Global Knowledge Based Technologies for Water Supply and Sanitation in Rural and Peri-Urban Areas – An Integrated Approach for Various Stakeholders and Decision Makers

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Abstract

Access to improved water supply and sanitation remains a big challenge for the developing world. This paper reviews global knowledge based technologies and practices for water supply and sanitation, including reuse and recycling technologies while focusing on technologies for the rural and peri-urban areas in developing countries. The review is based on a compilation of existing information provided by scientific literature, project reports and technical data sheets from international organisations. Differences between various technological systems for water supply and sanitation are considered. By classifying (waste) water treatment systems along with matrices and by using complexity and treated water/effluent quality as the main criteria, this paper gives a logical and understandable overview of different stakeholders and decision makers operating in the water sector. For sanitation systems an additional matrix was constructed with sanitation systems classified using size (of population to be served) and water demand as criteria.

Keywords: sanitation, water supply, technologies, stakeholders, decision making.

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1. Introduction

1.1 Water supply and sanitation (WSS) in rural and peri-urban areas, a global perspective.

Clean water supply and adequate sanitation remain a global challenge. It is estimated that 1.1 billion of people do not have an access to clean water, whereas 2.6 billion have inadequate sanitation (UNDP 2006). Achievement of Millennium Development Goal (MDG) number 7, target 10, which aims at halving the proportion of people without sustainable access to safe drinking water and basic sanitation by year 2015 is not certain in many parts of the world. Access to both improved water supply and sanitation lags behind in the poorest communities which are rural areas and urban and peri-urban slums (WHO 2004). There is a rapid urbanization process going on in the developing world, meaning that WSS targets will be mainly an urban challenge even with lower coverage rates in rural areas (WWC 2006).

WSS problems remain unsolved since half of water related projects around the world fail (water.org website). Only marginal improvements in the sanitation sector can be explained by the prevailing assumption that centralized water-based sewer system is the solution for urban, peri-urban and rural areas (Zurbrügg and Tilley 2009). A lack of awareness and acceptance of appropriate WSS technologies are believed to be key obstacles to their implementation together with a lack of interaction between community and government officials (Silveira 2002). Sustainability of WSS systems is necessary for achieving sustainable human settlements since the lack of adequate WSS services is affecting all aspects of a community's daily existence (Jones and Silva 2009). Scientists and policy makers are aware that transition to sustainable societies remains a challenge with the key question on how to handle issues involving a wide range of disciplines to develop strategies for regions' sustainable development (Grosskurth and Rotmans, 2005, Thabrew et al. 2009).

1.2 Stakeholders in WSS sector

Appropriate water supply and sanitation are essential parts of primary health care. Apart from improving health, appropriate water supply services are prerequisites for sustainable socio-economic development (Jones and Silva 2009). What is specific for WSS is the complexity and the large number of stakeholders as well as decision makers involved. Integration of WSS policies with other sector policies is important and reforms often fail because of an inadequate stakeholders' commitment and involvement at all levels (Seppälä 2002).

Managers of water resources are addressing demands of water uses in order to meet people's life sustaining requirements. However, constraints related to inadequate water, financial and/or human resources, or external forces, may hinder mangers of water resources mangers in fulfilling their objectives. In order to make progresses in sustainable water management it would be necessary to bring political actors in the decision-making process and take into account all the constraints found across (World Water Assessment Programme 2009).

The existence of different stakeholders' expertise and interests makes it difficult to analyze options. Therefore, within the work package number two of the funded EC Antinomos project, an attempt was made in addressing these issues by preparing an overview of global WSS technologies and practices for developing countries which can be used by stakeholders with different knowledge on water supply and sanitation issues. The project Antinomos aims at making an impact to current WSS situations through bridging contrasts and knowledge gaps between knowledge areas which have only recently been recognized by decision makers as a key issue in reaching the MDGs (Antinomos project website). Project results are being disseminated to different end-users, such as local decision makers, users associations, NGOs, academic and professional community and general population. In order to reach the target audience in the most effective way, it is possible to find in this paper a classification of WSS concepts by using matrices with different criteria.

1.3 An integrated approach

Management of water includes dealing with various aspects related to the steps of water cycle (Figure 1). Technology selection for the treatment of drinking water depends on water sources and, therefore, water composition. Water availability and consumption on a household level creates opportunities for different wastewater collection, treatment and re-use options.

