*Desalination and Water Treatment*
www.deswater.com
doi: 10.5004/dwt.2017.20605

91 (2017) 305–310
October

# Sanitation revolution: from waste to resource

Mooyoung Han*, Shervin Hashemi

*Department of Civil and Environmental Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea, Tel. +82-2-880-8915; Fax: +82-2-873-2684; email: myhan@snu.ac.kr (M. Han), Tel. +82-2-880-7375; Fax: +82-2-873-2684; email: shervincee@snu.ac.kr (S. Hashemi)*

Received 29 November 2016; Accepted 16 February 2017

**ABSTRACT**

Excretion is one of the most natural and frequent human biological processes that has existed since human beings first evolved. However, the lack of access to basic sanitation in many parts of the world makes it clear that current sanitation practices need to be improved. Accordingly, adequate and equitable access to clean water and sanitation for all, as per the sixth item of the United Nations' Sustainable Development Goals (SDG6), is not possible using current sanitation systems. In this paper, different sanitation practices that have been used throughout history are reviewed and compared based on water consumption, wastewater generation, and resource utilization. The ideal sanitation practice might be one that uses no (or less) water and considers excreta a resource, as has been practiced in East Asian countries for thousands of years. Research trends and ways to overcome cultural and technical barriers are introduced and suggested. To achieve SDG6, a sanitation revolution is required that considers human excreta a resource instead of waste, as learned from past sanitation practices.

*Keywords:* Resource-oriented sanitation; Separation and recycle; Sustainable development goals; Sustainable sanitation; Urine source separation

## 1. Introduction

Sanitation is a global issue. Approximately 2.4 billion people globally lack access to basic sanitation services, such as toilets or latrines, whereas at least 1.8 billion people use a source of drinking water that is fecally contaminated. Consequently, every day, nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases. Furthermore, more than 80% of wastewater resulting from human activities is discharged into rivers and seas without any pollution removal [1].

To find the root of these problems, it is essential to consider the mechanism of toilets. Referring to Merriam-Webster's Learner's Dictionary, a toilet is "a large bowl attached to a pipe that is used for getting rid of bodily waste and then flushed with water" [2]. Accordingly, a toilet is a sanitation fixture used for the disposal of human waste. It is a source of water consumption and wastewater production as well because it disposes of a mixture of human waste with water. Such a practice is not sustainable, as it has several challenges such as high water and energy consumption and complicated infrastructure [3,4]. A vicious cycle of water and sanitation exists, i.e., without water, there is no proper sanitation, and without proper sanitation, clean water sources are reduced.

Overcoming these problems is a critically important matter; thus, equitable access to clean water and sanitation was identified as the sixth Sustainable Development Goal (SDG6) [5].

Excretion has a history as long as human existence, and the concept of sanitation became important once the idea of hygiene was first defined. However, the abovementioned problems are specific to the modern world [3,6,7]. Reviewing the different sanitation practices throughout history can teach society lessons about how to deal with human waste.

In this paper, different historical sanitation practices, as well as their characteristics, are reviewed and compared based on water consumption, wastewater production, and resource utilization. Accordingly, the most suitable sanitation

* Corresponding author.

*Presented at the 13th IWA Specialized Conference on Small Water and Wastewater Systems & 5th IWA Specialized Conference on Resources-Oriented Sanitation, 14–16 September, 2016, Athens, Greece.*

1944-3994/1944-3986 

practice is suggested, and research trends regarding this practice are reviewed.

## 2. Sanitation practices throughout history

Since the beginning of humankind, eating and excreting have been an essential part of life. Therefore, varying sanitation practices might have developed because of different natural conditions, such as geography and climate, as well as economic backgrounds, creating distinct cultures and traditions [3]. Fig. 1 presents the development of sanitation practices over time. Next, each system is described and evaluated in terms of water consumption, wastewater production, and resource utilization.

Open excretion is the oldest excretion practice [7,8] and is still used in some parts of the world. As the population increased and advanced, humankind felt the need to reduce its contact with sanitary waste in order to live longer comfortably [7–9]. No water is consumed in open excretion, and the only wastewater produced includes urine, feces, or a mixture of the two. Consequently, for a controllable amount of excretion, it can be used as fertilizer; however, as the volume of excretion increases due to urbanization, water bodies including groundwater become contaminated.

