TECHNOLOGY SELECTION FOR WATER DRINKING TREATMENT – HOW TO TAKE INTO ACCOUNT ENVIRONMENTAL ASPECTS?

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INTRODUCTION AND OBJECTIVES

The implementation of drinking water treatment plants (WTPs) in developing countries communities brings benefits to the population in terms of an increase in quality life. However, for a long time the environmental impacts of such technological solutions were not taking into account in the decision making process. Nowadays, in contrast, it is required that water and sanitation projects assess their environmental performance. The environmental impacts in WTPs are mainly generated by the constructed area, construction volumes, wastes produced in the treatment and the demand on filtering media, electrical energy and chemical products. The mentioned wastes represent a growing concern for Latin American sanitation companies given the more restrictive environmental policy and legislation that are quickly spreading in the region. The situation has encouraged researchers to look for new water treatment alternatives as well as options for use and dispose of wastes from WTPs. In view of these consideration this article aims at: i) indicating the environmental impacts that have to be considered in the technology choice of WTP; ii) presenting a generic methodology which takes into account the wastes produced in the treatment process in the framework of technology choice with sustainability criteria; and iii) assessing the wastes characteristics in function of the WTP type.

METHODS

In order to evaluate the environmental impacts that have to be considered for technology choice of WTP and to develop a generic methodology which allows for wastes produced by water treatment technologies, an extensive literature review of Latin American authors was made. The purpose of the literature review was to assess the main factors, variables and indicators that are concerned about environmental aspects in the selection of technology for drinking water treatment. Through a systemic interaction of these components (factors, variables and indicators) it was proposed a generic methodology to facilitate the selection of the most appropriate technological option, from an environmental point of view.

To assess the influence of the WTP type on the waste characteristics two elements were assessed: the operation and the cleaning patterns of the units of each technology (Tables 1 and 2). The technologies assessed were: complete cycle (CC), flotation-filtration (FF), descending direct filtration (FDD), ascending direct filtration (FDA) and multiple stages filtration (FiME). The flow rates considered for the analysis were 10, 20 and 40 L/s with the water quality indicated in Table 3. The unit operation and processes of each WTP are mentioned in Table 4. The estimation of the solid concentration generated by a WTP was obtained by Equation 1, as indicated in Di Bernando and Sabogal Paz (2008), which associates the turbidity with this concentration:

$$SST = aT \qquad \text{(Equation 1)}$$

Where SST: total suspended solid generated by the WTP (mg/l)

a: experimental coefficient

T: turbidity (Tu)

The “a” value was fixed at 1.45 following Sabogal Paz (2007). Since for water with low true color (see Table 3) the coefficient may vary between 0.7 and 2.2, it was taken an average value. The daily mass of retained solid for each unit of the WTPs was calculated with Equation 2, also indicated in Di Bernando and Sabogal Paz (2008). The results were altered according to the removal percentages in the cleaning operation of each unit of the system (values between 10 and 100%). These percentages were defined according to literature and experts recommendation.

$$MSST = 86.4\ Q\ (SST_{u1} - SST_{u2}) \qquad \text{(Equation 2)}$$

Where MSST: daily solid mass retained by each unit (kg/d)

Q: flow (m^3/s)

SST_{u1}: solids removed by the first unit (mg/L)

SST_{u2}: solids removed by the second unit (mg/L)

Table 1. Patter frequency for filter cleaning (using water only)

Technology	Filter type	Filtration run	Intermediate bottom discharge period (DFIs)	Filter cleaning duration or time required for DFIs
Complete cycle Flotation-filtration Descending direct filtration	Descending filter	24 h	(-)	10 min to clean the filter
Ascending direct filtration	Ascending coarse sand filter	36 h	12h	10 min to clean the filter and 1 min to DFIs
Double filtration	Ascending gravel filter	1 week	6 h, 12 h e 24 h (in function of turbidity)	5 min to clean the filter and 2 min to DFIs
	Descending filter	24 h	(-)	10 min to clean the filter
Multiple stages filtration	Dynamic filter	1 week	24 h	3 min to DFIs 10 min to clean the filter
	Ascending filter	1 month	1 week	3 min to DFIs and 30 min to clean the filter
	Slow sand filter	2 months	(-)	Only considered the time for sand scrape (2.6 to 3.5 h/filter)

Note: filter cleaning can be carry out in different way generating a variable waste volumes

(-): not apply.

Table 2. Pattern frequency for decanters discharges, removal of floats sludge and Flocculator cleaning in WTP

Technology	Activity	Approximate discharge time
Complete cycle	Discharge from the decanter in function of TSS concentration in the floating water (considering turbidity percentiles of 95% and 90%) and the volume of the sludge well: Every 2, 4 and 8 hours (for a flow in the WTP of 10 L/s) Every 3, 6 and 11 hours (for a flow in the WTP of 20 L/s) Every 4, 8 and 15 hours (for a flow in the WTP of 40 L/s)	< 1 min.
	Decanter complete semiannual cleaning (walls, bottom, discharge, etc)	10 min.
Flotation - Filtration	Float sludge removal	Continuous (24h/d)
Complete cycle and Flotation - Filtration	Flocculator complete annual cleaning	30 min (hydraulic flocculator) 10 min (mechanical flocculator)
Note: The procedures used in decanters, floats and flocculators cleaning interfere with water quality, mainly, in the solid concentration		

Table 3. Raw water quality to be treated in WTP and adopted filtration rate

Parameter	Water Type 1			Water Type 2			
	FDD_1	FDA_1	$FiME_1$	DF_1	$FiME_2$	FF_1	CC_1, CC_2
Filtration rate (m^3/m^2d)	FRD: 180	FRAAG: 180	PFD: 24 FLA: 3	FAP: 120 FRD: 180	PFD: 24 PFVA: 18 FLA: 3	FRD: 180 TR: 10%	FRD: 180
Turbidity (uT)	100% ≤ 25; 95% ≤ 15; 90% ≤ 10			100% ≤ 100; 95% ≤ 50; 90% ≤ 30			
True color (uH)	100% ≤ 20; 95% ≤ 15; 90% ≤ 10			100% ≤ 20; 95% ≤ 15; 90% ≤ 10			

Note: the sub-indexes indicates the variations of the technology in accordance with unit operations and processes considered

FRD: descending filter; FAP: ascending gravel filter; PFD: dynamic filter; FLA: slow sand filter; PFVA: ascending filter in layers; TR: pressurized water recirculation rate; FRAAG: ascending filter in coarse sand