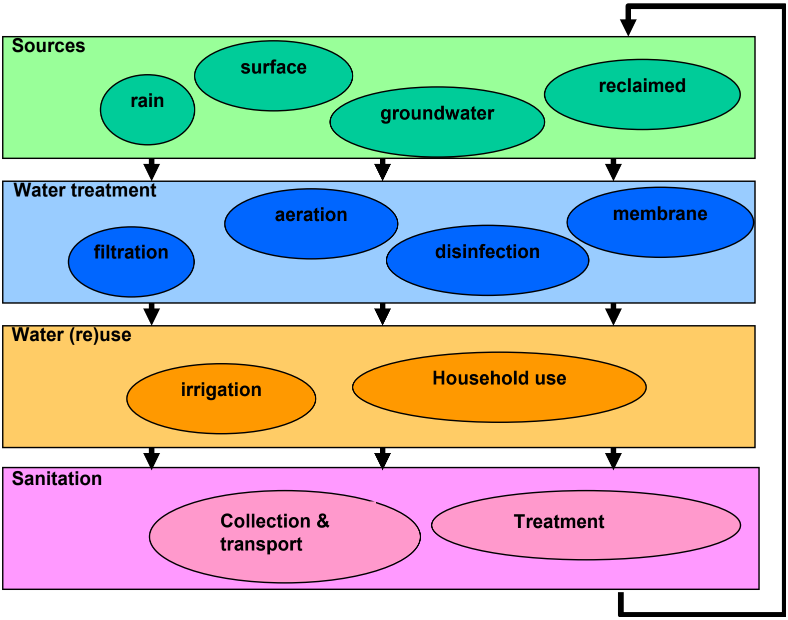

Figure 1: A simplified water cycle scheme

As mentioned previously, this paper gives an overview of global knowledge based technologies for water treatment, addressing both drinking water supply and sanitation concepts. Technologies are presented in a way that stakeholders and actors with different backgrounds should use them easily. For this purpose, matrices have been developed where technologies are classified in terms of complexity and treated water quality / performance. Sanitation concepts have been further presented and based upon their size and water demand and treatment systems for household wastewater have been further categorized on their complexity and treated wastewater / effluent quality.

2. WSS systems classifications

Water supply and sanitation systems, in fact, cover all aspects of the water cycle scheme depicted in Figure 1. However, in terms of technological approach, a division can be made into treatment technologies for water supply and technologies for sanitation. It is important to note that some technologies may apply to both systems, for example, even if sanitation provides a renewable source for water use. This section firstly discusses treatment technologies which are mostly related to water supply and then technologies related to sanitation.

2.1 Water supply

Drinking water can originate from different sources which require different treatment techniques. Ground water – in general terms, if not contaminated with industrial waste or intensive agriculture, is of a good quality. Rainwater quality, in general terms, is of a good quality too. However, it may be contaminated through the collection and storage process. Surface water, in order to be used as a drinking water source, usually requires several treatment steps that will be introduced in this paper. In particular, in developing countries the heavy pollution of surface water is often the case.

The majority of water-related health problems is caused by *microbial* contamination. Generally, the biggest risks are originating from ingestion of water that is contaminated with human or animal faeces - a source of pathogenic bacteria, viruses, protozoa and helminths.

However, serious health problems can also originate from *chemical* contamination of drinking water. High levels of fluoride and arsenic may naturally occur in drinking-water and are the main cause for severe health problems. The presence of nitrate and nitrite in water produces acute health risk for infants, leading to methaemoglobinaemia (blue baby syndrome). Nitrate may occur from an extensive use of fertilizers or the leaching of organic waste. Untreated and partially treated industrial wastewater can be a source of many organic pollutants, too (WHO 2006).

With an increased institutional capacity and economic activity, water treatment objectives also broadened, that are: technologies were combined to reduce not only acute microbial health risks, but also more chronic health risks having a physical and chemical origin (Figure 2).

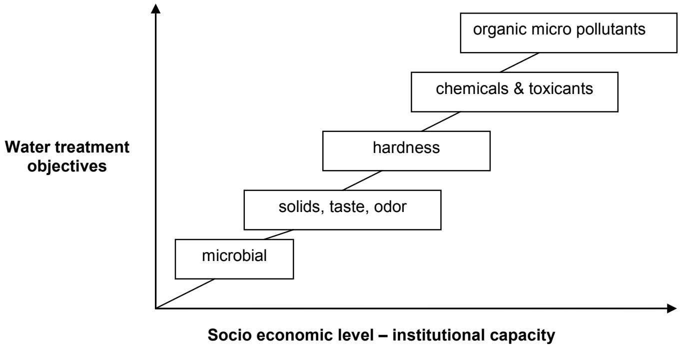

Figure 2: Socio economic level and water treatment objectives (adapted from Smet and van Wijk, 2002)

In the matrix below (Figure 3), water treatment systems that will be addressed in this paper are listed. They are classified on the basis of treated water quality that they can achieve and complexity of systems in terms of operation and maintenance requirements. In the matrix, the one star "*" indicates the lowest quality of treated water and implies that the water treatment system only aims to the removal of microbial hazards. Three stars "***" indicate the highest quality of the treated water and imply that the water treatment system, apart form the removal of pathogens, also aims at removing physical and chemical contaminants.

