REVIEW OF FEASIBLE CONSTRUCTED WETLAND SYSTEMS FOR DEVELOPING COUNTRIES

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ABSTRACT

Considering the constantly decreasing quantity of clean water and the very high cost of conventional water treatments, there is an increasing need for more affordable and practical wastewater treatment methods. As a solution to this problem, decentralized wastewater treatments were introduced, among them Constructed Wetland Systems. The purpose of this paper is to analyze 5 wastewater treatment systems which include constructed wetlands as primary treatment. The analysis was conducted using detailed design projects, regular rapports from owners or inspecting authorities, or otherwise anyone affiliated with the projects. Some of the technical aspects regarding capacity and hydraulic performance of the systems have been calculated based on existing data. Using a comparative analysis, it is concluded which of the systems is more effective regarding treatment performance and cost. After analyzing parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), Nitrogen and Phosphorus; design parameters such as area, hydraulic loading rate – HLR, hydraulic retention time – HRT, organic loading rate – OLR) and cost, a system was chosen as the best and most feasible system for a developing country or those without large financial means.

Key words: Constructed Wetland, Wastewater treatment, Treatment Performance, Cost, Evaluation

1 INTRODUCTION

Lately, the lack of clean water is constantly on the rise. Currently 844 million people live without clean water, approximately 1 in 9 people. Conventional wastewater treatment plants are huge constructions, expensive and not feasible for countries in a poor financial state. The large necessity for clean water, has yielded on-site decentralized wastewater systems. These systems

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are cost effective, environmentally friendly while at the same time offering the same quality of water as conventional treatment plants. Such systems are constructed wetland systems. Nowadays, constructed wetland systems are a common alternative for wastewater treatment in rural areas of Europe. In upcoming years, it is expected that their number will surpass 10'000 in Europe only. (United Nations Human Settlements Programme (UN-HABITAT), 2008). They are designed in such a way as to benefit from many of the processes that occur in natural wetlands, but in a more controlled environment. (Vymazal, 2010). These systems are most often used as primary or secondary treatment for household wastewater. (Davis, n.d.). For this exact purpose, 5 systems have been reviewed so that the most feasible one for a developing country can be chosen and implemented while maintaining water quality. In choosing the systems to be reviewed, their adaptability and ease of implementation in developing countries has been of utmost importance.

2 METHODS

To evaluate the effectivity of a system, one must first be aware of certain basic parameters. Such parameters are shown below:

- System Design
  - Type, area, population equivalent PE, dimensions
  - Construction (Structure), materials
  - hydraulic loading rate – HLR, hydraulic retention time – HRT, organic loading rate – OLR

- Operating and Maintenance
  - Treatment performance
  - Maintenance

- Cost
  - Construction, operating and maintenance costs

The figure below shows a typical constructed wetland system.