Between 460 and 377 BC, during the time of Greek physician, Hippocrates, the first definition of hygiene appeared and evolved [9]. During 300 BC–400 AD, the system of aqueducts was built and developed in ancient Rome [9]. People used to excrete over channels, in which water was running [10,11]. In these systems, waste was transported to and dispatched in free water bodies such as rivers and seas [7,10,11]. Therefore, water was used to remove sanitary matter, leading to the production of wastewater. This wastewater was generally dispatched into nature without any specific treatment nor intention for use as fertilizer.

Overlapping with the latter half of the sanitation development period in ancient Rome, sanitation practices began in Asia as well [6,7,11,12]. For example, in Korea, in a time period from the Silla dynasty to the Joseon dynasty (57 BC–1897 AD), people understood that excreta could be utilized as fertilizer [6,7,13]. In ancient Korean societies, it was well known that urine and feces could enhance land fertility if kept separate from each other and from the water. Following this concept, Korean temple toilets were designed to deposit the feces into well-ventilated compost chambers. The feces was then removed from the bottom of these chambers and used directly as fertilizer [3,6]. Additionally, ancient Koreans were familiar with source separation, and they had special instruments to separate and manually transport the excreta [3]. At that time, using a yogang (urine jar), which was usually situated near a room for easier access, was common. The collected urine waste was fermented to serve as agricultural fertilizer. Furthermore, the different fermentation stages of urine were made possible by using several urine jars, which were stored in an organized fashion. Farming equipment, known as ojum-janggun (urine jar) and ddong-janggun (feces jar), were

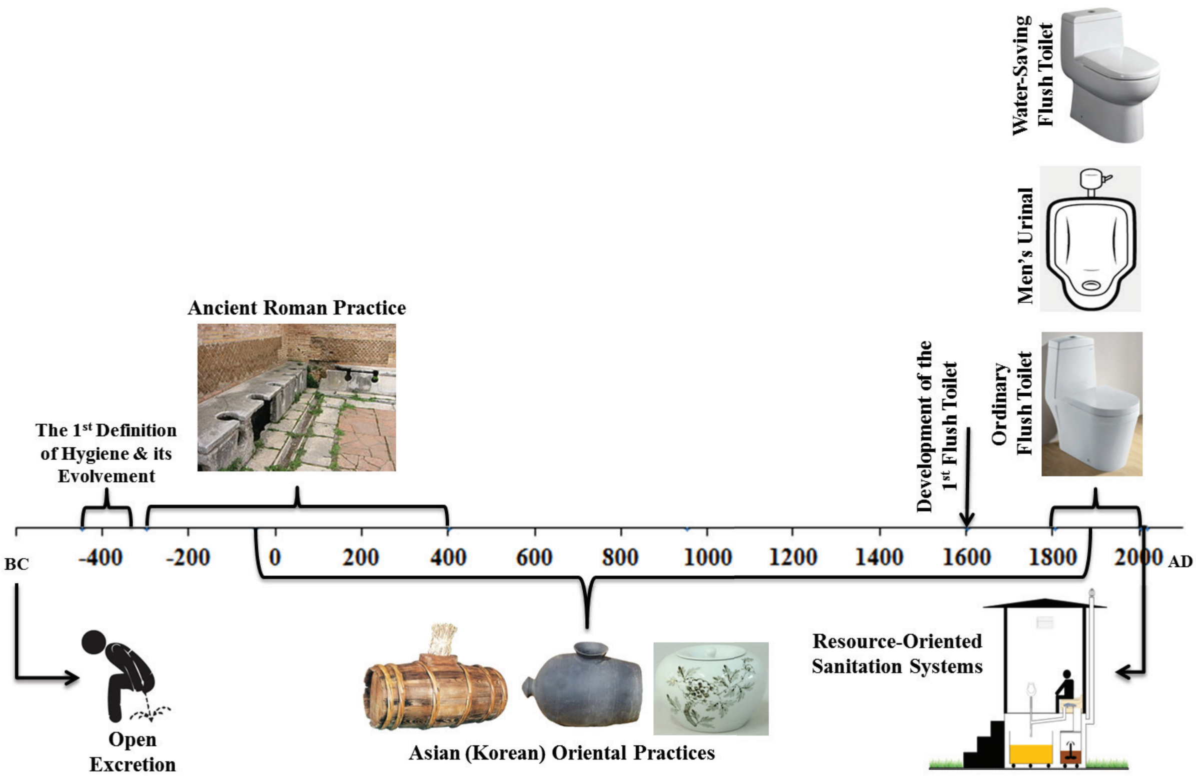


Fig. 1. Development of sanitation practices throughout history.

used to carry separated urine and feces, respectively. By these practices, urine and feces were collected separately without dilution, later to be utilized as fertilizer [6,7]. The same practices were common in Middle and East Asian countries such as China, Vietnam, and Japan [7,12–14]. For these practices, water was not consumed nor was wastewater produced, and all sanitary matters were served as a nutrient resource via utilization as fertilizer.