WATER TREATMENT SYSTEMS		**TREATED WATER QUALITY**		
		*	**	***
COMPLEXITY	Simple	Solar Water Disinfection	Chlorination Storage/ Sedimentation Ceramic Colloidal Silver Filter	-
	Medium complexity	UV Disinfection	Rapid Gravity Filtration Activated Carbon Filtration	Slow Sand Filtration
	Complex	-	Aeration	Coagulation / Flocculation and Sedimentation or DAF Membrane Filtration

Figure 3: Matrix with water treatment systems based on treated water quality and complexity

Simple systems

Chlorination is mainly used for microbial disinfection. However chlorine can also act as an oxidant and remove some organic matters. Chemicals used for chlorination include chlorine gas,

chlorinated lime (bleaching powder), high concentration of hypochlorites and sodium hypochlorite (Smet and van Wijk, 2002). Chlorination_allows various scales of application and covers a broad spectrum of germicidal power. The equipment needed for dosage is simple and low-cost but requires electricity in most of the cases. If raw water contains organic material, some disinfection by-products will be produced.
Solar Water Disinfection is a low cost water treatment method where solar light, with its UV radiation, is used to inactivate harmful micro-organisms which are present in water. Transparent plastic bottles should be filled with water that needs to be treated and later placed by the sunlight (NWP 2003). Technology requires very low initial costs (used plastic bottles). Bottles filled with contaminated water are placed by the sun for 6 hours, or 2 days in the case of cloudy weather.

Sedimentation is the removal of suspended particles through the settling and occurs when water stands still in or flows slowly through a tank. Sedimentation can take place in any tank but usually, in water treatment, specially designed tanks are used (Smet and van Wijk, 2002) and soon after, often, chemical coagulation treatment follows. Construction of tanks is relatively simple but requires a knowledge on engineering and a relatively big surface area (spatial requirement can be diminished when high rate sedimentation modules are implemented).

Ceramic colloidal silver filters are based on antibacterial action of silver. Apart from inactivating and removing bacteria, these filters also remove turbidity and are mainly intended for household use (NWP 2003). Their construction is simple but it requires training. Replacement of filters is required once every two years.

Medium complexity systems

UV radiation is well known for its germicidal effects: the capacity of sunlight to disinfect water comes from the UV rays which are present in the sunlight. Several UV devices have been developed and applied to water disinfection purposes, both at household and at water network levels. Light sources are commonly used for UV disinfection and are listed as follows: low-pressure mercury lamp, medium-pressure mercury lamp and pulsed lasers (OECD/WHO 2003). Usually, water requires a pre-treatment previously than UV treatment since turbidity and suspended solids are to hinder the effects of UV light treatment. Reliable electricity supply is also a prerequisite as well as skilled personnel for operation and maintenance.

Filtration has been used for a long period of time and many varieties of filtration processes have been developed. Amongst the most common filtration processes there are: rapid gravity filters, roughing filters and slow sand filters. Slow sand filters are a physical-biological process whereas other processes are considered physical treatments (Brikke and Bredero, 2003).

Rapid gravity filters are open rectangular tanks containing silica sand with downward water flow. They are mostly used to remove flocs from coagulated raw water and can also be used to reduce turbidity and oxidized iron and manganese from water.
Roughing filters with crushed stones and coarse gravel can be applied as pre-filters to other treatment units (such as slow sand filters) and they successfully treat high turbidity water.
Slow sand filters usually consist of tanks containing sand with raw water' downflow. Slow filters remove turbidity and micro-organisms mainly in the first centimetres of sand. At the filter's surface level a biological layer "schmutzdecke" develops that can be efficient in the removal of micro-organisms (Brikke and Bredero, 2003).
Construction of filters is relatively simple but requires a knowledge of engineering. The advantage of filters is that they can often be made of local materials and do not require chemicals (unless located after coagulation/flocculation step). Filters are most efficient as part of the treatment.

Activated carbon filters are mainly used for removing dissolved organic matter, taste and smells. These filters can also reduce the number of viruses and parasites (OECD / WHO 2003). Dissolved organic matter rapidly occupies absorption sites and therefore, a bio-film quickly develops on carbon causing an increase in the overall coliform's total. Additional treatment following activated carbon filter treatment is often needed. These filters need replacement when they become saturated after a certain period of time but they can be regenerated and reactivated after use.

Complex systems

Aeration is a widely used technique for treating groundwater containing high amounts of iron and manganese. For the treatment of surface water, aeration can be useful for treating water with high organic matter content. There are a number of ways in which adequate contacts needed for aeration could be obtained between water and air. Two main groups are: waterfall and bubble aerators (Smet and van Wijk, 2002).
Aeration requires skilled engineers for construction and reliable electricity supply.
If built vertically, aeration requires a small area. For high content of CO_2 in water, extra treatment might be necessary.