Table 4. Characteristics of the assessed water treatment technologies

Technology	Technology variations	Unit operations and treatment processes
Complete cycle	CC_1	MRHVR + FHCEH + DAT + FRDC + DES + FLU
	CC_2	MRHVR + FMEVTI + DAT + FRDC + DES + FLU
Ascending direct filtration	FDA_1	MRHIM + FRAAGC + DES + FLU
Descending direct filtration	FDD_1	MRHIM + FRDC + DES + FLU
Double filtration	DF_1	MRHIM + FAP + FRDC + DES + FLU
Flotation-filtration	FF_1	MRHVR + FMEVTI + FAD + FRDC + DES + FLU
Multiple stages filtration	$FiME_1$	PFD + FLA + DES + FLU
	$FiME_2$	PFD + PFVAC + FLA + DES + FLU

MRHVR: hydraulic rapid mix with rectangular hydraulic weir
MRHIM hydraulic rapid mix with injector and mesh
FHCEH: horizontal flow hydraulic flocculator
FMEVTI: vertical axis mechanical flocculator with inclined blades
DAT: plates high rate clarifier
FAD: flotation by dissolved air with pressurization of the recirculation
FRDC: descending quick filtration in sand, at constant rate
FRAAG: ascending filtration in coarse sand, at constant rate
FAP: ascending filtration in gravel, at constant rate
FLA: slow sand filter, at constant rate.
PFD: dynamic thick filter, at constant rate.
PFVAC: dynamic thick filter in layers, at constant rate.
DES: disinfection with sodium hypochlorite.
FLU: fluorination with fluorine silicic acid.
Note: the sub indexes indicates the variations of the technology in accordance with unit operations and processes considered

RESULTS AND DISCUSSION

Environmental aspects in the selection of technology for drinking water treatment

According to Gandini and Galvis (2000) the environmental aspects considered in the selection of technology for drinking water treatment have to deal with the conflict between development and environment. On the one hand, there is a significant increase in life quality in the population which benefits from a drinking water supply system, and on the other hand, the environmental impacts generated by the civil works of the raw water uptake, the distribution net and the production and consumption of drinking water. The meaning of sustainability in drinking water supply systems, from an environmental perspective, comes to terms with an environmental offer (available resources) confronted with a social demand (meet the drinking water needs). Thus, in the long term a sustainability criterion should guarantee the relationship: *environmental offer > social demand.*

The environmental offer includes two functions that render a water supply possible: the supply function and the reception function. While the former provides raw water to the system in terms of both quantity and quality, the latter is referred to the environment carrying capacity to receive and assimilate the wastes generated in the production and consumption of drinking water and the effects of raw water uptake and of the whole system construction.

The social demand for the supply functions regards: i) the quantity of water needed, which depends on the population characteristics and associated water uses; and ii) the quality of drinking water required to fulfill the health normative. The social demand for the reception function is related to the assimilation of the environmental impacts mentioned above. From an environmental point of view, the environmental impact is the most important factor to be considered in the selection of technology for drinking water treatment. Table 5 indicates the variables and indicators that configure this factor. Another relevant aspect is the associated sanitary risk due to the raw water quality. This factor deals with the technical aspects of technology choice and the treatment efficiencies of technologies.

Table 5. Factors, variables and indicator to evaluate the environmental aspects in the selection of treatment water technologies

Factors	Variables	Indicators (*)
Environmental Impact (environmental assimilative capacity > impact produced by WTPs)	Build area (change in land uses)	$IIA_1 = \frac{\text{Assessed technology area } (m^2)}{\text{Area required by the most extensive technology } (m^2)}$
	Construction volumes (**) (WTP dimensions)	$IIA_2 = \frac{\text{Assessed technology concrete volume } (m^3)}{\text{Volume of the technology that needs more concrete } (m^3)}$
	Impact due to wastes production (liquid or solid)	$IIA_3 = \frac{\text{Assessed technology liquid waste volume } (m^3)}{\text{Volume of the technology that generates more liquid waste } (m^3)}$ $IIA_4 = \frac{\text{Assessed technology generated solid waste } (kg)}{\text{Solid waste generated by the technology which contributes the most } (kg)}$
	Used water in units cleaning (additional treated water volume which is not distributed into the population)	$IIA_5 = \frac{\text{Water used in cleaning activities in the assessed technology } (m^3)}{\text{Water used in cleaning activities in the technology which contributes the most } (m^3)}$
	Energy needs (impacts associated to electrical energy generation)	$IIA_6 = \frac{\text{Consume of electrical energy by the assessed technology } (kWh)}{\text{Consume of electrical energy by the technology which contributes the most } (kWh)}$
	Chemical products needs (impacts associated with the production and transport of chemical inputs)	$IIA_7 = \frac{\text{Chemical inputs required by the assessed technology } (kg \text{ o } L)}{\text{Chemical inputs required by the technology which contributes the most } (kg \text{ o } L)}$
	Filter media needs (impacts associated with the extraction and transport of materials)	$IIA_8 = \frac{\text{Media filter required by the assessed technology } (m^3)}{\text{Media filter required by the technology which contributes the most } (m^3)}$
	Total environmental impact	$IIA_T = a\,IIA_1 + b\,IIA_2 + c\,IIA_3 + d\,IIA_4 + e\,IIA_5 + f\,IIA_6 + g\,IIA_7 + h\,IIA_8$ Where: $a + b + c + d + e + f + g + h = 1{,}0$ e $0 \leq IIA \leq 1{,}0$

(*)Considering the particularities of the study area, it is the design engineer who has to weigh the indicators presented for assessing the environmental aspects in the selection of water treatment technologies.
(**)The volume can be calculated with another material, for example, resin, metal plate, masonry, etc.
a, b, c, d, e, f, g, h: weighting factors for each activity which generates environmental impact;
IIA: environmental impact index

In Table 5 the indicators can be calculated by establishing an environmental quality index for a quantifiable magnitude of a certain activity that generates an environmental impact, as it is shown in Figure 1. It can be observed that in the x-axis the magnitudes of the activity that generates impacts are located (build area, construction volumes, waste production, water consumption for cleaning, etc) and in the y-axis an indicator of environmental quality so-called Environmental Impact Index (IIA).

In Figure 1, the magnitude of the generating impact activities is known, for a set of applicable technologies, so it is possible to establish IIA=1.0 for the technology which has greatest magnitude. Then proportionally, according to the slope of the line, the IIA for the other technologies en consideration can be read. In the figure the technology Tx has a IIA=1.0, the technology Tm a IIA=0.7, and the technology Tk a IIA=0.2 for a given impacting activity. In this sense, if IIA=1 for a technology, it means that this technology will cause the biggest impact among the possible technologies. Accordingly, if IIA goes near zero for a technology it points out that its associated impact is smaller than the expected effects of the other possible technologies. To apply this methodology, first the IIAs have to be calculated in accordance with Table 5. Then the technology selection criterion will be the minor environmental impact associated to water treatment.