In 1596, toilets with flushing function were invented, and in the nineteenth and twentieth centuries, modern sewer systems were developed and constructed in many European and US cities, initially discharging untreated sewage to waterways [7,9,11]. When the discharge of untreated sewage became increasingly unacceptable, experimentation toward improved treatment methods resulted in different advanced treatment practices and ordinary flush toilets, and men's urinals became common at that time [11]. These systems are based on water and, obviously, consume water and accordingly produce wastewater, which undergoes the advanced treatments. However, these treatment processes still are not sufficient and send partially treated waste to natural water bodies, which transfers contaminants such as pharmaceuticals, personal care products (PPCP), endocrine disrupting compounds (EDC), and micro-pollutants into the water resources [3,6]. Except for limited utilization of treated sewage sludge as a resource for energy production, there is no systematic treatment process considered for an aimed utilization [15,16].

In the year 2000, the seventh item of the Millennium Development Goals (MDG7) was defined with the aim of improving sustainable access to safe drinking water and basic sanitation. Consequently, several trials were performed in order to modify the flushing function of toilets and reduce the water required for flushing [15,16]. At this stage, water-saving toilets and urinals were produced [16]. Furthermore, there were trials for developing sanitation practices with minimum water and energy consumptions, such as waterless urinals and composting toilets [3,17]. Recently, resource-oriented sanitation (ROS) practices are being developed, which are receiving increased attention after the definition of SDG6 [3,18–20]. These systems, which are also understood as sustainable or ecological sanitation, are enabling nutrient reuse, mainly by source separation and covering a full range from high- over medium- to low-tech and from decentralized to centralized solutions [21]. The urine-diverting dry toilets (UDDTs) can be a good example for these systems, which are based on minimum water consumption, for hygienic purposes such as hand washing and anal cleansing, and accordingly minimum wastewater production, which usually can be treated in situ, as well as source separation of urine and feces and the utilization of such after treatment. Table 1 summarizes the characteristics of the mentioned sanitation practices.

## 3. Comparison of different sanitation practices throughout history

To compare the efficiency of different sanitation practices toward SDG6, three main indicators were defined as follows:

- Water consumption: Indicates the amount of freshwater used for removing sanitary matter by any means, e.g., flushing.
- Wastewater production: Indicates the amount of sanitary matter that is mixed together (with or without the addition of water) and dispatched as waste into a water body as is or without sufficient treatment.
- Resource utilization: Indicates the types of sanitary matter that are considered resources and thus treated and utilized as fertilizer.

Based on these indicators, these practices can be compared as presented in Fig. 2.

It is obvious that the ideal sanitation practice to achieve SDG6 is to use less water and utilize sanitary matter as a resource instead of considering it a waste. This means a revolution against the generally (nowadays) accepted sanitation practices, which use too much water and produce waste. According to Fig. 2, there are two methods to achieve this purpose:

- (Arrow 1): Reducing water consumption and consequently wastewater production.
- (Arrow 2): Considering sanitary matter a resource instead of waste and applying suitable treatment.

Accordingly, among all mentioned sanitation practices, ROS systems produce the greatest amount of resources as well as consume no or very limited water, which makes them sustainable. These practices can be considered alternatives for ordinary and water-saving flush toilets to achieve the goals of SDG6.

## 4. Research trends

All ROS systems contain three main concepts: (1) toilet seat (and men's urinals) as well as facilities for hand washing and in situ treatment of the produced gray water, (2) urine treatment and disposal system, and (3) feces treatment and disposal system, as presented in Fig. 3.

Although all mentioned ROS systems are environmentally friendly sanitation practices, they have challenges, which make them unpopular for all users [24]. Similar to any other sanitation systems, the potential costs for developing countries, cleanliness, and proper maintenance are important challenges that should be managed to achieve higher public acceptability.

First of all, although there are several scientific studies showing the high potential of human excreta to be utilized as good fertilizer to produce more food [25,26], there is a gap in public knowledge, and many people nowadays do not understand the concept. Furthermore, there are several cultural barriers such as necessitating water consumption in sanitation practices in some religions [27].

