Efficiency of two natural wastewater treatments at inactivating coliforms for reuse in agricultural irrigation

Alejandra Ortiz, Environmental engineer, University of Cundinamarca
Brayan Riascos, Environmental engineer, University of Cundinamarca
briascos182@hotmail.com
(57) 313 - 465 -1905
Girardot, Cundinamarca – 19 -19A-83 St.

Introduction

Agriculture consumes 70% of world´s freshwater withdrawals. The global percentage of water for use in agriculture is estimated to increase by 20% for 2050, which would mean a significant pressure on water resources to satisfy food production all over the world. This situation may be aggravated due to difficulties linked to climate change such as: water cycle variations, changes in rainfall distribution or droughts[1].

For decades, treated, partially diluted or untreated wastewater has been used to water crops to satisfy irrigation needs and to take advantage of nutrients it contains for fertilization purposes[2]. This practice is carried out mostly in developing countries, where high demand for food production is related to the growth of the urban population. Therefore, wastewater is understood as a valuable nutrient resource and water supply for irrigation, which can be available throughout the year, especially in arid or semiarid regions[3].

Although wastewater reuse is a widespread practice, there is not homogeneous data regarding to volumes and areas irrigated with it. However, it's estimated between 5 and 20 million hectares are irrigated with wastewater around the world[4,5]. In Colombia, it is even more difficult to obtain reliable data. Approximately 2,204 million cubic meters of wastewater are reused, but the volume used to irrigate crops is still unknown. Furthermore, only 27% of this water receives any type of treatment[6].

Under non-controlled conditions and inefficient treatment processes, wastewater represent a serious public health problem[7], because of farmers or crops can be contaminated by having contact with pathogens contained in fecal matter or with toxic

[1] WWAP, *The United Nations World Water Development Report 4: managing water under uncertainty and risk*, (UNESCO, 2012), 47-49, https://unesdoc.unesco.org/ark:/48223/pf0000217175
[2] UNEP, *A Snapshot of the World's Water Quality: Towards a global assessment*, Kenya, (UNEP 2016), 86 https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf
[3] Blanca Jiménez, "Irrigation in Developing Countries Using Wastewater". International Review for Environmental Strategies (2006) n. 2, 229-50 https://www.iges.or.jp/en/publication_documents/pub/peer/en/1199/IRES_Vol.6-2_229.pdf
[4] WWAP, *Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2017. Aguas residuales: El recurso desaprovechado*, (UNESCO, 2017), p.77, http://www.unesco.org/new/es/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/
[5] Jiménez, "Irrigation Wastewater", 229-50.
[6] DNP, "Consultoría sobre productividad del uso del agua y la eficiencia en el tratamiento de aguas residuales y en el reúso del agua en Colombia: Resumen ejecutivo del diagnóstico", 2017, p.11 https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Agua/Resumen_Dagnostico_Prodcutividad%20del%20agua.pdf
[7] James Winpenny, Ingo Heinz and Sasha Koo-Shima*, Reutilización del agua en la agricultura: ¿Beneficios para todos?*, (FAO, 2013), 11, http://www.fao.org/3/a-i1629s.pdf

chemical substances in water[8]. Due to this, the World Health Organization (WHO) has been a pioneer in establishing guidelines for the safe wastewater reuse according to its microbiological content since 1989.

Natural wastewater treatments use biological processes to remove pollutants from wastewater with low energy consumption, low costs and no need for chemical additives. These treatments are more ecologically and economically efficient than conventional treatments, and may be especially effective to implement as a sustainable strategy for water resources in rural areas[9]. Moreover, using biological treatment processes can easily fit into the 6th objective of sustainable development goals (SDG).

This research was carried out at “El Jardín” farm, a small agricultural household located in Tocaima municipality. It has fruit crops for farm consumption and local sale. Due to its location in an arid zone, water supply for irrigation is limited to the extraction of a groundwater well that in times of drought does not provide enough water to irrigate crops. Therefore, the objective of this research is to determine the efficiency of two natural treatments (slow sand filter and maturation pond) to remove coliforms and physicochemical components from the farm's wastewater, and thus perform preliminary assessment of its quality for agricultural reuse.