Chemical coagulation is one of the most common surface water treatments used for removal of turbidity and to some extent organic matter, together with microbes. Aluminium or iron salts are dosed to raw water as coagulants under controlled conditions to form solid flocs of metal hydroxide. The floc is later removed by solid-liquid separation processes such as sedimentation, flotation and filtration (WHO 2006). Process efficiency depends on raw water quality, pH and dose of coagulants and requires post-treatment. Required dosage of coagulant and pH need to be determined by small scale batch (jar) tests.

Dissolved Air Flotation (DAF) is a process of dispersing very fine air bubbles in water where bubbles adhere to suspended particles and cause them to float. DAF is used to remove flocs containing colour or algae and usually follows coagulation and flocculation step (Smet and van Wijk, 2002). DAF treatment requires skilled engineers for construction, reliable electricity supply and pre-treatment. As in coagulation, DAF requires chemical reagents and best performance pH and dosage can be determined by small scale batch tests.

Membrane filtration is a physical treatment for separation of chemicals and pathogens. Depending on the membrane pore size, membrane filtration can have different objectives. For desalinization of brackish and salt water as well as water softening and pathogens' removal, membranes with the smallest pore size are used that ar: reverse osmosis and nano-filtration. For the removal of particles and micro-organisms, instead, micro-filtration and ultra-filtration are used (OECD / WHO 2003).

Membrane filtration requires reliable electricity supply and skilled personnel for operation and maintenance. Pre-treatment for the prevention of membrane fouling, backwashing and cleaning are necessary. A summary of the introduced water treatment systems with their removal effectiveness is shown in Figure 4 (where 0 indicates no removal, + little removal, ++ significant removal and +++ indicates high removal effectiveness).

		Removal effectiveness						
		Bacteria viruses	Fe, Mn	Fluoride	Arsenic	Odour, taste	Organic matter	Turbidity & suspended particles
Water Treatment System	Chlorination	+++	++	0	0	0	++	0
	Solar water disinfection	++	0	0	0	0	0	0
	Storage /sedimentation	+	+	0	0	+	+	++
	Ceramic colloidal silver filter	+++	0	0	0	+	0	+++
	Rapid gravity filtration	+	++	0	0	+	+	++
	Activated carbon filtration	+	0	0	0	+	+++	+
	Slow sand filtration	+++	++	0	++	++	+	+++
	Aeration	0	+++	0	0	++	+	0
	UV disinfection	+++	0	0	0	0	0	0
	Coagulation /flocculation and sedimentation or DAF	+	+	+++	+++	+	+	++
	Membrane filtration	+++	+++	+++	+++	+++	+++	0

Figue 4. Summary of household and community water treatment systems and their removal effectiveness (adapted from Brikke and Bredero, 2003)

2.2 Sanitation systems

When domestic wastewater happens to be discharged as untreated or partially treated, biodegradable organics, nutrients and pathogens reach the aquatic environment causing various effects listed as above:

- *Oxygen depletion* occurring in the aquatic environment in the case of discharge of wastewater containing biodegradable organic matters. Decaying organic matter consumes dissolved oxygen from water and makes it unavailable for aquatic animals and plants.
- Discharge of nutrients (nitrogen, phosphorous) in the aquatic environment is to cause *eutrophication*, an extensive growth of undesired aquatic plants, oxygen depletion and potential groundwater pollution.
- Many *pathogens* (viruses, protozoa and bacteria) contained in wastewater are the cause of communicable diseases. If these pathogens entered the aquatic environment, water bodies would become a potential source of disease.

In this paper a system's approach is undertaken where all sanitation system components are introduced. Sanitation systems include toilets, collection of human excreta, transport (or storage), treatment and discharge or reuse.

Besides to a waste stream containing human excreta (black water), households produce alternative waste stream such as shower, laundry and kitchen wastewater (greywater). Some sanitation concepts are meant only for the treatment of black water (marked with ■ in Figures 5 and 6), whereas others can be also used for treatment of grey water (marked with ■ in Figures 5 and 6).

Furthermore, a classification of sanitation concepts based on their water demand will be introduced. A lower quantitiy of water demand means that a very little amount of water for flushing is needed; rather, a medium water demand refers to a flush water demand of 1 to 5 litres per each usage and a high water demand refers to traditional flush toilets which use more than 5 litres per flush. In addition, sanitation options are classified according to the size of area to be served while acknowledging the fact that different sanitation concepts are available for different sizes of the service area. In such a circumstance, a small size refers to on-site concepts, a medium size refers to communal options and decentralised concepts, and ultimately, a large size refers to traditional large scale centralised options. Communal options are often scaled-up small on-site options and, therefore, their principle has been explained only once (e.g. for the description of communal pit latrines see under pit latrines). Many domestic activities are associated with the removal of polluting materials such as body washing, laundry, disposal of feces, etc, and water is used in various quantities to convey these pollutants. In fact, sanitation concepts are often seen in relation to disposal of feces and urine. This category of waste has the potential to be disposed with a minimum of water that is in separate or black water form wheras other pollutants are usually disposed of with relatively large quantities of water resulting in grey water.