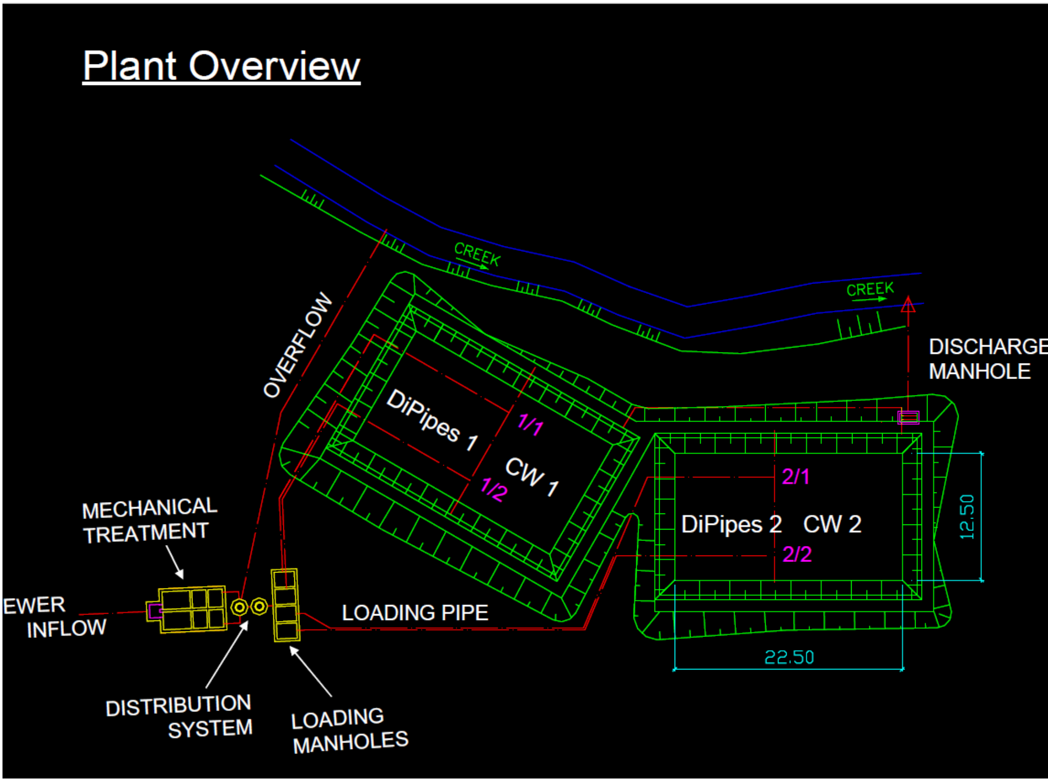

Figure 1. Schematics for a typical constructed wetland system (Knoll, 2005)

To answer the question of which system is the most effective and feasible, all 5 systems were reviewed, and the comparative analysis was implemented regarding performance and cost.

The five systems chosen are:

- **System 1,** a combination of sedimentation tank and vertical sub-surface flow constructed wetland, used for treating domestic wastewater (kitchen, toilets, laundry) by a center for people with special needs. It is operating actively from 2011. The center has a total capacity of 95 beds. (Albold, et al., 2011)

- **System 2,** a process that combines a screen and a sand channel as preliminary treatment, followed by an Imhoff tank as primary treatment, and a horizontal sub-surface flow constructed wetland with two parallel beds as secondary treatment. The system treats domestic wastewater of a region with 800 PE capacity, where the main activities are agriculture, agroindustry and tourism. (Albuquerque & Marecos do Monte, 2010)

- **System 3,** a system that combines a screen followed by a septic tank as primary treatment, and a vertical sub-surface flow constructed wetland with two beds. The system is designed for 249 PE. Consumption quota is 150 l/PE*d. The system treats wastewater from a hospital. (Bramberger, et al., 2017)

- **System 4,** has a sedimentation tank as preliminary treatment, followed by a hybrid constructed wetland with three beds (1 HSSF + 2 VSSF) and a phosphorous filter at the end. (GAJEWSKA & OBARSKA-PEMPKOWIAK, 2008). The treated water is discharged in a pond of a national park, which allows gradual infiltration of the water in the ground. The system is built for 20 PE and treats the wastewater of a small village. (Jozwiakowski, et al., 2014)

- **System 5,** a system that uses a sedimentation tank as preliminary treatment. A hybrid constructed wetland with 2 beds, one with horizontal sub-surface flow, the other vertical, is used as primary treatment. The system treats wastewater from an orphanage and the water is slotted for reuse as nitrogen enriched water for irrigation for the orphanage's orchards. The system is designed for 220 PE. (Gjinali, et al., 2011)

Regarding treatment performance, that depends firstly on system design parameters. Special importance was put on area, PE, water quantity and organic loading rate as seen on Table 1. The table also introduces briefly every system and their basic characteristics.