Methodology for technology choice considering the wasted produced in WTPs

While in the last item technology choice for water treatment was evaluated from the perspective of the environmental impact originated by the systems as a whole, in this section technology choice is discussed in relation to the impacts originated by the production of wastes in the treatment processes only. In this case, after selecting the unit operations and processes that conform a WTP, it has to be assessed the treatment, potential use and final disposal of the wastes. The factors, variables and indicators proposed for this purpose are presented in Table 6. Additionally, Figure 2 shows a flow diagram for the recommended methodology. The indicators weighting depends on the following activities: i) literature review of wastes generated in WTPs; ii) review of pertinent environmental legislation; iii) selection of technologies for treatment, use and final disposal to be evaluated; and iv) systemic analysis between WTPs and the technologies mentioned in (ii) according to Figure 3.

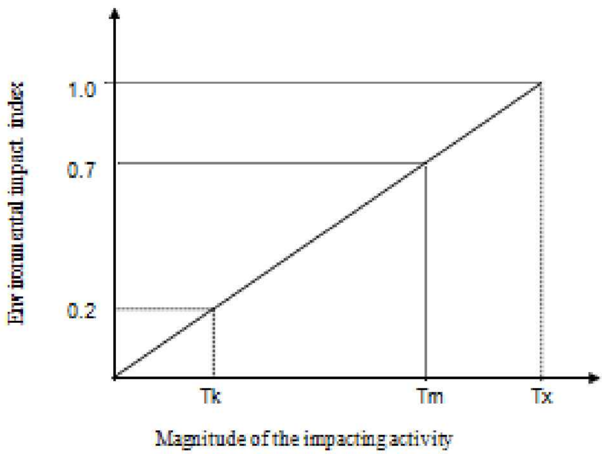


Figure 1. Representation of the environmental impact index

Table 6. Factors, variables and indicator

Factors	Variables	Indicators (*)
WTP characteristics	WTP type	• Existing or in draft form • Complete cycle, direct filtration, flotation-filtration, multiple stages filtration, among others
	Type of chemical products used in the treatment	• Coagulant, polymer, activated carbon, etc.
	Quantity and quality of raw water	• Variable, constant.
	Cleaning operation of the units	• Daily, weekly, monthly and yearly.
	primary coagulation mechanism	• Sweeping or neutralization of charges
Characteristics of the wastes generated in WTP	Waste type	• Cleaning of filters, discharge decanters, shaving of floats, and so on.
	Methods for determining the qualitative and quantitative characteristics of the sludge.	• Chemical analysis and laboratory tests
	Parameters adopted to evaluate the characteristics of the wastes.	• Dry solids concentration (% mass / mass)
Unit operation and processes of treatment of WTP wastes	Treatment objectives	• Reducing moisture content compatible with the techniques for the use or disposal
	Characteristics of treatment processes and operations	• Hydraulic, mechanical, others.
	Type of units to carry out the treatment processes and operations	• Conditioning, equalization, adjustment, thickening, dewatering, drying and incineration.
Wastes treatment plants – PTRs	Combination of treatment processes and operations	• Types of PTRs (systems with sludge lagoons, drying beds, etc)
	Dry solids concentration expected after treatment	• Concentration as a function of treatment (% mass / mass)
	Chemicals used in the treatment	• Polymer, lime, among others.
Technologies for wastes uses	Available techniques to use the wastes from WTP	• Manufacture of brick or block ceramic matrix incorporation into concrete, recovery of agricultural land, and so on. .
	Dry solids concentration needed to use wastes	• Depending on the type of technique utilization of waste (% mass / mass).
Wastes final disposal methods	Techniques for waste disposal from WTP	• Wastewater treatment plant- WWTP, water supply source, landfill, etc.
	Solids concentration needed to waste final disposal	• Depending on the type of final disposal technology available
Clarified water generated by PTRs	Define the PTRs that produce clarified water	• Sludge lagoons, drying beds, centrifuge, etc..
	Evaluation of treatment technologies, use and disposal.	• Disposal on water sources, agricultural use, among others.

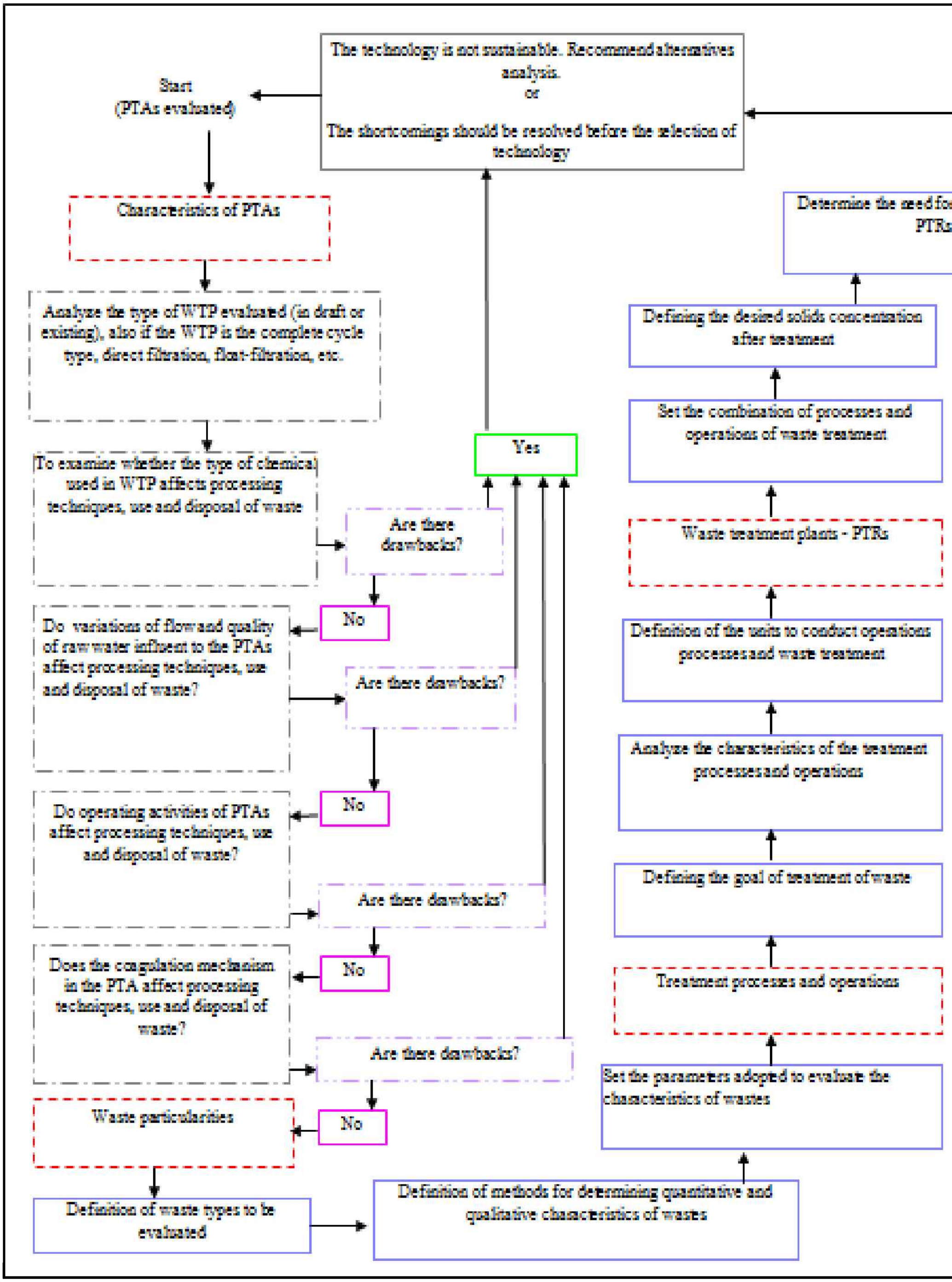
Technology transfer	• Use of certain process and processing operations in built PTRs. • Processes and waste treatment operations that are taught in universities (**) • Consultation with experts in the area or treatment, use and disposal of waste.	• Index 1 (%) = number of PTRs built with the treatment process or operation studied / evaluated number of PTRs • Index 2 (%) = number of universities that teach the process or operation of treatment assessed / number of universities consulted. • Index 3 (%) = number of experts recommend the process or operation analyzed / total number of experts consulted. • Level of institutionalization (%) = Index 1 + Index 2 + index 3
Legislation	Treatment, use and disposal of waste under national legislation.	• Resolutions, rules, laws, etc.
Study area particularities	Availability of spare parts, building materials and services.	• Number of stores that sell hydraulic, mechanical, electrical and construction accessories. • Continuity and origin of the electrical service (interconnection, local or on-site generation), and installed capacity. • Distance to the nearest urban center you can find chemicals, construction materials and spare parts.
	Local technical support	• Number of Offices MEE in the community • Number of technicians in the community in the fields of mechanics, electricity, chemistry, etc.
	Availability of chemicals	• Number of stores selling chemicals in the community.
	Location of the community.	• Easy or difficult to access by land, air, river or sea. • Features access to PTA. • Distance to the nearest urban center and means of transport. • State of the track, if it's terrestrial
	Distance from the PTA to the final destination of the waste.	• Km
	Weather in the region	• Evaporation rate, precipitation rate, etc.
	Availability of WWTP in the study area	• There is or not
	Availability of industrial landfill in the community	
	Availability of brick or ceramic blocks in the study area	
Systemic analysis	Relationship between WTP, PTRs, waste uses techniques and methods of waste disposal	• Assessment of all the variables and indicators selected according to Figure 3.

