wastewater through the use of organic materials and nutrients (14) and could serve as a model for the rural environment.

3.2 Statistical analysis

The data from the multi-criteria matrix (Tab.1) are then entered into the basic software and statistical analyses were carried out by SPSS package version 20.

Table 1: Component matrix

	COMPONENT		
	1	2	3
VS	,860		
BAM	,817		
T.latif	,792		
TF		,657	
AS		,649	
BD		,603	
AL			,707
NL			,667

The consolidation or regrouping of wastewater treatment techniques into three components, which allowed us to appoint them according to the nature of their associated variables (Tab. 2).

- **Component 1**: includes the Vetiver System, Typha. Latifolia, and the Bamboo, this component may be named by “Ecological and Sustainable Component”.
- **Component 2**: Associates the Bio-Disk, the Activated Sludge, and the Trickling Filter, and can be named by “Cost and Technology Component”.
- **Component 3**: Associates Natural lagoon and Aerated lagoon, which may be referred to as “Surface Component”.

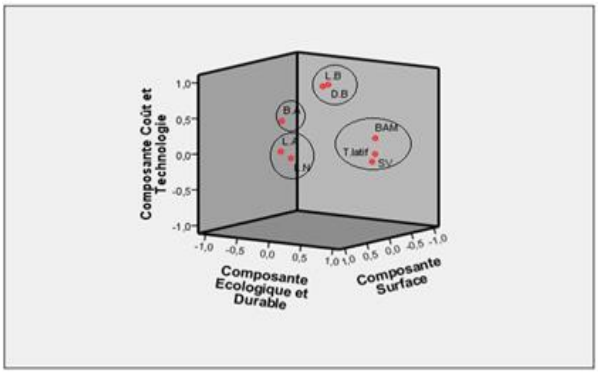

Figure 1: Rotated Component diagram

The Component diagram (Fig. 1) clearly showed blocks of remediation techniques that share almost common characteristics. In order to facilitate the interpretation those blocks can be named as the following:

- **Block 1** : includes TF: trickling filter; BD: bio-disc, known as “Fixed culture process”;
- **Block 2** : includes AS: activated sludge, named “Intensive Technique”
- **Block 3** : AL: aerated lagoon, and NL: natural lagoon, known as Extensive Techniques;
- **Block 4**: T.latif, VS: vetiver system, and BAM, nominated “Alternative techniques for ecological and sustainable sanitation”.

The relevance of the choice of the best block, which can be a solution for rural areas, requires the introduction of a technique called "Perfect Model", it is an innovative, efficient wastewater treatment process, and all the criteria previously mentioned in its design are advantageous; it has been attributed a value of "1" in the multi-criteria matrix. This perfect model allowed us to measure the distance that separates it from these 4 blocks; so that we can know the closest block that is the most suitable for the area of intervention, as shown in Figure 2.

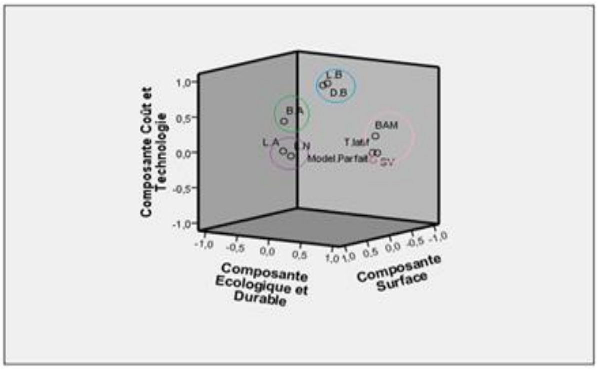

Figure 2: Component diagram with the presence of «Perfect Model»

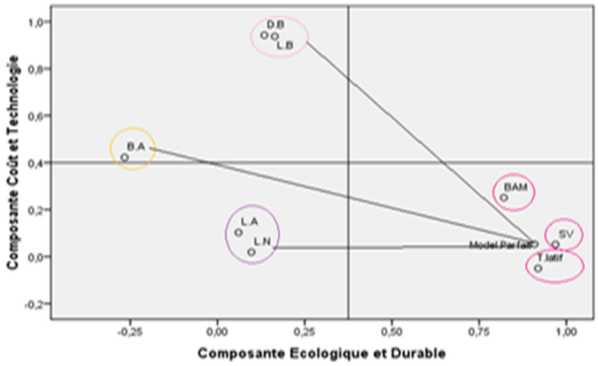

Figure 3: Representation of components and distance between blocks

The distance between each block and the perfect model was calculated using the Euclidean distance determination (Tab.3). The results showed that the only sanitation techniques close to the perfect model are the Vetiver system, Typha.latifolia, and Bamboo because of the small Euclidean distance calculated from the perfect model.