Table 1. Comparing design parameters for 5 systems

System	1	2	3	4	5
Type	VSSF[2]	HSSF[3]	VSSF	Hybrid (1 HSSF + 2VSSF)	VSSF + HSSF / Hybrid
Preliminary treatment	ST[4]	SR[5]+SC[6]+ Imhoff tank	SR+ST[7]	ST	ST
Area of the wetland (m^2)	266	1550	665	180	550
Volume (m^3)	172.9	1550	932.4	180	495
PE	76	800	249	20	220
Water quantity(m^3/d)	11	96	37.35	2	16.8
HLR (cm/d)	4	7-15	6	4	3.05454
OLR (gBOD/m^2/d)	9	15	11	7	12
Plants	Reed	Phragmites Australis	Phragmites Australis Typhia Latifoia	Phragmites Australis Glyceria Maxima Salix Viminalis	Reed
Filter medium	Sand 0/4	Gravel	Sand/Gravel 1/4	Soil	Sand 0-2 mm
HRT	8 days	4.5 – 9 days	10 days	N/A	N/A
Dosage	2-3 times/day 3m^3/dose	N/A	every 3-6 hours	N/A	3-4 times/day with 5 m^3/dose
Discharge	River	N/A	Field	Infiltration pond	Reuse/irrigation

Considering that all these systems are active, the operating aspect has been evaluated regarding treatment performance. Treatment performance depends on the removal percentage of all substances in the water that ought to be removed.

This was done by comparing the values of each substance from analysis done in influent water and effluent water. An example of such analysis is shown in Table 2.

To compare systems with different capacities, their performance was graded from 1 to 5, with one 1 being the worst performance to 5 being the best. Worst performance meaning the least amount of change between values of influent and effluent water on particular substances or parameters. Grading was done by comparing the effluent analysis with European Standards 91/271/EEC (Table 3).

Table 2. Water parameters for system 2, (Albuquerque , Arendacz, Obarska-Pempkowiak, Borges, & Correia, 2008)

Parameters	Unit	Influent	Effluent
pH		6.4 - 7	7 - 7.4
Temperature	°C	19 ± 2	20 ± 2
DO[2]	mg/L	1.0 ± 0.2	1.2 ± 0.3
BOD_5[3]	mg/L	286 ± 16	15 ± 4
COD[4]	mg/L	344 ± 44	110 ± 15
NH_4-N	mg/L	33 ± 3	7 ± 3
NO_3-N	mg/L	1.5 ± 0.6	0.7 ± 0.1
Total Phosphorous	mg/L	7 ± 1	3 ± 1
TSS[5]	mg/L	116 ± 20	34 ± 10

Table 3. *European Standards for post-treatment effluent* (COUNCIL DIRECTIVE, 1991)

Parameters	**Standard**	**Boundary value**
BOD	EN 1899-1	40 mg/l
COD	ISO 6060	125 mg/l
TSS	ISO 11923	35 mg/l
Phosphorus	EN ISO 11885	2 mg/l
Nitrite	[6]	1 mg/l
Nitrate		10 mg/l
Chloride		750 mg/l
Sulfate		750 mg/l
Phenols	EN ISO 14402	0.5 mg/l
Nitrogen	EN ISO 11732	15 mg/l

2 Dissolved oxygen
3 Biological Oxygen Demand, measured for 5 days
4 Chemical Oxygen Demand
5 Total Suspended Solids
6 (Anon., n.d.) for Nitrite, Nitrate, Chloride and Sulfate

For each parameter, during grading, 2 things were considered: 1) Are effluent values within the acceptable standards? and 2) What was the removal percentage after treatment? The grade was given firstly based on how close to the standard maximal value allowed was a parameter, and then it was increased or decreased based on removal percentage of a parameter during treatment as seen on Table 4.

Finally, a little leeway was allowed for those systems that measure and monitor more parameters than the others, meaning a small increase in points.