Methodology

Location

The Tocaima municipality is located in the southwest part of the department of Cundinamarca and belongs to the Alto Magdalena´s warm valley province. It has a temperature average of 28 °C, an annual rainfall average of 1051 mm and is situated at an altitude between 287 and 1568 *masl*. The predominant life zone corresponds to Tropical dry Forest (Td-F) into to the Tropical Alternohydric Zonobioma[10] .

“El Jardín” farm is located in La Salada village in the south-western part of the municipality, with coordinates of 4 ° 25´23.52´´ N - 74 ° 42´7.41´´ W. The total area of the farm is 1.8 hectares where it has crops of mango (20 plants) and aloe (500 plants) for local sale and household consumption. It´s soil is a clay soil with low nitrogen content and the predominant climate in the area is arid and semi-arid.

Flow gauging

To calculate the wastewater production volume in the farm, the flow rates of gray and sewage pipes were measured once per day for 8 consecutive days. Because the gray water was discharged into the ground, it was necessary to build a well with 1000 liters of capacity for its storage. The sewage (black water) was directed to an existing septic tank. The volumes of kitchen wastewater were not recovered for this research.

[8] WHO, *Guidelines For The Safe Use of Water, Excreta and Greywater. Wastewater use in agriculture*, v. 2, (WHO, 2006), 12, https://www.who.int/water_sanitation_health/publications/gsuweg2/en/
[9] Kiara Winans *et al*, “Small-Scale Natural Wastewater Treatment Systems: Principles and Regulatory Framework”, Institute of Food and Agricultural Sciences, (2012), 2-6, https://ufdcimages.uflib.ufl.edu/IR/00/00/09/86/00001/SS56600.pdf
[10] CAR, *Plan de Accion de Educación Ambiental del CIDEA*, (2013), 58-62,

Natural treatment setup

The slow sand filter (SSF) had as main structure a high-density polyethylene tank with volume of 500 liters and height of one meter. For drainage, the tank was conditioned with a 10 cm high false bottom and a galvanized steel mesh with orifices of $64mm^2$ to allow de output effluent

To fit the filter bed, 3 layers of previously sieved and washed material were used: gravel with a half-inch diameter and a layer thickness of 10 cm; gray coarse sand with a diameter of 0.6 mm and a layer thickness of 10 cm; and fine sand with a diameter of 0.2 mm and a layer thickness of 20 cm. The depth of the filter bed was 40 cm and the depth of the water column was 50 cm.

The design guidelines were based on the technical regulations for drinking water and sanitation sector for slow rate filtration[11]. With this taken into account, a hydraulic load of 0.1 m^3 / m^2.day, an input volume of 260 L/day, a filtration surface area of 2.6 m^2 and a sand bed maturation time of 3 days were established.

The maturation pond (MP) was built in cement, with dimensions of: 1 meter deep, 4 meters long and two meters wide. Subsequently it was waterproofed with two layers of polyethylene plastic of $27m^2$.The maturation pond operated with a design volume of $2m^3$ and hydraulic retention of 18 days. The complete mix model for coliform removal proposed by Marais and the flow dispersion model by Polprasert were applied[12][13]. For the measurements of organic load, surface organic load, the equations proposed in CONAGUA were used[14].

Wastewater pumping to the treatments units

The pumping of wastewater toward the SSF and MP was carried out through motor pumps installed into the septic tank and in the pre-built gray water well. Flow rates of 0.4 to 0.7 L/s were maintained. The volume proportions of gray and black water in each treatment unit were 50/50 to maintain the same physicochemical and microbiological conditions in the affluent.