SANITATION CONCEPTS		**WATER DEMAND**		
		Low	Medium	High
SIZE	Small: on-site	Pit latrines ■ Composting toilets ■ Dry urine separation toilets + Storage units ■	Pour flush toilets + pit latrines ■ Pour flush toilets + septic tanks ■▨ Wet urine diversion toilets + *treatment system** ■	Flush toilets + septic tanks ■▨ Aqua privy ■▨
	Medium: Communal options & decentralised concepts	Communal pit latrines ■ Communal composting toilets ■ Communal dry urine separation toilets + Storage units ■	Communal pour flush toilets + pit latrines ■ Communal pour flush toilets + *treatment system** ■▨ Communal pour flush toilets + vacuum sewers + *treatment system** ■▨	Communal flush toilets + septic tanks ■▨ Communal flush toilets + septic tanks + small diameter sewerage + *treatment system** ■▨ Flush toilets + simplified sewers + *treatment system** ■▨ Flush toilets + vacuum sewers + *treatment system**■▨
	Large: Centralised concepts	-	-	Flush toilets + conventional sewerage + *treatment system**■▨

Figure 5: Sanitation concepts based on size and water demand (■ indicates that sanitation concept is intended for the treatment of black water; ▨ indicates that sanitation concept is intended for the treatment of grey water) (See Figure 6 for different treatment system options)

The following section briefly describes the basic components of sanitation concepts (toilets, collection systems) which are followed by the description of on-site sanitation options. Treatment systems as part of (semi) off-site sanitation options are described in a separate section.

Toilets

Dry urine separation toilets are similar to a composting toilet whereas there is an added implementation of a bowl or a pan with a divider in such a way that user separates urine from feces. Depending on the storage or treatment technology that follows, drying material such as ash, lime or soil should be added to the same hole after defecating (Tilley *et al.* 2008). Dry urine separation toilets do not require water and they are characterized by low capitals and operation costs. They offer a potential of reusing the urine as fertilizer. However, trained personnel is required for an appropriate handling of feces and there would be a risk that users would not accept that.

Wet urine diversion toilets also separate urine from feces but a small amount of water for toilet flushing is used. Urine is stored and can be reused after a sufficiently long period whereas feces are flushed to further treatment. These toilets require little water. Since dry toilets offer a potential for reusing the urine as a fertilizer it might follow that users would not accept that. (Strakl *et al.* 2008). The separated black water requires further treatment.

Pour flush toilets consist of a bowl or a pan with a water-seal trap preventing odours and insects problems. Excreta are flushed away with 2-3 litres of water that is being poured manually. They use less water than flush toilet and are easy to operate and maintain. They require handling and storage of water (UNEP 2004).

Flush toilets consist of a toilet bowl or a pan with water seal and a small reservoir with water (volume of 5 to 20 liters). Excreta are flushed away with water stored in reservoir. These toilets use large amounts of water and costs are usually higher when compared to pour flush toilets. They offer a high level of convenience (UNEP 2004).

Collection

The term sewerage is usually applied in relation to the removal of mixed wastewater that is: black water plus grey water which may be supplemented with runoff water and industrial effluents. *Conventional sewers* are gravity sewers so designed that the slope and size of the pipe is adequate to maintain flows towards the discharge point. Conventional sewers are designed for serving urban areas and large diameter pipes are laid deep in the ground to prevent interference from traffic. Sewers must be designed to maintain a flow preventing solids from accumulating. Conventional sewers require high capital costs and an expert knowledge in planning and construction (Tilley *et al.* 2008, US EPA 2002). They do not require pre-treatment and can handle grit and solids in sanitary sewage. If gravity cannot be obtained, pump stations should more likely to be installed, leading to a pressure sewer system.

Simplified sewers are using smaller diameter pipes laid at a shallower depth compared to conventional sewers. These sewers are lying within the users' property boundaries instead than beneath central roads. Each house should have a grease trap installed before the sewer connection. Simple inspection chambers are used instead of costly manholes of conventional sewerage. Since simplified sewers are more communal, they are often referred to as condominium sewers (Tilley *et al.* 2008). These sewers are appropriate for dense urban areas. Simplified sewers require experts for designing and construction supervision. Capital costs are 50-80 % lower than conventional sewers.