Table 4. Comparing treatment performance parameters for the 5 systems

%	System 1	System 2	System 3[7]	System 4	System 5
DO[8]	**N/A**	**Class V**	**Class II**	**N/A**	**N/A**
BOD_9	**N/A**	**5**	**4.5 / 4.5**	**5**	**5**
COD	**N/A**	**4.5**	**4.7 / 5**	**3**	**5**
TSS	**N/A**	**3.5**	**0**	**2.5**	**5**
Nitrite	**N/A**	**N/A**	**2 / 4.7**	**N/A**	**N/A**
Nitrate	**N/A**	**4**	**0**	**N/A**	**0**
Ammonia	**N/A**	**3**	**5 / 5**	**N/A**	**3.5**
Total Phosphorus	**N/A**	**4**	**N/A**	**4.5**	**1**
Chloride	**N/A**	**N/A**	**4**	**N/A**	**N/A**
Sulfate	**N/A**	**N/A**	**0 / 3.7**	**N/A**	**N/A**
Performance	**N/A**	**3.6**	**3.5**	**3.55**	**3.35**

To review the systems based on cost, coefficient β - cost/area, was calculated (smallest number was graded with a 5, the other systems were graded by taking the cheapest system as a reference point). (Table 5)
Lacking concrete data, costs for systems 2 and 4 were calculated approximately from data regarding the standard cost of such systems in respective countries.

[7] System 3 has 2 separate sets of analysis

[8] Class I (>7 mg/l), Class II (6 – 7 mg/l), Class III (4 – 6 mg/l), Class IV (3 – 4 mg/l) , Class V (<3 mg/l) (Enderlein, et al., n.d.)

Table 5. Cost comparison for the 5 systems

Cost€	System 1	System 2	System 3	System 4	System 5
Construction Costs	49’500 €	95'009.5 €	91’900 €	85'553.40 €	50’000 €
Operating and maintenance costs/year	100 €	0	0 €	0	500 €
Other costs	0	0	0	N/A	10’000 €
Total	49’600 €	95'009.5 €	91’900 €	85'553.40 €	60’500€
Coefficient β (€/m²)	186.46	61.296	138.195	475.296	110
Coefficient α[10]	1.65	5	2.78	0.65	3.97

Another component that has been taken into account during the grading of the systems, is maintenance. Depending on whether maintenance was done or not, the systems either gained a point (+1) or lost a point (-1). Maintenance most often means the undertaking of actions often specific for the system, but also in general activities such as:

- Inspecting the sedimentation tank for structural damage (the concrete),
- Recording the exiting amount of sludge (date and volume),
- Monitoring dosage intervals and volume per dose of the pump,
- Monitoring pumps and floating valves, and, if necessary, cleaning them,
- Maintenance of plant growth (reaping the reeds),
- General pump maintenance, cleaning and oil changing, etc.

Data shows that the lack of maintenance in a system has caused certain issues as listed below, hence the downgrading.

- Uncontrollable growth of plants and blockage of preliminary treatment pipes,
- Blocked screen,
- Defects in hydraulic valves,
- Dosage not done right in connection points,

Operating procedures not conducted right, etc. (Bramberger, et al., 2017)

[10] Grade given for cost

3 RESULTS

According to the analysis of the 5 systems, the table below is a summary of the results reached regarding performance, maintenance, and coefficient α. The table also shows the ultimate grade of a system as the average with ± 1 depending on maintenance done or not.

Table 6. Evaluation of the 5 systems

Parameters	*System 1*	*System 2*	*System 3*[11]	*System 4*	*System 5*
Treatment performance	**N/A**[12]	**3.6**	**3.5**	**3.55**	**3.35**
Maintenance	+	N/A	-	+	+
Area m²	266	1550	665	180	550
Coefficient α	1.65	5	2.78	0.65	3.97
Grade point average	N/A	4.3	2.14	3.1	4.66

Ranking of the systems based on the evaluation has been shown below:

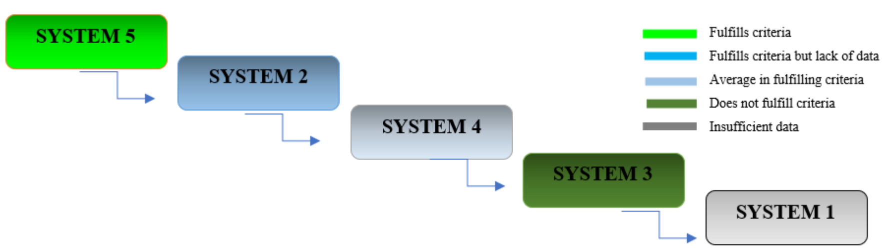

Figure 2. Ranking of the systems

As shown by the table, system 5 is in the lead with a score of 4.66/5, meaning it fulfills all necessary criteria for implementation and use. System 2 follows with a score of 4.3/5, fulfilling necessary criteria, but lacking the data regarding the occurrence of maintenance. System 4 follows with a good score