Sampling

Sampling of raw and treated wastewater was carried out following the technical instructions of the Standard Methods for the Examination of Water and Wastewater edition 2012[15].The following physicochemical and microbiological parameters were analyzed:
Total Coliforms (Enzyme Assay Method SM 9223 B), Faecal Coliforms (Enzyme Substrate Assay SM 9223 B), BOD (5-day Incubation SM 5210B and Membrane electrode, 4500-0 G), COD (Open reflux 5220 B), Total Phosphorus (Acid digestion,

[11] Ministerio de Desarrollo Económico*, Reglamento Técnico Para el Sector de Agua Potable y Saneamiento Básico- RAS*, (2000), 68-73, section C, title 2.
[12] Armando Cubillos, "Estado del Arte En El Diseño de Lagunas de Estabilización", Revista de Ingeniería (2001), n.2, 85, https://revistaingenieria.univalle.edu.co/index.php/ingenieria_y_competitividad/article/view/2331/3081
[13] Duncan Mara and Miguel Peña, "Waste Stabilisation Ponds", IRC International Water and Sanitation Centre (2004), 14, https://www.pseau.org/outils/ouvrages/irc_university_of_leeds_waste_stabilization_ponds_2004.pdf
[14] CONAGUA, *Manual De Agua Potable, Alcantarillado Y Saneamiento*, ed, (2007), 28,
[15] American Public Health Association, American Water Works Association and Water Environment Federation, *Standard Methods for Examination of Water and Wastewater* 22th ed, 1796, (2012).

Ascorbic acid SM 4500-PB, E), Total Nitrogen (Macro Kjeldahl, distillation and volume), Suspended Solids (Dried at temperature 103ºC-105ºC), Dissolved Solids (Gravimetric method dried at temperature 180ºC) and Total Solids (Gravimetric method dried at temperature 103ºC-105ºC).

Samples were stored in autoclaved sterilized glass jars at 120 °C and 15 Psi of pressure. In total, twelve bottles of 500mL and three bottles of 250mL were used. The analysis of samples was made at the water quality laboratory of the Colombian Corporation for Agricultural Research (CORPOICA) in the municipality of Mosquera-Cundinamarca.

Finally, to assess the treated wastewater quality in this research, the results were compared with the acceptable levels established in the international guidelines proposed by WHO[16], US-EPA[17] and Colombian regulations Decree 1594 of 1984[18] and Resolution 1207 of 2014[19] to determine the potential for agricultural reuse.

Results and discussion

Based on gauging results, an available volume of 1325 liters per week of wastewater was obtained. The activity that provides the largest volume of water is related to laundry as seen in Table *1*. A generation of 118 liters per person per day was also observed.

Table 1. Gauging results and wastewater production at El Jardín farm

Pipe	Activity	Flow average (L/s)	Wastewater production (Liters/ Hab·day)	Total liters per week
Gray water	Laundry	0,084	43,2	604, 8
	Bath	0,034	20,4	285,60
Black water	Flush toilet	0,069	31,05	434,7
Total			118, 05	1325,1

Source: Authors, 2016

The main sources of gray water are laundry, bathroom and kitchen. Gray water composition depends on family size, age of residents, eating habits and the amount of detergent used. The volume is related to the availability of drinking water and the household´s socioeconomic status. For this reason, it is possible that in developing countries approximately 100 liters of gray water[20] is produced per habitant per day. This figure coincides with those presented by (IDEAM, 2010, 173)[21], which proposes drinking

[16] WHO, *Health Guidelines For The Use Of Wastewater In Agriculture And Aquaculture, (*WHO, 1989), 39
[17] U.S Environmental Protection Agency, *Guidelines For Water Reuse: Manual*, (EPA, 1992), 132
[18] Decreto 1594 de 1984, Por el cual se reglamenta parcialmente el Tí-tulo I de la Ley 9 de 1979, así como el Capí-tulo II del Tí-tulo VI -Parte III- Libro II y el Tí-tulo III de la Parte III -Libro I- del Decreto Ley 2811 de 1974 en cuanto a usos del agua y residuos líquidos, art 40, Paragraph 1.
[19] Resolución 1207 de 2014, por la cual se adoptan disposiciones relacionadas con el uso de aguas residuales tratadas, art 7.
[20] WHO, *Guidelines For The Safe Use of Water, Excreta and Greywater. Excreta and Wastewater Use in agriculture*, v. 4, (WHO, 2006), 14, https://www.who.int/water_sanitation_health/publications/gsuweg4/en/
[21] IDEAM, *Estudio Nacional Del Agua*, (IDEAM, 2010), 173, http://documentacion.ideam.gov.co/openbiblio/bvirtual/021888/021888.htm

water consumption in Colombia between 65 and 110 liters per day. Therefore, the volumes obtained on the farm are within these values.