(*) Considering the particularities of the study area, it is the design engineer who has to weigh the indicators presented for assessing the environmental aspects in the selection of water treatment technologies.
(**) Only undergraduate level because not all professionals have the opportunity to undertake graduate studies

As indicated by Sabogal Paz (2007), the selection of technologies for WTP with bigger perspectives of sustainability can be guided using Figure 3. The scheme **(a)** is used to explain the concept of sustainability in sanitation projects. Thus, from the perspective of water treatment three correlated dimensions have to be taken into account: environment, technology and community.

The environment is the surroundings where the community manages is development. It can be seen as water offer (quantity and quality of raw water) and resources availability (energy, weather, area, raw construction materials, etc). The community is the people who are the target of the project (beneficiaries, operators and system maintainers). From the relationship between environment and community rise the risk factors (presence of heavy metals, microorganisms, organic, inorganic and

Figure 2. Flow chart of the recommended methodology for evaluating the wastes generated in WTP



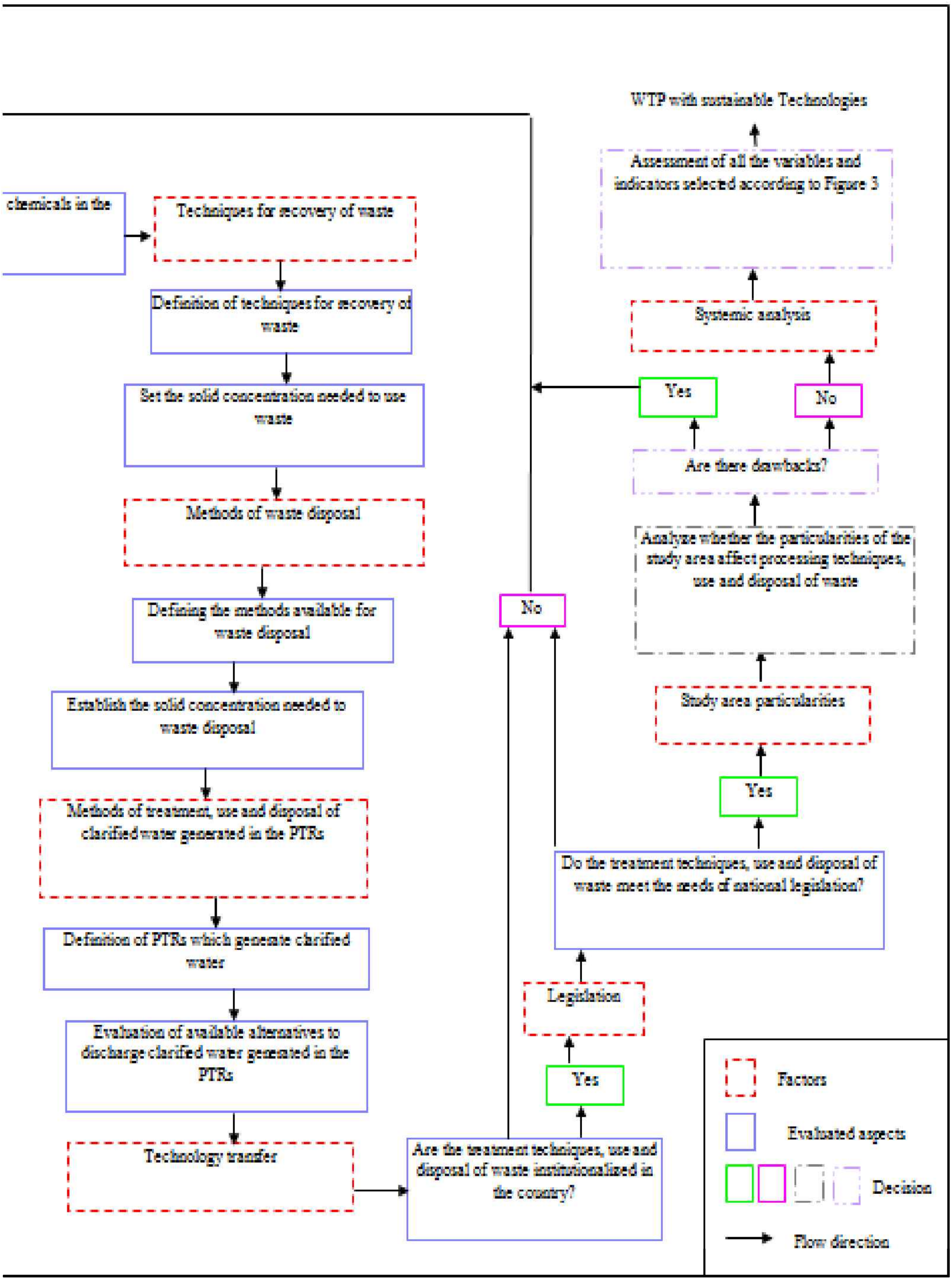
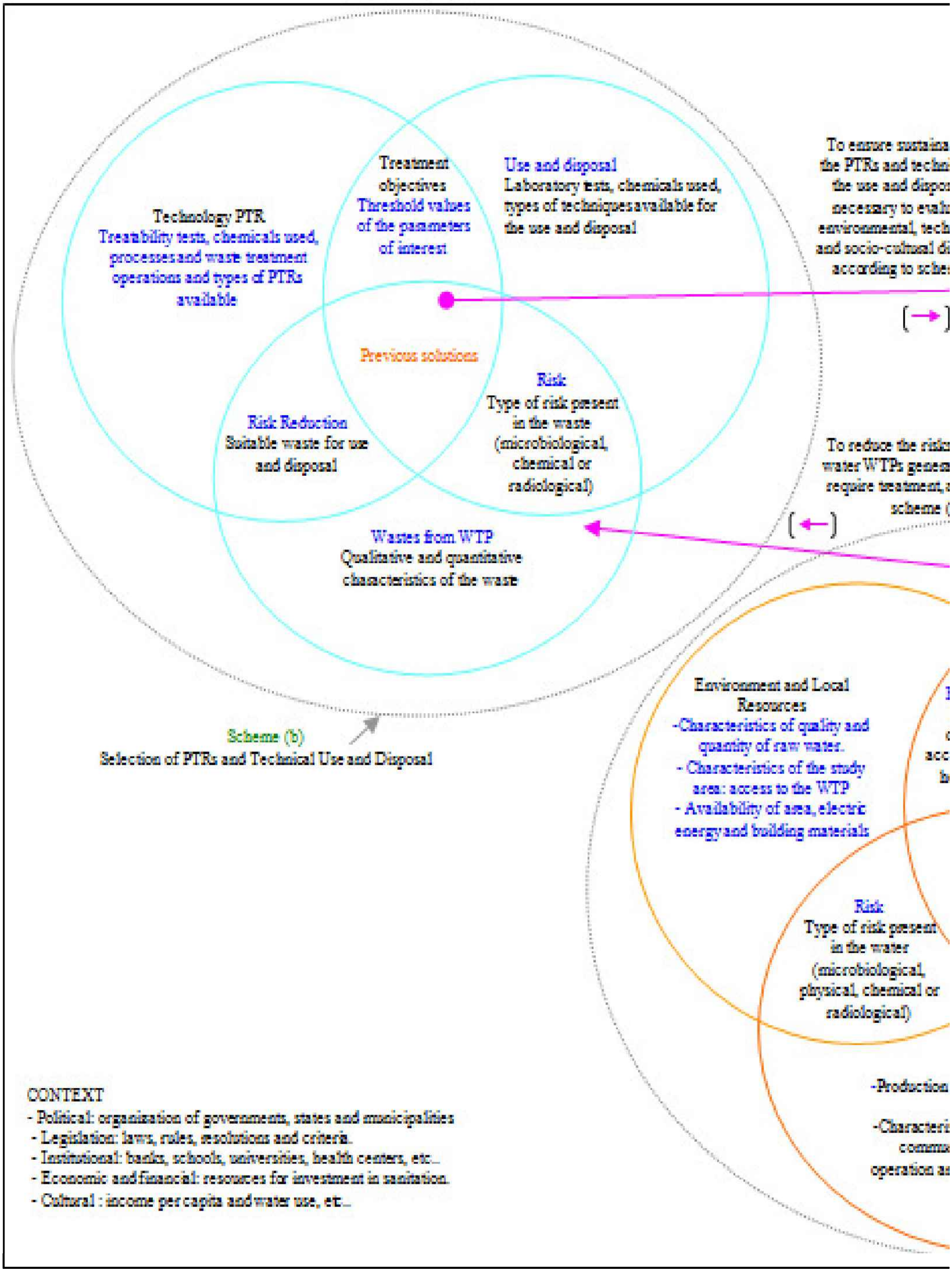
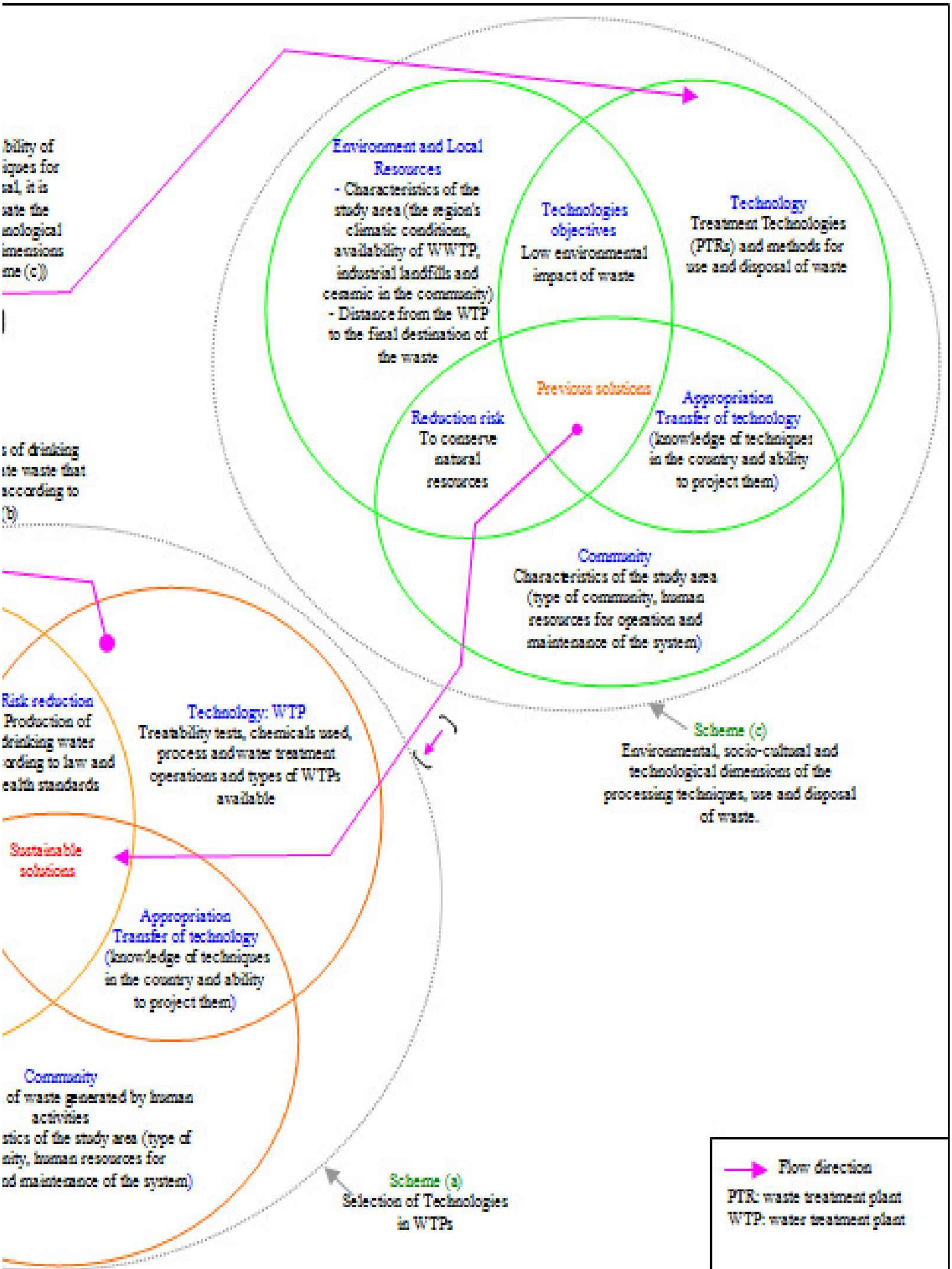