[11] System 3 has 2 pairs of independent analysis. An average of both was taken.
[12] No data regarding performance of System 1, but due to a really low coefficient α, no matter the value, it still would not rank 1st or 2nd.

of 3.55/5, with good performance but less favorable in financial aspects. System 3 and system 1 are both found lacking.

4 CONCLUSIONS

After reviewing all five systems, their treatment performance, cost and maintenance, it was concluded that system 2 and system 5 are the preferred systems with respective grades of 4.3 and 4.66. System 2 is mostly preferable for tropical climate conditions, while system 5 is adaptable to changing climate. System 5 is also preferable if the available area is not very large seeing that System 2 requires a vast swath of land.
However, in choosing a system, performance and cost are not the only parameters evaluated. Other parameters such as available area, density of population, type of land and soil, destination of the effluent etc., are necessary for evaluation. However, this paper is a useful tool in decision making when choosing a practical system to implement in developing countries, countries or areas with lack of finances, small budget and so on.
Also, due to the lack of data noticed during this research, it is recommended that further analysis and monitoring of the system be conducted.

REFERENCES

1. Enderlein, U. S., Enderlein , R. E. & Peter, W., n.d. Water Quality Requirements. In: s.l.:s.n.
2. Albold, A. etj., 2011. *Constructed Wetlands: Sustainable Wastewater Treatment for Rural and Peri-Urban Communities in Bulgaria.* Vidrare: WECF – Women in Europe for a Common Future.
3. Albuquerque , A., Arendacz, M., Obarska-Pempkowiak, H., Borges, M., & Correia, M. (2008). S*imultaneous Removal of Organic and Solid Matter and Nitrogen in a SSHF constructed Wetland in a Temperate Mediterranean Climate. KKU Res J 13 (10)*, 12.
4. Albuquerque, A. & Marecos do Monte, H., 2010. Analysis of constructed wetland performance. *Water Science & Technology— WST | 61.7* | , p. 7.

5. Bramberger, J. et al., 2017. *MUNICIPAL SERVICES IMPROVEMENT PROJECT – (MSIP). FINAL SUMMARY REPORT WITH,* s.l.: Ministry of Finance Macedonia.
6. COUNCIL DIRECTIVE, 1991. 91 /271 /EEC. *Official Journal of the European Communities.*
7. Davis, L., n.d. *A HANDBOOK OF CONSTRUCTED WETLANDS.* Washington D.C: USDA-Natural Resources Conservation Service and the US Environmental Protection.
8. GAJEWSKA, M. & OBARSKA-PEMPKOWIAK, H., 2008. CONSTRUCTED WETLANDS SYSTEMS FOR WASTEWATER TREATMENT IN POLAND. *ACEE, The Silesian University of Technology,* p. 8.
9. Gjinali, E., Niklas, J. & Smid, H., 2011. *Wastewater treatment using constructed wetlands Tirana, Albania,* Tirana: Sustainable Sanitation Alliance, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.
10. Jozwiakowski, K. et al., 2014. The Concept of Construction of Hybrid Constructed Wetland for Wastewater Treatment in the Roztocze National Park. *Barometr Regionalny TOM 12 Nr 4*, p. 12.
11. 11. Knoll, G. (2005). *Design Details for Constructed Wetlands: Jasenovo Lung Disease Hospital.* Caska: UNESCO-IHE.
12. United Nations Human Settlements Programme (UN-HABITAT), 2008. *CONSTRUCTED WETLANDS MANUAL.* Nairobi, Kenya: United Nations Human Settlements Programme (UN-HABITAT).
13. Vymazal, J., 2010. Constructed Wetlands for Wastewater Treatment. *Water 2010*, pp. 530 - 549.