Regarding the physicochemical parameters, it was found that BOD and COD concentrations were at medium high levels, total solids at medium levels, and dissolved and suspended solids at low levels (Table *2*). Total phosphorus was found at medium levels and total nitrogen at very high levels[22]. High nitrogen contents represent a valuable nutrient supply that may improve the fertilization and yield on crops, but its concentration will depend on the resident´s diet[23] .

Table 2. Raw wastewater´s microbiological and physicochemical quality

Parameters	**Value**
Biochemical Oxygen Demand (BOD_5)	255 mg/L
Chemical Oxygen Demand (COD)	380 mg/L
Total Solids (TS)	203 mg/L
Dissolved Solids (DS)	222 mg/L
Suspended Solids (SS)	96 mg/L
Total Nitrogen (NT)	250 mg/L
Total Phosphorus (TF)	15,2 mg/L
Total Coliforms (TC)	2055 MPN/100mL
Faecal Coliforms (FC)	2033 MPN/100mL
pH	8,01

Source: Authors, 2016

The sample of faecal coliforms presented low concentrations according to (Ministry of Environment 2002, 14)[24], which establishes maximum values on 10^9 MPN/100mL and minimum values on 10^5 MPN/100mL. Similar situation was presented with total coliform, where low concentrations were observed according to (Henze *et al*, 2008, 37)[25] who proposes 10^8 MPN/100 mL for high values and 10^6 MPN/100 mL for low values. Low bacterial content in raw wastewater can be seen as an advantage for its treatment, since at lower concentrations it is easier to achieve better microbiological quality in the effluent.

Maturation pond performance

After 18 days of hydraulic retention time, the maturation pond operated with an organic load of 8.4 Kg BOD/day and a surface organic load of 4.2 Kg BOD/m^2.day. The removal percentages for the analyzed microbiological and physicochemical parameters were between 20% and 56%. The higher removals were obtained in total coliforms, faecal coliforms and dissolved solids as observed in *Table 3*:

[22] Ministerio de Ambiente, *Gestión, Tratamiento, Disposición Final de Aguas Residuales Municipales*, (Minambiente, 2002), 14, https://repository.agrosavia.co/handle/20.500.12324/18911
[23] WHO, *Excreta And Wastewater*, 8-11
[24] Ministerio de Ambiente, Aguas Residuales Municipales, 14
[25] Mogens Henz, et al, *Biological Wastewater Treatment: Principles, Modelling and Design*, (IWA, 2008). 37, https://doi.org/10.2166/9781780401867

Table 3. Removal efficiency of maturation pond

Parameter	Maturation pond effluent	Removal efficiency (%)
BOD_5 (mg/L)	202	20,8
COD (mg/L)	255	32,9
TF (mg/L)	11,3	25,7
TS (mg/L)	150	26,1
DS (mg/L)	100	55,0
SS (mg/L)	73	24,0
TN (mg/L)	205	18,0
TC (MPN/100mL)	1023	50,2
FC (MPN/100mL)	901	55,7
pH	7,3	-

Source: Authors, 2016

The flow dispersion coefficient had a value of 0.46, indicating that the maturation pond performed with a dispersed plug flow regime and not with complete mixing model flow as was expected[26]. This means that water moves throughout the pond in the same flow layer from the inlet to the outlet with presence of hydraulic short-circuiting. Several researchers agree that Marais complete mix model is not realistic because in ponds it is not possible to eliminate short-circuiting or "dead" spaces[27].