There are several research opportunities and approaches for investigating solutions for these challenges. For improving social acceptability, informative cultural activities are required. For instance, in 2015, the movie *Martian* broadly showed the potential for growing potatoes on Mars using human feces [28]. Such social approaches should be encouraged to increase public knowledge and acceptance.

Technically, high-efficiency separation is the first essential step that should be functional at all times including for cases such as diarrhea. Urine scale formation and odor are two critical challenges, which lead to bottlenecking, making

Table 1
Characteristics of different sanitation practices throughout history

| Sanitation practice | View | Characteristics |
|---|---|---|
| Open excretion (urine and feces) |  | • It does not use direct water.<br>• All sanitary matter enters a water body without treatment. |
| Ancient Roman practice (urine and feces) |  | • Sanitary matter is mixed with running water.<br>• This mixture is delivered into a water body without treatment. |
| Yogang (Korean oriental practice) (urine only) |  | • No water is consumed.<br>• Urine and feces are collected separately and stored.<br>• Separated urine and feces are utilized as fertilizer. |
| Ojum-janggun (Korean oriental practice) (urine only) |  | |
| Ddong-janggun (Korean oriental practice) (feces only) |  | |
| Ordinary flush toilets (urine and feces; water consumption: 10–15 L/flush) |  | • Sanitary matter is mixed with flushing water, and the produced wastewater, including gray water, is delivered to centralized wastewater treatment plants [3].<br>• The treatment process is not sufficient and materials such as PPCPs, EDCs, and micro-pollutants cannot be removed completely [3].<br>• Water with insufficient treatment is delivered to the water body [3]. |
| Ordinary/water-saving men's urinals (urine only) |  | • They consume less water compared with ordinary flush toilets [22].<br>• The treatment function and process are similar to ordinary flush toilets. |
| Water-saving flush toilets (urine and feces; water consumption: 3–4 L/flush) |  | |
| Waterless and resource-oriented sanitation practices (i.e., UDDTs, etc.) [3,23] (urine and feces) |  | • No/less water is consumed.<br>• There is source separation of the sanitary matter.<br>• The gathered sanitary matter is utilized as fertilizer.<br>• Easy operation and maintenance processes occur.<br>• Limited water consumption is required for hygienic purposes such as hand washing and anal cleansing. Accordingly, the produced gray water is treated and recycled in situ. |

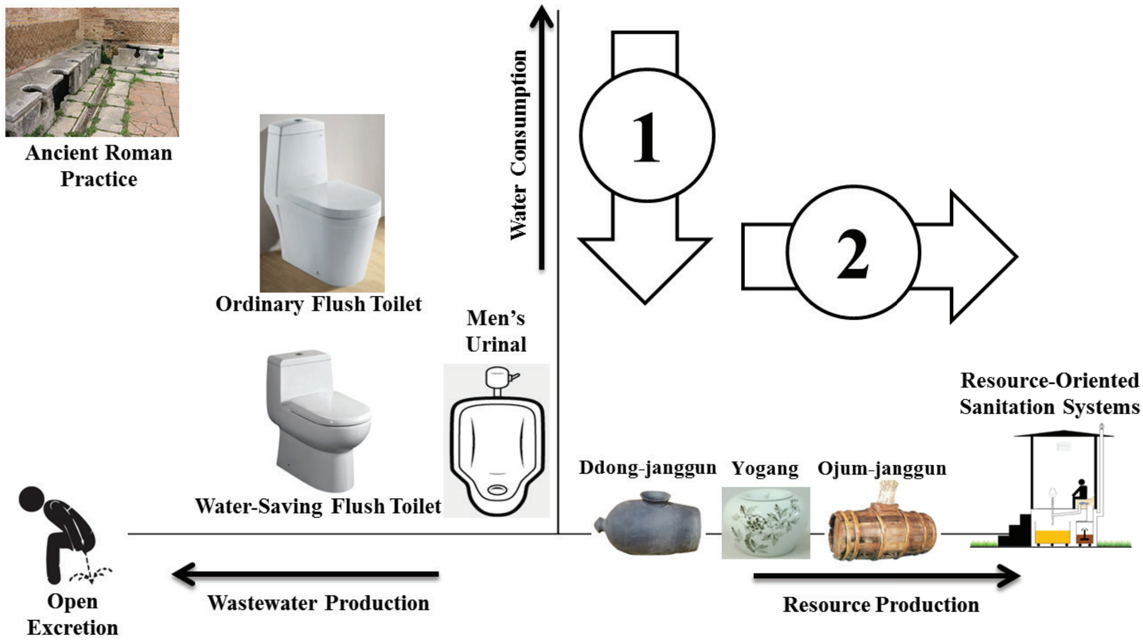


Fig. 2. Comparison of different sanitation practices based on wastewater, waste, and resource utilization. Arrow 1 indicates the reduction in water consumption and, consequently, wastewater production, and Arrow 2 shows consideration of sanitary matter as a resource instead of a waste and application of suitable treatment.