In hilly or flat areas implementation of conventional sewerage might require deep excavation and, therefore, they would increase costs. Alternative collection systems, such as *small diameter gravity sewers*, can be more appropriate to these cases as well as to other site-related limitations, poor soil conditions or high groundwater tables. As the name implies, small diameter gravity sewers use a small diameter pipes to convey the effluent from septic tank by gravity to treatment facility (US EPA 2000a). Small diameter sewers require experts for designing and construction supervision. Excavation costs are reduced compared to conventional sewers.

Vacuum sewers consist of a central vacuum source that conveys sewage from individual households to a central collection station. Flat topography is preferred for the excellent sewers' performance. Vacuum sewers are usually used where population density is lower and soils are rocky or where groundwater is high since pipes are airtight. Vacuum sewers consist of vacuum station, pipeline system, collection chambers with pumps and interface valve units (UNEP 2002). Again, this type of sewers requires skilled engineers, contractors and operators and lower capital costs compared to conventional sewers. The vacuum station requires reliable electricity supply. Risk of blockage might increase when small diameter pipes are found.

On-site sanitation options

There are many variations of *pit latrine* designs but all of them are based on the same principle of collecting excreta in a pit dug in the ground, with a toilet built on top. During the storage liquid leaches to the soil underneath. Organic matters in excreta undergoes anaerobic digestion where methane and carbon dioxide gases are produced while the volume of excreta is being reduced (UNEP 2000). Some of the various designs of pit latrines are: *ventilated improved pit* (VIP) latrine which has a ventilation shaft for odour reduction and insect control; *double vault pit latrine* where one vault is in use at a time while excreta are being composted in the other one. Pit latrines are easy to be constructed and be maintained but technical support is required when installation occurs since proper construction is crucial. Risk of malodour is not fully controlled and there is the risk of groundwater and surface water pollution (WHO, 1996).

Composting toilets are located above the ground as elevated latrines. Air is introduced to the sludge through openings so that aerobic degradation can take place. Excess liquid is drained and collected or evaporated. Two vaults should be used in an alternating manner. If maintained properly, composting toilets would provide reuse of organic matters and quality fertilizer (UNEP 2000). Food waste can be added to faecal sludge (together with sawdust, leafs, straw or newspapers) to balance C/N ratio. They are more complex to design than simple pit latrines. Composting should last at least 6 months and appropriate handling of faeces requires a trained personnel. There is the potential risk that uses may not accept that (UNEP 2000 and field observations).

Separate storage units for faeces and urine have been developed for different dry urine separation toilet systems (also referred to as No-mix toilets and Ecological sanitation). For storage of faeces, usually, two watertight chambers are used: while one chamber is in use full digestion takes place in the other one. Dry urine separation toilet systems are located above the ground. Urine is stored in watertight tanks and usually time for storage about six months is sufficient for pathogen to die-off (Tilley *et al.* 2008). The faecal chamber should be always kept dry and covered with ashes, lime, soil, sawdust or other. It should be closed at least one year to allow pathogen to die-off and safe reuse as a soil conditioner in agriculture. Construction costs of toilet systems with separate storage units are higher than for pit latrines. Education of users is required for maintenance and operation of the system (WECF, 2006).

A *septic tank* is a watertight tank, below ground level, that receives excreta, flush water and other household wastewater. Liquids remain for a short time in the tank and then successively flow to a soak away or to a drained field. Solids settle in the tank and are degraded by the biological activity in the septic tank (WHO 1996). Septic tanks are only suitable where (pour-) flush toilets are used. They have low operational and maintenance requirements. Septic tanks are odour free and no breeding of flies occur. They offer isolation and partial treatment of excreta.

Digested solids are build up in the tank and need to be removed every 3 up to 5 years (WHO 1996)

In an *aqua privy* the excreta fall into a water-filled tank, equipped with a water seal to prevent odour problems (WHO 1996). The effluent is disposed of by means of a soak-away, in a similar way as an effluent from the septic tank. Aqua privy must be emptied every three years and is relatively expensive to build when compared to septic tanks and pit latrines. Large volumes of water are necessary to work and water seal can be hard to maintain. If leakage occur, the one or two buckets of water should be added daily. They cannot be blocked by bulky anal cleansing materials (WHO 1996).

2.3. Treatment systems

In order to achieve the desired effluent quality, more treatment steps are required to be as necessary (usually primary, secondary and tertiary treatments steps). All treatment systems mentioned in the matrix below should follow primary treatment steps where course suspended solids (larger material and sand) are removed.
Treatment systems are classified as being based on effluent quality to be achieved and systems' complexity. One star "*" indicates the lowest effluent quality and that treatment system remove only one of the three main pollution sources (described previously in the paragraph 2.2 sanitation systems). Two stars "**" indicate that the treatment system removes two main pollution sources, whereas three stars "***" indicate that the treatment system can remove all three main pollution sources (organic matter, pathogens and nutrients), if they are designed to operate properly.
Systems' complexity is classified in terms of operation and maintenance requirements as being of simple, medium or complex. Treatment systems listed under *** Effluent Quality, offer more possibilities for effluent and sludge to be reused.