Although the Marais coliform removal formula applied showed an ideal estimated concentration of 54.94 MPN in the effluent, only 55% of real faecal coliform removal (901 MPN/100mL) and 50% real of total coliform removal (1023 MPN/100mL) were obtained. Ideal conditions in algal growth, sunlight intensity, dissolved oxygen, and a high pH promote coliform removal; but the presence of short circuiting spaces that modify the designed retention times must be taken into account, because they directly affect the coliform removal efficiencies[28].

Therefore, it is probable that the maturation pond did not reach the sufficient algal biomass to raise the water´s pH to 9 or higher, and achieve greater coliform removal. As a consequence of low algal load and short circuits associated with the dispersed flow, the removal levels of BOD and solids in the pond were also low, coinciding with results in (Bernal *et al*, 22)[29].

[26] Luis Cruz, Walter Alayón and Carlos Monsegny, "Metodología Para la Selección del Regimen de Flujo en Lagunas de Estabilización", *Ingeniería e Investigación*, (2000), http://dx.doi.org/10.15446/ing.investig
[27] Chimwemwe Banda, "*Modern Design of Waste Stabilization Ponds in Warm Climates: Comparison with Traditional Design Methods"* , (MSc Diss., University of Leeds, 2003), 4
[28] Chimwemwe Banda, *Design of Waste Stabilization,* 41
[29] Diana Bernal, Amparo Cardona, Galvis and Miguel Peña, "Guia de Selección de Tecnologías Para El Tratamiento De Aguas Residuales Domésticas Por Métodos Naturales", 22, https://www.researchgate.net/profile/M_Pena2/publication/266219442_GUIA_DE_SELECCION_DE_TECNOLOGIA_PARA_EL_TRATAMIENTO_DE_AGUAS_RESIDUALES_DOMESTICAS_POR_METODOS_NATURALES/links/55bb8a0308aec0e5f4418c0d.pdf

Slow sand filter performance

The maturation time in the upper layer was 16 days. The averaged filtration rate was 0.03 m/h with an effluent flow of 10.08 L/h. The organic load and surface organic load of SSF were 0.06 Kg of BOD/day and 0.01 Kg/m^2.day respectively. As observed in Table *4*, the removal percentages for the slow sand filter exceeded 70% in most of the parameters analyzed, except for nitrogen and total phosphorus.

Table 4. Removal efficiency of slow sand filter

Parameters	**Slow sand filter effluent**	**Removal efficiency (%)**
BOD_5 (mg/L)	60	76,5
COD (mg/L)	60	84,2
TF (mg/L)	8	47,4
TS (mg/L)	40	80,3
DS (mg/L)	20	91,0
SS (mg/L)	21	78,1
TN (mg/L)	100	60,0
TC (MPN/100mL)	8	99,6
FC (MPN/100mL)	Not observed	100,0
pH	7,7	-

Source: Authors, 2016

Low sand filters are popularly used to remove suspended organic matter and pathogenic organisms. These processes are carried out in a matured biofilm (*Schmutzdecke*) on the surface of filter bed, and through several physical mechanisms such as adsorption, sedimentation, mass attraction and electrostatic forces developed in deeper layers[30][31].

The effectiveness of SSF in bacterial removal was reflected in results of coliform content in the effluent. In general, the most biological removal occurs in the top layer due to biochemical processes and breakdown of organic matter between algae and bacteria, as well as predation mechanisms by protozoan and rotifer[32].

Relation between filtration rate and coliform removal shows that at lower rates, better efficiencies are obtained. Thus, with a rate of 0.03 m/h and a maturation time of 16 days, optimal results were obtained.

BOD removal efficiency is determined by sand size, filter bed depth and organic load. With fine sands, deeper beds and stable organic loads, it is possible to remove up to 90% of the BOD from wastewater influent[33]. In this research, it was observed that at

[30] L Huisman and W Wood, *Slow Sand Filtration*, (WHO, 1974), 22, https://apps.who.int/iris/handle/10665/38974
[31] Ephrem Guchi, "Review on Slow Sand Filtration in Removing Microbial Contamination and Particles from Drinking Water", *American Journal of Food and Nutrition*, 3, n. 2 (2015), 47-54, http://pubs.sciepub.com/ajfn/3/2/3
[32] Ephrem Guchi, "Review on Slow Sand Filtration", 50
[33] Marshall, Gary R. and Middlebrooks, E. Joe, "Intermittent Sand Filtration to Upgrade Existing Wastewater Treatment Facilities, Reports", *Utah Water Research Laboratory*, (1974), 8, http://digitalcommons.usu.edu/water_rep/226

sand size of 0.2 mm and a bed depth of 40 cm drives an adequate BOD removal, maintaining similar organic loads according to (Zaidun, 2011)[34].