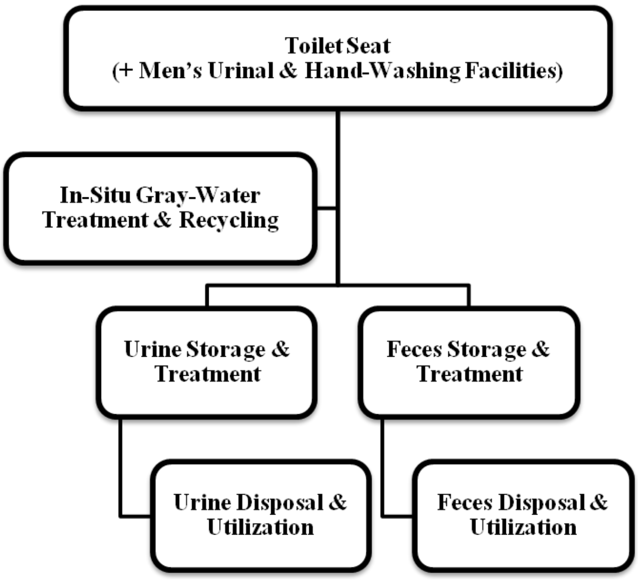


Fig. 3. General structure of resource-oriented sanitation systems.

wide acceptance of ROS systems impossible in a decentralized wastewater system. In these cases, suitable operation and maintenance management is required. Furthermore, a certain amount of water should be available for other hygienic processes such as hand washing and anal cleansing, and the gray water that is produced from such should be treated and recycled in situ. This can also satisfy the obligation of water consumption in some cultures [27].

The separately stored sanitary matter must be treated in order to be utilized as fertilizer. In this case, the treatment processes should be designed based on the quantity and characteristics of the sanitary matter as well as on consideration of the economic aspects, including costs and benefits of the system.

Advances in these concepts can greatly increase the efficiency and acceptability of ROS systems as substitutions for the current unsustainable practices.

## 5. Conclusions

In this paper, different sanitation practices throughout history have been reviewed based on water consumption and wastewater production. Some practices consume more water and produce more wastewater than others do. Some practices consider human excreta as waste, whereas others consider it as a potential resource.

It is noteworthy to see some of the old practices in East Asia, which consume no water and use the excreta as fertilizer instead of considering it a waste. This concept can be a model for a sustainable solution toward SDG6. However, some cultural, as well as technical, barriers exist. Research on trends and ways to make sanitation processes more aesthetical and efficient are in progress in the science and technical fields. To achieve SDG6, a revolution of sanitation is required, in which human excreta is considered a resource instead of a waste by learning from past practices of sanitation.

## Acknowledgments

This research was supported by "Development of Nano-Micro Bubble Dual System for Restoration of Self-purification and Sustainable Management in Lake" project and "Waste to Energy Recycling Human Resource Development" project, both funded by the Republic of Korea Ministry of Environment. Furthermore, this research was supported by Institute of Construction and Environmental Engineering at Seoul National University. The authors wish to express their gratitude for the support.