Table 2: Euclidean distances

	Block 1	Block 2	Block 3	Block 4
Perfect model	0.98	0.84	0.6	0.44

This analysis allowed the identification of the most suitable treatment system for a small agglomeration, and to select the 3 ecological and sustainable techniques, then the extensive technique, the intensive technique, and finally the 2 fixed culture processes.

3.3 Wastewater characterization

In order to study the effect of vetiver system on purification, several samples were prepared and analysed for various parameters quality. The average value of the parameters monitored for four months in the influent and effluent and their removal percentages obtained with the application of pilot system are presented in Table 4. Physico-chemical parameters at the inlet, constructed wetland outlet and respective removal efficiencies. The National effluent quality standards are also shown (19). The removal efficiency is determined as follows:

$$R_E = 100 \times (C_{Inlet} - C_{Outlet}) / C_{Inlet}$$

where RE is removal efficiency; C_{Inlet} is concentration of the parameter considered for raw wastewater; and C_{Outlet} is concentration of the parameter considered after purification.

Table 3: Matrix multi-criteria

		AS	TF	BD	NL	AL	VS	T.latif	BAM
Urban criteria	**1. Expropriation**								
	1.1 Surface (m2/EH)	1	1	1	-1	0	0	0	0
	1.2 Proximity	-1	1	1	-1	-1	1	1	1
	1.3 Distance/Discharge point	1	1	1	1	1	1	1	1
Physical criteria	**2. Topography**	1	1	1	1	1	1	1	1
	3. Landslide protection	1	1	1	-1	1	1	1	1
	4. Géotechnical field	-1	-1	-1	-1	-1	1	1	1
	4.1 Type of soil	1	1	1	1	1	1	1	1
	4.2 granulometry of soil	1	1	1	0	1	1	1	1
	4.3 bearing capacity of ground	-1	0	0	0	0	1	1	1
	5. Preservation of the qualityof the existing environment								
	5.1 Groundwater	1	-1	-1	-1	-1	-1	-1	-1
	5.2 Surface water	1	1	1	1	1	-1	-1	-1
Environmental citeria	**6. Protection of the environment**								
	6.1 Noise pollution	-1	1	1	1	-1	1	1	1
	6.2 Landscape integration	-1	-1	-1	1	1	1	1	1
	6.3 odour nuisance	-1	1	1	-1	1	1	1	1
	7. Qualitative characteristics of treated water								
	7.1 Elimination of the carbonated pollution	1	1	1	1	1	1	1	1
	7.2 Elimination of the SM pollution	1	1	0	1	1	1	1	-1
	7.3 Elimination of nitrate pollutants	1	1	-1	1	1	1	1	1
	7.4 Elimination of phosphorus pollutants	0	-1	-1	1	1	1	1	1
	7.5 Elimination of pollution of germs	0	-1	-1	1	0	0	1	-1
Financial criteria	**8. Financial**								
	8.1 investment cost	-1	0	0	1	1	0	0	0
	8.2 operating cost	-1	0	0	1	1	0	0	0
	8.3 energy consumption	-1	1	1	1	-1	1	1	1
Technical criteria	**9. Treatment infrastructure**								
	9.1 the design and construction	-1	0	0	1	1	1	1	1
	9.2 Support and maintenance	-1	0	0	1	1	1	1	1
	9.3 service life.	1	1	1	1	1	1	1	1
	10. Water reuse								
	10.1 Reuse for irrigation / in agriculture	1	0	0	0	0	1	1	1
	11. Fate of sludge								
	11.1 Reuse in agriculture	1	-1	-1	-1	1	1	1	-1
Socio-economic criteria	**12. Socio-economic**								
	12.1 Acceptation by local community and professionals	-1	0	0	-1	-1	1	1	1
	12.2 Capacity of traitement (EH)	1	1	1	1	1	1	1	1
	12.3 changing geography	1	1	1	1	1	1	1	1

Table 4: Influent and Effluent wastewater characterization

Parameter	Inlet Conc. (mg/l)	Outlet Conc. (mg/l)	Removal efficiency (%)	National Standards Conc. (mg/l)
BOD	170	20	88,3	120
COD	520	69	86,7	250
SS	300	5	98,5	150