Results suggested by (Marshall, 1974, 32)[35], propose that removal of suspended solids increase when sand sizes between 0.17 and 0.72 mm are selected, confirming that sand diameters implemented (0.2 and 0.35 mm) in this research were adequate, obtaining removal higher than 70% for all solids analyzed.

Low phosphorous and nitrogen removals can be associated with formation of phosphates and nitrates as by-products derived from the oxidation and break down of organic matter through bacteria´s metabolism[36]. However, greater nitrate removal has been registered in SSF with filtration rates similar to those established in this research[37]. These elements may be transported to the effluent and can be used as nutrients supply for plant up take which presents an advantage in crop fertilization.

Removal efficiencies in treatments units

Comparing the two natural treatments respect to the removal efficiency, a better performance was observed in the SSF. For instance, removal of BOD, had 76.5% efficiency in SSF compared to 20.8% achieved in MP, considering that this type of ponds is not designed to remove high organic loads. To eliminate initial concentrations of BOD, the implementation of anaerobic or facultative ponds is advisable[38].

The removal of solids was carried out with greater efficiency in the SSF due to the physical-mechanical retaining mechanisms present in the filter bed, reaching removals of 80.3%, 91% and 78% for total, suspended and dissolved solids respectively. Comparatively. The MP obtained percentages of 26.1%, 55% and 24% for the same parameters.

Nutrient removal had better results in SSF, although this was not a significant removal compared to the other parameters. A reduction of 47% in total phosphorus and 60% in total nitrogen was obtained by the SSF, while in the MP 25.7% and 18% phosphorus and nitrogen removals were reached respectively. Cleaning the top layer by scrapping off was a principal factor of removal of these nutrients in SSF. Although the maturation pond is designed for disinfection and nutrient removal, the low algal growth did not allow for an adequate conversion of nutrients.

Quality assessment for agricultural reuse

Based on the concentrations obtained in the effluent from each treatment unit, the microbiological quality of the treated wastewater was assessed according to the parameters established by international guidelines and Colombian legislation to determine its viability for agricultural reuse *Table 5.*

---

[34] Zaidun Naji Abundi, "The Effect Of Sand Filter Characteristics On Removal Efficiency Of Organic Matter From Grey Water", *Al-Qadisiya Journal For Engineering Sciences*, n.2, (2011), 152, https://www.iasj.net/iasj?func=fulltext&aId=33554

[35] Marshall, Gary R. and Middlebrooks, E. Joe, "Intermittent Sand Filtration", 32.

[36] L Huisman and W Wood, *Slow Sand Filtration,* 32

[37] Sukru Aslan, "Biological Nitrate Removal In A Laboratory-Scale Slow Sand Filter", *Water SA*, n.1, (2008),100, http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1816-79502008000100012

[38] Duncan Mara and Miguel Peña, "Waste Stabilisation Ponds", 2

Table 5. Potential reuse assessment based on standards and regulations

Parameter	Treatment	WHO Standard 1989	US-EPA Standard 1992	Decree 1594/1984	Resolution 1207/2014	Reuse option
BOD	MP*	N/A***	Not suitable	N/A	N/A	----
	SSF**	N/A	Not suitable	N/A	N/A	----
Total Coliforms	MP	N/A	Not suitable	Suitable	Not suitable	None
	SSF	N/A	Not suitable	Suitable	Suitable	Unrestricted
Faecal Coliforms	MP	Suitable	Not suitable	Suitable	Suitable	Restricted
	SSF	Suitable	Suitable	Suitable	Suitable	Unrestricted

*Maturation pond
**Slow sand filter
*** Not applied

Source: Authors, 2016

As indicated in the table above, the effluent quality that complies with international and national guidelines regarding to microbiological conditions for agricultural reuse is the SSF However, in the MP, an effluent with prospective for agricultural reuse was only obtained for Colombian laws.