WTP with sustainable Technologies
Assessment of all the variables and indicators selected according to Figure 3
chemicals in the
Techniques for recovery of waste
Definition of techniques for recovery of waste
Systemic analysis
Set the solid concentration needed to use waste
Yes
No
Are there drawbacks?
Methods of waste disposal
Analyze whether the particularities of the study area affect processing techniques, use and disposal of waste
Defining the methods available for waste disposal
No
Establish the solid concentration needed to waste disposal
Study area particularities
Yes
Methods of treatment, use and disposal of clarified water generated in the PTRs
Do the treatment techniques, use and disposal of waste meet the needs of national legislation?
Definition of PTRs which generate clarified water
Legislation
Evaluation of available alternatives to discharge clarified water generated in the PTRs
Yes
Factors
Evaluated aspects
Technology transfer
Are the treatment techniques, use and disposal of waste institutionalized in the country?
Decision
Flow direction

Figure 3 - Systemic vision to select sustainable WTP (Sabogal Paz, 2007)




Environment and Local Resources
- Characteristics of the study area (the region's climatic conditions, availability of WWTP, industrial landfills and ceramic in the community)
- Distance from the WTP to the final destination of the waste
Technologies objectives
Low environmental impact of waste
Technology
Treatment Technologies (PTRs) and methods for use and disposal of waste
Previous solutions
Reduction risk
To conserve natural resources
Appropriation
Transfer of technology
(knowledge of techniques in the country and ability to project them)
Community
Characteristics of the study area (type of community, human resources for operation and maintenance of the system)
Scheme (c)
Environmental, socio-cultural and technological dimensions of the processing techniques, use and disposal of waste.
Risk reduction
Technology: WTP
Treatability tests, chemicals used, process and water treatment operations and types of WTPs available
Sustainable solutions
Appropriation
Transfer of technology
(knowledge of techniques in the country and ability to project them)
Community
of waste generated by human activities
Scheme (a)
Selection of Technologies in WTPs
Flow direction
PTR: waste treatment plant
WTP: water treatment plant

radiological substances in the supply source) as a consequence of environmental impacts brought about by entropic activities. As a response to the risks the community creates technologies to modify and reduce them, with the aim of producing drinking water that meets health criteria. In order to be efficient, the technologies must be appropriated by the community (technology knowledge and capacity for designing, building and sustaining it).

The scheme **(a)** does not assure the sustainability of water supply projects given that treatment, potential uses and final disposal of wastes generated by WTP were not considered in the analysis. Since these wastes increase the environmental impacts due to human interventions, scheme **(a)** becomes a vicious circle. In consequence, schemes **(b)** and **(c)** arise with the intention of intruding the lacking factors, in order to close the loop.

In scheme **(b)** the characteristics, potential uses and final disposal options of wastes are considers with their respective interactions. From the relationship between wastes and their final disposal risk emerges, which has to be minimized in accordance with the goal-parameters of treatment for potential uses and disposal in the environment. Then, scheme **(c)** carries out the assessment of the solutions obtained in **(b)** in line with environmental, technological, social and cultural dimensions and their mutual dependencies. The outcome of this process goes again to scheme **(a)** with a higher probability of sustainability, in the political, normative, institutional, economical, financial and cultural framework.

Schemes **(a)**, **(b)** and **(c)** represent the systemic vision of sustainability. In this context, the selection of technologies for WTP cannot be separated from the technologies for treatment, use and final disposal of wastes, as it is frequently being done by several Latin American companies, causing important degradation of environmental resources (For example see Figure 4).

In the search for sustainable solutions, the ideal condition would be to decide on technologies which do not generate wastes. Given that this condition is not real, the chosen technology must be efficient in reducing the risk associated with the raw water quality (following the legislation guidelines) and, at the same time, produce a waste that can be treated, used and disposed in a way that minimize the potential negative effects.

Figure 4. Sludge discharge from WTP (DIAS *et al.* 2004)