## References

[1] Water and Sanitation – United Nations Sustainable Development. Available at: http://www.un.org/sustainabledevelopment/water-and-sanitation (Accessed 23 January 2017).
[2] Merriam-Webster's Learner's Online Dictionary, Simple Definition of Toilet, http://www.merriam-webster.com/dictionary/toilet, accessed July 25, 2016.
[3] S. Hashemi, M. Han, T. Kim, Y. Kim, Innovative Toilet Technologies for Smart and Green Cities, Proc. 8th Conference of the International Forum on Urbanism, Incheon, 2015, pp. 873–879.
[4] Y. Kim, S. Hashemi, M. Han, T. Kim, H.G. Sohn, The waterless portable private toilet: an innovative sanitation solution in disaster zones, Disaster Med. Public Health Prep., 10 (2016) 281–285.
[5] World Health Organization, Sanitation, 2015. Available at: http://www.who.int/topics/sanitation/en (Accessed 25 July 2016).
[6] M.Y. Han, M.K. Kim, Revising the Technical and Social Aspects to Wastewater Management in Ancient Korea, A.N. Angelakis, J.B. Rose, Eds., Evolution of Sanitation and Wastewater Technologies through the Centuries, IWA Publishing, London, 2014, pp. 301–311.
[7] P. Bracken, A. Wachtler, A. Panesar, J. Lange, The road not taken: how traditional excreta and greywater management may point the way to a sustainable future, Water Sci. Technol., 7 (2007) 219–227.
[8] S. Cavill, R. Chambers, N. Vernon, Sustainability and CLTS: Taking Stock, Frontiers of CLTS: Innovations and Insights, Issue 4, Institute of Development Studies, Brighton, 2015.
[9] A.E. Aiello, E.L. Larson, R. Sedlak, Against Disease: The Impact of Hygiene and Cleanliness on Health, The Soap and Detergent Association, Washington, D.C., USA, 2007.
[10] C.E. Clement, The Eternal City, Rome: Its Religions, Monuments, Literature and Art, Vol. I, Estes and Lauriat, Boston, 1896.
[11] J.J. Mattelaer, Some historical aspects of urinals and urine receptacles, World J. Urol., 17 (1999) 145–150.
[12] U. Winblad, M. Simpson-Hebert, The Traditional Vietnamese Double Vault Toilet, Stockholm Environment Institute (SEI), Sweden, 2004.
[13] E.P. Hoyt, Hygiene in ancient China, Chest, 61 (1972) 133.
[14] J. Needham, L. Gwei-Djen, Hygiene and preventive medicine in ancient China, Health Educ. J. 17 (1959) 170–179.
[15] United Nations Millennium Development Goals, 2015. Available at: http://www.un.org/millenniumgoals/environ.shtml (Accessed 23 January 2017).
[16] A.E.F. La Berge, Mission and Method: The Early Nineteenth-Century French Public Health Movement, Cambridge University Press, Cambridge, 2002.
[17] E. Tilley, L. Ulrich, C. Lüthi, P. Reymond, C. Zurbrügg, Compendium of Sanitation Systems and Technologies, 2nd ed., Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, 2014.
[18] N. Chiarawatchai, F. Klingel, C. Werner, P. Bracken, Technical Data Sheets for Ecosan Components, 02 Dehydration Toilets – B3 Dehydration Toilets without Urine Diversion, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Bonn, 2005.
[19] T.A. Larsen, J. Lienert, NoMix – A New Approach to Urban Water Management, Eawag, Dübendorf, Switzerland, 2007.
[20] C. Lüthi, T.A. Larsen, Sanitation Innovation for Urban Slums: the Blue Diversion Toilet, 3rd International Conference on Technologies for Development, Lausanne, Switzerland, 2014.
[21] International Water Association, Resource Oriented Sanitation. Available at: http://www.iwa-network.org/groups/resource-orientated-sanitation (Accessed 12 February 2017).
[22] United States Environmental Protection Agency, High-Efficiency Toilets, Wastewater Technology Fact Sheet, EPA 832-F-00–047, USEPA, Washington, D.C., 2000.
[23] M. Han, S. Hashemi, S.H. Joo, T. Kim, Novel integrated systems for controlling and prevention of mosquito-borne diseases caused by poor sanitation and improper water management, J. Environ. Chem. Eng., 4 (2016) 3718–3723.
[24] SANItaryRecycling ESCHborn, Summary of the Presentations Held at the Meeting of the SANIRESCH Project Partners. Available at: http://www.saniresch.de/images/stories/downloads/Summary-20120605-en.pdf (Accessed 25 July 2016).
[25] United Nations Environment Programme, Environmentally Sound Technologies in Wastewater Treatment for the Implementation of the UNEP Global Programme of Action (GPA) "Guidance On Municipal Wastewater". Available at: http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/2.asp (Accessed 25 July 2016).
[26] S.A. Esrey, J. Gough, D. Rapoport, R. Sawyer, M. Simpson-Hebert, J. Vargas, U. Winblad, Ecological Sanitation, SIDA (Swedish International Development Cooperation Agency), Stockholm, 1998.
[27] S. Hashemi, M. Han, T. Kim, Identification of urine scale problems in urinals and the solution using rainwater, J. Water Sanit. Hyg. Dev., 5 (2015) 322–329.
[28] P. Cohn, The Science behind 'The Martian' Movie Gets a NASA 'thumbs up'. Available at: http://www.foxnews.com/science/2015/08/28/science-behind-martian-movie-gets-nasa-thumbs-up.html (Accessed 25 January 2017).