As was evidenced, the wastewater treated by the SSF is suitable for reuse on crops as fruits, and vegetables eaten raw or without removing the peel. Likewise, the total coliform concentration could not be compared because no specific international parameters are established for whole bacterial group. However, under Colombian law, this is suitable for crop irrigation.

It is also observed that international guidelines for the quality of wastewater in agricultural reuse are more restrictive than Colombian laws. This may be due to fact that international guidelines are formulated in relation to the treatment levels achieved in developed countries, whose processes are more efficient and can achieve higher purification levels on wastewater.

Conclusions

The slow sand filter performed with better removal for all the parameters analyzed in this research; therefore the treated wastewater from the “El Jardín” farm can be reused in unrestricted irrigation according to international and national guidelines.

The slow sand filter showed best efficiency in the inactivation of total coliforms and fecal coliforms with a removal of 99.6% and 100%, respectively, compared to the results obtained in the maturation pond with a removal of 50%, 2% and 55.7% for the same parameters. Slow sand filter success was due to the physical-chemical and biological removal mechanisms developed in the filter bed at low filtration rates, a 16-day maturation time, and sand sizes between 0.2 mm and 0.6 mm.

Bibliography

Abundi Zaidun Naji, "The Effect Of Sand Filter Characteristics On Removal Efficiency Of Organic Matter From Grey Water", *Al-Qadisiya Journal For Engineering Sciences* n.2, (2011): 152. https://www.iasj.net/iasj?func=fulltext&aId=33554

Aslan Sukru, "Biological Nitrate Removal In A Laboratory-Scale Slow Sand Filter", *Water SA* n.1, (2008):100. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1816-79502008000100012

American Public Health Association, American Water Works Association and Water Environment Federation, *Standard Methods for Examination of Water and Wastewater* AWWA, 2012. PDF Edition.

Banda Chimwemwe, "Modern Design of Waste Stabilization Ponds in Warm Climates: Comparison with Traditional Design Methods". MSc Diss., University of Leeds, 2003

Bernal Diana, Cardona Amparo, Galvis and Peña Miguel, "Guia de Selección de Tecnologías Para El Tratamiento De Aguas Residuales Domésticas Por Métodos Naturales". https://www.researchgate.net/profile/M_Pena2/publication/266219442_GUIA_DE_SELECCION_DE_TECNOLOGIA_PARA_EL_TRATAMIENTO_DE_AGUAS_RESIDUALES_DOMESTICAS_POR_METODOS_NATURALES/links/55bb8a0308aec0e5f4418c0d.pdf

CAR, *Plan de Accion de Educación Ambiental Del CIDEA*, 2013.

CONAGUA, *Manual De Agua Potable, Alcantarillado Y Saneamiento*, CONAGUA, 2007.

Cubillos Armando, "Estado Del Arte En El Diseño de Lagunas de Estabilización", *Revista de Ingeniería* n.2 (2001): https://revistaingenieria.univalle.edu.co/index.php/ingenieria_y_competitividad/article/view/2331/3081

Cruz Luis, Alayón Walter and Monsegny Carlos, "Metodología Para la Selección Del Regimen de Flujo en Lagunas de Estabilización", *Ingeniería e Investigación*, (2000): http://dx.doi.org/10.15446/ing.investig

Decreto 1594 de 1984, *Por el cual se reglamenta parcialmente el Título I de la Ley 9 de 1979, así como el Capítulo II del Título VI -Parte III- Libro II y el Título III de la Parte III -Libro I- del Decreto Ley 2811 de 1974 en cuanto a usos del agua y residuos líquidos*, art 40, Paragraph 1.