Influence of the WTP type on the wastes characteristics

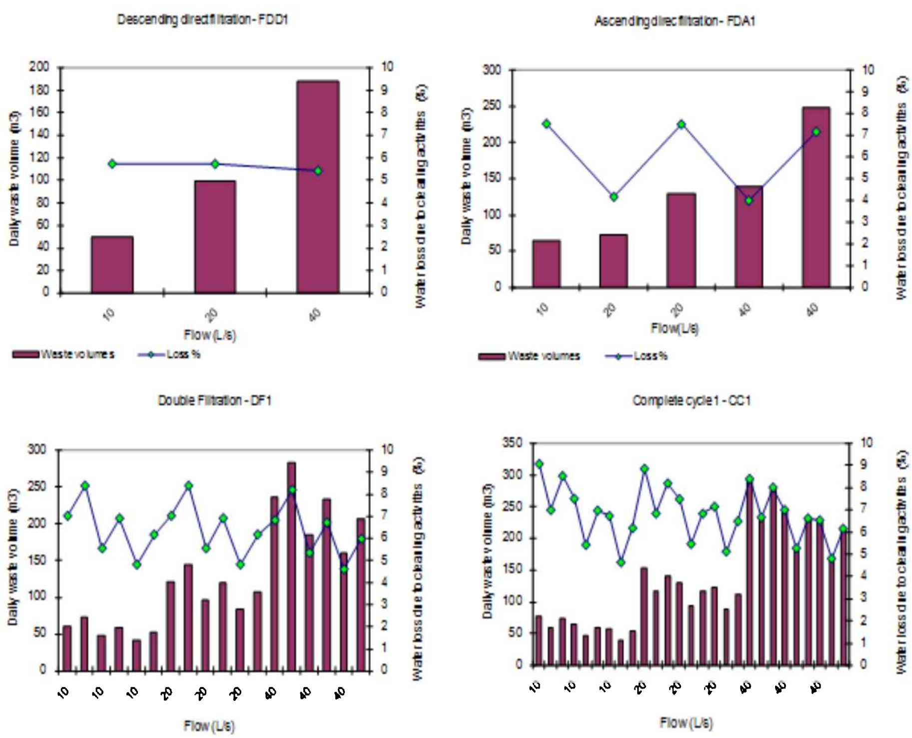
The daily volumes of waste produced by the WTP were calculated according to the pattern clean indicated in Tables 1 and 2. In Figure 5 and Table 7 it is verified that the systems of descending direct filtration (FDD_1) and ascending direct filtration (FDA_1) present the minor variability in the daily waste production. This situation occurs because the biggest proportion sludge is produced in one unit, the filter. Thus, in other treatment systems such as double filtration (DF_1), complete cycle (CC_1 and CC_2) and filtration in multiple stages ($FiME_2$) there is a big variation of daily waste volumes since they have more treatment units. It can be seen in Figure 5 and Table 7 that treatment systems spend, on average, 6% of treated water for units cleaning. The biggest lost (9%) was fond for complete cycle (CC_1 and CC_2) when flocculators and filters were cleaned in the same day as well as the discharge from the decanters.

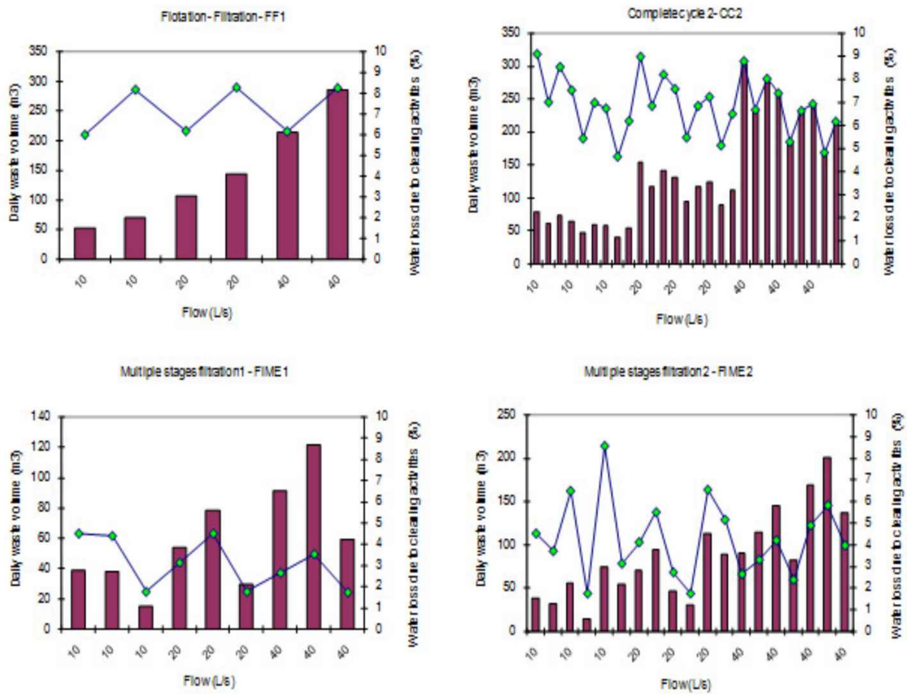
Table 7 - Volumes of waste produced by the WTP

ETA	Flow (L/s)	Flow (m^3/d)	Daily waste volume (m^3)	Loss of treated water daily due to cleaning activities (%)
FDD_1	10	864	49,7	5,75
	20	1720	99,3	5,75
	60	3456	188,1	5,66
FDA_1	10	864	65,2	7,55
	20	1728	72,2	4,18
			130,0	7,52
	60	3456	138,6	4,01
			248,1	7,18
DF_1	10	864	60,7	7,03
			72,4	8,38
			48,1	5,57
			59,7	6,91
			41,8	4,84
			53,4	6,18
	20	1728	121,5	7,03
			144,8	8,38
			96,2	5,57
			119,5	6,92
			83,6	4,84
			106,9	6,19
	60	3456	236,1	6,83
			283,2	8,19
			185,2	5,36
			232,4	6,72
			159,8	4,62
			207	5,99
CC_1	10	864	78,3	9,06
			60,4	6,99
			73,6	8,52
			64,8	7,50
			46,9	5,43
			60,2	6,97
			58,1	6,72
			40,1	4,64
			53,4	6,18
	20	1728	152,8	8,84
			118,1	6,83
			141,5	8,19
			129,3	7,48
			94,5	5,47
			118	6,83
			123,4	7,14
			88,6	5,13
			112,1	6,49
	60	3456	289,8	8,39
			230,4	6,67
			276,6	8,00
			241,8	7,00
			182,4	5,28
			228,6	6,61
			225,7	6,53
			166,4	4,81
			212,6	6,15
CC_2	10	864	78,4	9,07
			60,4	6,99
			73,6	8,52
			64,9	7,51
			46,9	5,43
			60,2	6,97
			58,1	6,72
			40,1	4,64
			53,4	6,18
	20	1728	154,8	8,96
			118,1	6,83
			141,5	8,19
			130,7	7,56
			94,5	5,47
			118,0	6,83
			124,8	7,22
			88,6	5,13
			112,1	6,49
	60	3456	303,0	8,77
			230,4	6,67
			276,6	8,00
			255,0	7,38
			182,4	5,28
			228,6	6,61
			239,0	6,92
			166,4	4,81
			212,6	6,15

	40	3456	255,0	7,38
			182,4	5,28
			228,6	6,61
			239,0	6,92
			166,4	4,81
			212,6	6,15
FF_1	10	864	52,0	6,02
			70,8	8,19
	20	1728	107,2	6,20
			143,4	8,30
	40	3456	213,4	6,17
			285,9	8,27
$FIME_1$	10	864	39,0	4,51
			28,0	4,60
			15,0	1,74
	20	1728	54,0	3,13
			78,0	4,51
			30,0	1,74
	40	3456	91,0	2,63
			122,0	3,53
			59,0	1,71
$FIME_2$	10	864	39,0	4,51
			32,0	3,70
			56,0	6,48
			15,0	1,74
			74,0	8,56
	20	1728	54,0	3,13
			71,0	4,11
			95,0	5,50
			47,0	2,72
			30,0	1,74
			113,0	6,54
			89,0	5,15
	40	3456	91,0	2,63
			114,0	3,30
			145,0	4,20
			82,0	2,37
			169,0	4,89
			201,0	5,82
			137,0	3,96
Note: the volume of wastes change in function of operation and cleaning of units.				