TREATMENT SYSTEMS		**EFFLUENT QUALITY**		
		*	**	***
COMPLEXITY	Simple	Constructed reed bed ■▨ Biogas plant ■	Waste stabilization ponds■▨	
	Medium complexity		Anaerobic baffled reactor ■▨ UASB ■▨ Activated sludge ■▨ Oxidation ditch ■▨ SBR ■▨ Trickling filter ■▨	
	Complex			Combined anaerobic / aerobic processes ■▨ MBR ■▨ Nutrient removal systems■▨

Figure 6: Treatment systems based on effluent quality and complexity (■ indicates that treatment system is intended for the treatment of black water; ▨ indicates that treatment system is intended for the treatment of grey water)

Simple treatment systems

Constructed reed beds are natural treatment systems. They consist of a bed, filled with sand or other soil media where reeds are allowed to grow on the bed and remove nutrients from the wastewater. Direction of the flow in the filter media can be horizontal or vertical (WSP-EAP 2007). They have relatively low construction costs and require a large area. Periodic harvesting of reeds and washing of filter material is necessary.

Biogas plants are facilities consisting of a digester tank, waste inlet pipe, gas outlet pipe, pressure relief and dome. In a digester tank the organic matter degrades through anaerobic manners while biogas containing methane and carbon dioxide is being produced.

Biogas plants do not function well on human excreta alone and animal faeces or crop stalks are usually added. Therefore, the technology is most suitable in rural areas for large animals (e.g. pigs or cattle) breeding (UNEP 2002). Moreover, if slurry was kept sufficiently long in a digester tank, the effluent would be safer to be reused as a fertiliser in agriculture and aquaculture. Biogas plants are characterized by relatively high construction costs. If properly designed and operated, an individual household digester could produce enough gas to cover the needs of an entire household. Larger units serving several households or a whole community are feasible. For optimal performance they must be de-sludged every 3 up to 5 years (UNEP 2002).

Waste stabilization ponds are basically shallow basins that contain wastewater. There are many variations to number and size of ponds used for treatment but one of the basic system designs is a series of three ponds: anaerobic pond (for removal of organic matter), facultative pond (for pathogen removal and organic matter treatment) and maturation pond (for suspended solids and pathogen removal) (WSP-EAP 2007). They are characterized by low construction costs so that a very large area is required. Waste stabilization ponds should be located far from communities as they can be a potential breeding place of insects.

Medium complexity treatment systems

Anaerobic baffled reactor can be also seen as a septic tank in a series where wastewater has a downflow. It consists of a settler (integrated with septic tank), baffled chambers and a downflow pipe (or down-shaft) (WSP-EAP 2007). The main difference with septic tank is found at its staged operation, hence improving conversion in kinetics. Anaerobic baffled reactor requires experts for designing as well as supervision and it performs at best at temperatures between 29 and 38 °C. The effluent from this reactor is not completely odourless (WSP-EAP 2007).

In *UASB (Upflow Anaerobic Sludge Blanket)* reactors, most of biodegradable organic matter from the wastewater, are converted into biogas containing methane and carbon dioxide. Wastewater is introduced and equally distributed to the reactor through the bottom and is flows upwards through the sludge blanket. Sludge, treated water and biogas are separated in a three-phase separator in the top of the reactor. The UASB reactor is suitable for treating domestic wastewater in warm climate regions (> 20 °C). It has low land requirements and low sludge production (when compared to aerobic systems). For bigger installations, it is economically feasible to capture and to reuse the methane in order to generate energy. Start-up is lengthy in absence of seed sludge and the anaerobic process is sensitive to waste composition (von Sperling, M. and de Lemos Chernicharo, C.A. 2005a).

The *activated sludge treatment process* consists of the following components: a basin where aeration takes place and the micro-organisms responsible for treatment are kept in suspension in a sedimentation tank while systems for returning activated sludge solids from sedimentation tank to aeration basin (Tchobanoglous et al. 2003).

Variations of the activated sludge process include oxidation ditch and SBR (sequencing batch reactor). Activated sludge processes are heavily mechanised and offer high removal efficiency of organic matter and (at long enough sludge age) nitrogenous matter. Excess sludge needs to undergo additional sludge treatment and energy costs are higher due to aeration (von Sperling, M. and de Lemos Chernicharo, C.A. 2005b)

An *oxidation ditch* is an oval channel providing aerobic biological treatment through a mechanical aeration device (Droste 1997). It is a modified activated sludge treatment process with long and timely sludge solids' retention in order to remove biodegradable organics. Some forms of preliminary treatment, such as bar screens or grit removal, are usually required. They are characterized by a large energy requirement for aeration and operation as well as a large volume of generated sludge. They require highly skilled technical staff for designing and maintenance while producing a high effluent quality (WSP-EAP 2007).