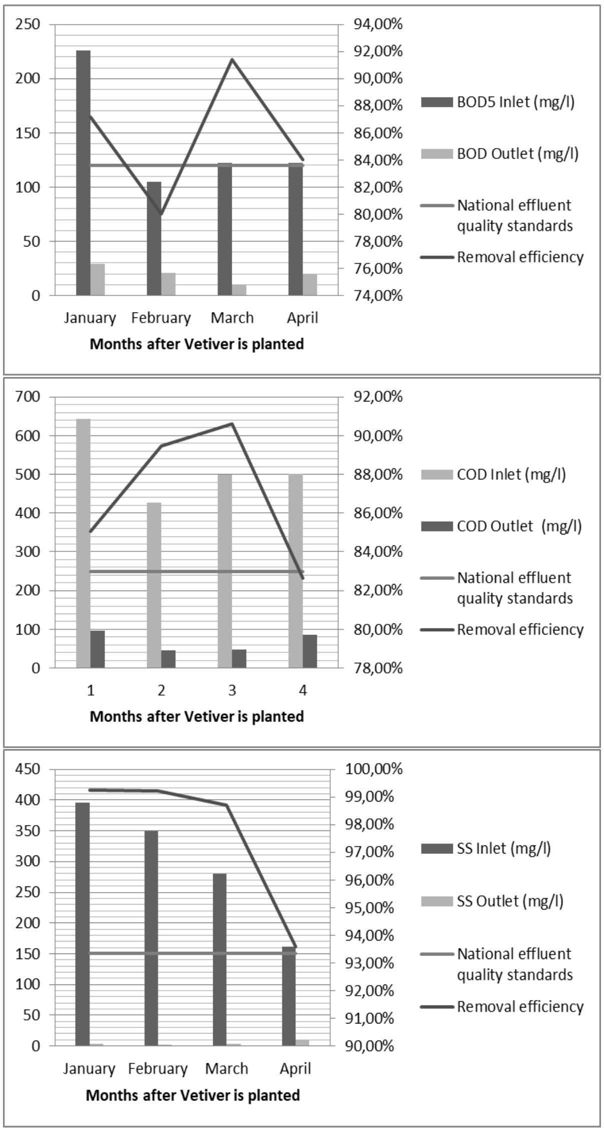

Figure 4: Treatment performance of Vetiver system, a) Percentages of BOD_5 removal, b) Percentages of SS removal, c) Percentages of COD removal.

Constructed wetlands are ecological engineering systems designed to treat various types of effluents by reproducing the physical, chemical and biological purification mechanisms that exist in natural environments. Suspended solids are removed by sedimentation and filtration according to Crites and Tchobanoglous (1998). Sedimentation as a physical process by which suspended particles stop moving and settle to form sediment. During filtration, the particles in transport come into contact with the grains of the filter or with material already deposited on the filter and settle or by impaction of particles in the roots and stems of macrophytes (Sanmuga Priya & Senthamil Selvan, 2017). For the suspended solids, the removal efficiency in the vetiver system was 98%. The SS content of the influent ranged from a maximum value of 396 to a minimum value of 162 mg/L. This content is reduced at the outlet to an average of 29.5 mg/L in accordance with Moroccan discharge standards. Organic material biodegradation takes place in the plant roots, stems and the surface of the substrate grains, which allows to reduce the BOD_5 concentration. The influent has a BOD_5 that varies between 245 and 85 mg/L. In addition, the effluent has a BOD5 value over the range (110-65 mg/L). The elimination efficiency of BOD_5 was at 88,3%. The treatment with the herbaceous produces purified water that is well discharged in the Moroccan standards set at 120 mg/L for BOD_5. With reference to COD, Vetiver system presents a removal of 86,7%.

4 Conclusion

The vetiver system, Typha.latifolia and Bamboo, are the three environmentally friendly and sustainable techniques adopted by multi-criteria analysis. The treatment of wastewater generated by the campus outlet of National Office for Electricity and Potable Water (ONEE) of Rabat using vetiver system was carried out. The elimination efficiency of BOD5, COD, and SS was at 88, 86 and 98% respectively. The results obtained are within the permissible limits for domestic rejects according to National legislation of Morocco. According to the results obtained, the vetiver system planted is recommended because it achieves high yields in the elimination of pollutants present in domestic wastewater especially for small communities. The system is very efficient and low cost method for treatment of wastewater in rural area.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors'contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing

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