Figure 5. Daily waste volumes in function of WTP type (Sabogal Paz, 2007)





In Figure 5 it is shown than the lowest water consumption for cleaning (about 2%) was observed for multiple stages filtration systems ($FiME_1$ and $FiME_2$), when during the day the discharge from the dynamic filter was made only. From Figure 5 and Table 7 it is hard to determine the systems which produce the biggest waste volumes in function of daily variations , but in a monthly accumulated basis, the complete cycle (CC_1 and CC_2), the double filtration (DF_1) and flotation-filtration (FF_1) systems are the ones with major impacts. In the analysis it was verified a proportional relationship between the WTP flow and the generated waste produced by the system.

With Equation 1 it was calculated the daily mass of solids removed in the WTP (Table 8), based on raw water turbidity, considering the use of 1.45 as the value of the "a" coefficient. It is emphasized that this coefficient varies significantly depending on the characteristics of raw water, so the values given in this article should be analyzed only as a guide.

Table 8. Mass of Total Suspended Solids removed daily in WTP

ETA	Turbidity percentile								
	100%	95%	90%	100%	95%	90%	100%	95%	90%
	Daily Mass of TSS removed by WTP (kg/d)								
	10 L/s			20 L/s			40 L/s		
DF_1	101	51	31	203	103	63	406	205	125
	125	63	38	251	125	75	501	251	150
FDD_1	31	19	13	63	38	25	125	75	50
FDA_1	31	19	13	63	38	25	125	75	50
CC_1 e	125	63	38	251	125	75	501	251	150
CC_2	127	64	38	255	127	76	509	255	153
$FiME_1$	15	9	6	32	19	13	65	39	26
	22	13	8	37	22	14	72	42	28
	17	10	7	34	20	14	68	41	27
$FiME_2$	40	20	12	85	43	26	174	87	52
	163	82	49	204	102	61	332	166	99
	181	90	53	221	110	65	355	177	105
	45	23	14	209	104	63	338	169	101
	101	51	30	90	45	27	249	124	75
	(-)	(-)	(-)	142	71	42	272	135	81
	(-)	(-)	(-)	147	73	44	256	128	77
(-) not applicable									

It can be observed in Tabla 8 that direct filtration (FDD_1 and FDA_1) and multiple stages filtration ($FiME_1$) evidence the minor daily production of SST, given the better quality of the raw water for which these technologies are suitable for. Table 9 shows the annual volume of wastes generated by WTP and that are treated by dehydration reaching a 20% dry solids concentration (mass/mass).

Table 9. Annual volume of solids of dried sludge

ETA	Turbidity percentile								
	100%	95%	90%	100%	95%	90%	100%	95%	90%
	Annual volume of the cake (dry solids concentration in the cake of 20% m / m) - m^3 (*)								
	10 L/s			20 L/s			40 L/s		
DF_1	≤172	≤87	≤53	≤343	≤173	≤105	≤690	≤346	≤210
FDD_1 / FDA_1	≤51	≤29	≤22	≤102	≤62	≤40	≤204	≤124	≤84
CC_1 / CC_2 / FF_1	≤204	≤102	≤62	≤412	≤204	≤124	≤824	≤412	≤248
$FiME_1$	≤30	≤18	≤12	≤52	≤32	≤21	≤106	≤65	≤43
$FiME_2$	≤122	≤60	≤36	≤224	≤111	≤67	≤470	≤235	≤141
(*) The value of dry solids can be achieved with natural techniques of treatment (sludge lagoons or drying beds) or machined (thickener and centrifuge or filter press).									

With the waste volume without treatment (Table 7) or with the volume of dehydrated sludge (Table 9) it can be determined the costs of wastes use and final disposal, adopting a unit value per cubic meter of uptake, transport, use or disposal, including for the latest the rates of the wastes acceptance in industrial landfill or wastewater treatment plants.

In accordance with Tables 7 and 9, the descending direct filtration (FDD_1), ascending direct filtration (FDA_1) and multiple stages filtration ($FiME_1$) technologies generate smaller environmental impacts, since they accordingly produce less wastes, suggesting that these technologies should be preferably chosen for WTP. However, technology choice does not only lie on environmental considerations, but also on technical, economical, financial and cultural aspects, as presented in Figure 3. Obviously, preserved water source imply that treatment can be carried out with more simple technologies that generate less wastes and associates costs. It then results that preserving water resources entail minor environmental impacts coming from WTP wastes and functions.

CONCLUSIONS

The environmental aspects which have traditionally been left out of the decisions making in relation to selection of technology for drinking water treatment are an important element for the sustainability of water supply systems. In this sense, the environmental offer en terms of the supply function and the reception function should be regarded having in mind its fragile and finite character.

Tables 5 and 6 and Figure 3 show the main factors, variables and indicators that have to be considered in the selection of technologies for WTP in function of environmental aspects. It is noted that there is a great variety of indicators that a professional in charge of a project must quantify, depending on the area of interest.

Given that all the water treatment technologies do cause environmental impacts the final choice has to assure the required efficiency to meet health drinking water standards while minimizing the associated environmental impact through treatment, use and final disposal of wastes.

WTPs present great variations in the daily waste produced in cleaning activities commonly adopted, as it is the case of complete cycle (CC_1 and CC_2), double filtration (DF_1) and multiple stages filtration ($FiME_2$) systems. Thus, in terms of dehydration of the sludge (wastes), the equalization and regularization of flow is required.

BIBLIOGRAPHY

DIAS, L. M; BATALIONE, G; MORAIS, F. U; SOBRINHO, J. F; RIBEIRO, M. C; LISBOA, M. S (2004). *Alternativas de Destinação Final do Lodo de Estações de Tratamento de Água – Fabricação de Blocos Cerâmicos.* XXIX Congreso Interamericano de Ingeniería Sanitaria y Ambiental. San Juan, Puerto Rico. AIDIS.

DI BERNARDO, L; SABOGAL PAZ, L. P (2008). *Seleção de Tecnologias de Tratamento de Água.* Editora LDiBe. v 1 e v.2. p.1560.

GANDINI, M. A; GALVIS, C.A (2000). *La Dimensión Ambiental en la Selección de Tecnología de Agua Potable.* Seminario Taller de Selección de Tecnología para el Mejoramiento de la Calidad del Agua. Cali. Colombia.

SABOGAL PAZ. L. P (2007) *Modelo Conceitual de Seleção de Tecnologias de Tratamento de Água para Abastecimento de Comunidades de Pequeno Porte.* 509 p. These PhD. Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos. Brazil.

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