The *SBR (Sequencing Batch Reactor)* is a variation of the conventional activated sludge system where a single reactor basin is used for aeration, sedimentation and effluent withdrawal. A typical SBR system is made of five consecutive steps: fill, react (aeration), settle (no aeration), draw (decant) and idle (Tchobanoglous et al. 2003). If nutrient removal is required additional steps would be added, including anaerobic and anoxic. SBR is fully automatic and requires skilled personnel for operation and maintenance. It provides effluent of high quality and requires relatively small space (WSP-EAP 2007) .

A *trickling filter* uses micro-organisms attached to a medium (filter material) to remove organic matter and possibly nitrogen from wastewater. This treatment system is aerobic and is common for technologies such as bio-towers (packed bed reactors) or rotating biological contactors. Wastewater flows over the filter material and micro-organisms from coming water attach the filter and form a thin film layer (US EPA 2000b). It is characterized by relatively low energy requirements, moderate technical expertise required for operation and maintenance and durable system elements. However, risks of clogging and vectors are present.
Complex treatment systems

Good quality effluent in warm climates can be achieved if activated sludge systems (*aerobic treatment*) are used for treatment of UASB effluents (*anaerobic treatment*). Excess sludge from aerobic treatment may be returned to UASB where it undergoes thickening and digestion together with anaerobic sludge. Furthermore, treatment of sludge is simplified (thickeners and digesters are not needed) and there is the only need for a dewatering step. Less energy is needed for aerobic treatment since organic matter has already been significantly removed in an anaerobic reactor. C/N ratio after the anaerobic treatment is not favourable for the biological removal of nitrogen and phosphorous but this may be circumvented by bypassing some wastewater to the aerobic system (von Sperling, M. and de Lemos Chernicharo, C.A. 2005b).

The *membrane bioreactor (MBR)* is a treatment system consisting of a biological reactor with solid separation by micro-filtration membranes. MBR systems can be used with both aerobic and anaerobic processes to separate treated wastewater from the active biomass. MBR provides a high quality effluent that may meet the reuse criteria. It has a high energy requirement and needs skilled personnel for operation and maintenance. Membrane life is limited and there is the potential that high costs of membrane replacements will be present (Tchobanoglous et al. 2003).

Biological Nutrient Removal (BNR) systems are designed to remove only nitrogen or both nitrogen and phosphorus from the wastewater. Nitrogen removal's systems consist of an aerated zone where nitrification of ammonia to nitrate takes place and an anoxic zone where the nitrate is denitrified to nitrogen gas. Simultaneous biological phosphorus removal can be accomplished when an additional anaerobic zone is created where growth of phosphorus accumulating micro-organisms is stimulated leading to a production of phosphorus-rich biomass. Various process designs exist where different zones are linked to different configurations and to different recycle schemes. Furthermore, in order to distinguish physical zones anaerobic, anoxic and aerobic conditions may also be achieved in oxidation ditches, Sequencing Batch Reactors and even in bio-film systems. Note that in BNR systems nitrogen nutrient is lost whereas phosphorus is conserved in the form of surplus sludge. BNR systems require high operational skills as they are characterized by complex operational issues. They offer superior effluent quality whereas phosphorus-rich sludge may be used for fertiliser production (Water Environment Federation, 1998; Henze et al. 2008)

3. Discussion and conclusions

This paper makes an attempt to provide a basic easy to use information on available WSS technologies and, therefore, a ground for communication and decision making purported by various stakeholders operating in the WSS sector. By classifying (waste) water treatment systems in matrices using complexity and treated water/effluent quality as main criteria, the paper gives a rational and understandable overview. Moreover, the emphasis is put on those elements involved in the whole water cycle and potential bottle necks and advantages of different WSS concepts. Drinking water treatment systems usually consist of several treatment units whereas the technology selection depends on water sources, as water characteristics coming from different sources vary significantly (Parsons and Jefferson, 2006). For sanitation systems an additional matrix (Figure 5) was introduced with sanitation systems classified on size (of population to be served) and water demand as criteria. Classification of global knowledge based WSS technologies in the form of matrices should be used as an entry point for the decision making procedure on water related issues.

Sustainability of WSS infrastructure remains a challenge for the developing world. Technology's appropriateness is site specific and hence, technologies suitable for the industrialized world will not be appropriate for the water scarcity in the developing world (Mara 2003). The involvement of all stakeholders and end-users is important in the WSS decision making process. Apart from obvious "front-end users", the selected stakeholders should include "back-end users", those who could benefit from outputs of a treatment system and i.e. they use treated water for irrigation, biogas, composted faecal matter, (Murray and Ray 2010). By communicating possible WSS solutions, it will be possible to raise awareness on advantages and disadvantages, as well as reuse options of different technical options.

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