DNP, *Consultoría sobre productividad Del Uso Del agua y la eficiencia en el tratamiento de aguas residuales y en el reúso Del agua en Colombia: Resumen ejecutivo Del diagnóstico* 2017. https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Agua/Resumen_Dagnostico_Prodcutividad%20del%20agua.pdf

Guchi Ephrem, “Review on Slow Sand Filtration in Removing Microbial Contamination and Particles from Drinking Water”, *American Journal of Food and Nutrition* n. 2 (2015): 47-54, http://pubs.sciepub.com/ajfn/3/2/3

Henz Mogens *et al*, “Biological Wastewater Treatment: Principles, Modelling and Design”. *IWA*, (2008): https://doi.org/10.2166/9781780401867

Huisman L and Wood W, *Slow Sand Filtration*. WHO, 1974. https://apps.who.int/iris/handle/10665/38974

IDEAM, *Estudio Nacional Del Agua*. IDEAM, 2010. http://documentacion.ideam.gov.co/openbiblio/bvirtual/021888/021888.htm

Jiménez Blanca, “Irrigation in Developing Countries Using Wastewater”. *International Review for Environmental Strategies*, n. 2, (2008): 229-50. https://www.iges.or.jp/en/publication_documents/pub/peer/en/1199/IRES_Vol.6-2_229.pdf

Mara Duncan and Peña Miguel, “Waste Stabilisation Ponds”, *IRC International Water and Sanitation Centre* (2004): https://www.pseau.org/outils/ouvrages/irc_university_of_leeds_waste_stabilization_ponds_2004.pdf

Marshall, Gary and Middlebrooks Joe, "Intermittent Sand Filtration to Upgrade Existing Wastewater Treatment Facilities, Reports”, *Utah Water Research Laboratory*, (1974): 8. http://digitalcommons.usu.edu/water_rep/226

Ministerio de Desarrollo Económico, *Reglamento Técnico Para el Sector de Agua Potable y Saneamiento Básico- RAS*. 2000, section C, title 2.

Ministerio de Ambiente, *Gestión, Tratamiento, Disposición Final de Aguas Residuales Municipales.* Minambiente, 2002. https://repository.agrosavia.co/handle/20.500.12324/18911

Resolución 1207 de 2014, por la cual se adoptan disposiciones relacionadas con el uso de aguas residuales tratadas, art 7

UNEP, *A Snapshot of the World’s Water Quality: Towards a global assessment, Kenya*. UNEP, 2016. https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf

U.S Environmental Protection Agency, *Guidelines For Water Reuse: Manual*. EPA, 1992. PDF Edition.

Winans Kiara, “Small-Scale Natural Wastewater Treatment Systems: Principles and Regulatory Framework”, *Institute of Food and Agricultural Sciences*, (2012): 2-6. https://ufdcimages.uflib.ufl.edu/IR/00/00/09/86/00001/SS56600.pdf

Winpenny James, Heinz Ingo and Koo-Shima Sasha, *Reutilización del agua en la agricultura: ¿Beneficios para todos?* FAO, 2013. http://www.fao.org/3/a-i1629s.pdf

WHO, *Health Guidelines For The Use Of Wastewater In Agriculture And Aquaculture*. WHO, 1989. PDF Edition

WHO, *Guidelines For The Safe Use of Water, Excreta and Greywater. Wastewater use in agriculture.* WHO, 2006. https://www.who.int/water_sanitation_health/publications/gsuweg2/en/

WHO, *Guidelines For The Safe Use of Water, Excreta and Greywater. Excreta and Wastewater Use in agriculture*, v. 4. WHO, 2006. https://www.who.int/water_sanitation_health/publications/gsuweg4/en/

WWAP, *The United Nations World Water Development Report, 2014: water and energy*. UNESCO, 2014. https://sustainabledevelopment.un.org/content/documents/1714Water%20Development%20Report%202014.pdf

WWAP, *The United Nations World Water Development Report 4: managing water under uncertainty and risk*. UNESCO, 2012. https://unesdoc.unesco.org/ark:/48223/pf0000217175

WWAP, *Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2017. Aguas residuales: El recurso desaprovechado*. UNESCO, 2017. http://www.unesco.org/new/es/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/

.

.