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ORIGINAL PAPER

Stream Segregation in Household Use: A Review of Grey Water as an Alternative Source of Water and Yellow Water as an Alternative Source of Fertilizers

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Abstract Resource recovery and conservation of resources have been attracting increasing attention in the recent years for finding sustainable solutions to environmental problems. One of such efforts is segregation of domestic wastewater streams as grey, yellow and brown or black water. This enables revaluation of domestic wastewater as an alternative renewable source of water as well as a potential source of plant nutrients, i.e. fertilizers. Reuse of grey water (the stream excluding toilet wastewater) can help reduce the unnecessary utilization of pristine water in line with "fit for purpose" use and can provide an alternative source for water stressed/scarce areas. Yellow water (human urine) constitutes only 1 % of conventional domestic wastewater by volume yet contains over 80 % of nitrogen, over 50 % each of phosphorus and potassium, hence lending a high potential to be used as fertilizer. Direct and indirect application may be practiced. Ion exchange/adsorption with clinoptilolite is a promising option for indirect use. Recoveries exceeding 90 % have been attained for nitrogen and phosphorus from clinoptilolite exhausted with N&P in yellow water. Preliminary results on pot trials have revealed that the alternative fertilizer produced is comparable to synthetic fertilizers. This paper presents a review focusing on grey water reuse as opposed to reuse after conventional combined collection; and the use of plant nutrients in yellow water as an alternative source of fertilizers. Segregated collection provides a promising route towards sustainability by contributing to "fit for purpose" use of scarce fresh water resources through the reuse of grey water while providing a means of conservation through the recovery of plant nutrients from "wastes".

Keywords Stream segregation/ECOSAN · Domestic wastewater · Grey water · Yellow water (human urine) · Fertilizer · Alternative water supply

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Introduction and Background

Revaluation of wastes of different types and resource recovery has been receiving increasing attention in the recent years. As suggested by the recent sanitation approach based on stream segregation, called ECOlogical SANitation (ECOSAN), domestic wastewater is one of those "wastes" which can be benefited from provided that domestic wastewater fractions are separated at their sources of generation. Water and plant nutrients are two significant materials which may be recovered from such practice.

Despite that water constitutes three fourths of the globe, fresh water is considerably limited and it is vital for almost all living things. However, only about 2 % of all water resources are fresh and less than half of this is readily available for use to fulfil the demands for almost all beneficial uses, including drinking water, domestic water supply, industrial use and irrigation. Increasing levels of water stress and water scarcity are being reported throughout the world at this time, with further threats awaiting mankind in the future. Sustainability of water resources, necessitating effective use and wise allocation of water resources in line with "fit for purpose" approach, is one of the major concerns of all nations at this time which also has reflections into the future.

Managing concerns of quality and quantity of water is a challenge which necessitates the allocation of adequate quantities of water with appropriate quality for each type of water demand. "Fit for purpose" use of water with proper quality for each beneficial use is one important issue of water management which needs attention. Matching quality of water with the requirements of each and every beneficial use is essential for this purpose. Potable water and water which can possibly be ingested requires highest quality and appropriately gets the highest priority. For purposes not requiring as high a quality as potable water, wastewater lends a promising alternative which will reduce the unnecessary utilization of unused pristine water. This includes irrigational water which makes up about 70 % of the use on a global basis. Agricultural irrigation is probably the most significant water use in rural areas while considerable quantities of water may be employed for urban irrigation.

Demand for water shows differences depending upon location, habits of communities, predominant economic sectors, etc. For instance, in water scarce regions, highly populated urban areas like megacities and touristic areas with pronounced seasonal population increases, finding the water to meet the demand all year round may even be a greater challenge and reuse of domestic wastewater may be a viable alternative. Domestic wastewater is actually a renewable source since it will inevitably be generated as long as humans exist.

When reuse of domestic wastewater is intended, conditions under which reuse will be practiced is a significant issue. The classical approach is to collect all wastewater from various units of the household in one single stream and to treat the entire volume of conventional mixed domestic wastewater for practically all polluting agents before reuse. The other option, which has been attracting attention in the recent years, is collection of domestic wastewater as segregated streams, where each stream is separated from the rest at the source, rather than being collected in one single combined stream. Upon segregation, each stream with distinctly different characteristics is to be processed for recovery/reuse of valuable material each one contains. Volumes of segregated streams are indeed smaller as compared to the conventional combined domestic wastewater; as a matter of fact, each stream is a fraction of the latter. Segregation not only reduces volumes but also the number of significant components/parameters to be dealt with. Moreover, fractions of what is conventionally comprehended as a "waste" to be discarded, i.e. domestic wastewater, now become a source to be benefited from. A meaningful suggestion is to use the term "used water" instead of "wastewater" to account for the idea that water used for domestic purposes is not a "waste", as was also done by Daigger (2011).

Separation at the source leads to benefits through revaluation of segregated streams. One of those streams is grey water which refers to all other than toilet wastewater, which may be processed to reclaim water for almost all functions in the water cycle. Another one of the segregated streams is yellow water which is separately collected human urine. As it is very rich in terms of nitrogen, phosphorus and potassium, which are the three active ingredients of plant fertilizers, the use of yellow water in agriculture through direct and indirect routes provides a considerable potential in fulfilling the millennium development goals and targets of sustainability.

The purpose of this paper is twofold: on the one hand it addresses the use of grey water as an alternative source of water supply, while addressing yellow water as an alternative source of fertilizers. The paper will present a review of present information together with an appraisal and outlook into future work. Within this context, the paper focuses on segregation of domestic wastewater fractions as opposed to mixing all in one single line. Emphasis is placed on the water cycle and recovery of reusable water from one of those streams, i.e. grey water, as a recurring renewable source. Grey water as an alternative source of water is discussed with specific emphasis on the comparison of characteristics and handling of grey water as opposed to conventional domestic wastewater through mixed collection. The paper also underlines the merit of separating yellow water from the rest of domestic wastewater as a source of plant nutrients which in turn may be used for agricultural and landscape purposes. Within this context, examples of revaluation of yellow will be provided, specifically emphasizing recovery of plant nutrients through processing with clinoptilolite as well as demonstrating how separating this 1 % may change conventional domestic wastewater treatment schemes and help protect water resources.

Mixed Collection, Stream Segregation and Characteristics of Segregated Streams

An average person typically produces 150–250 litres of domestic wastewater per day with organic matter, nutrients, and pathogens along with others as pollutants to be treated. Wastewater in the household is generated through toilet use, personal cleaning at wash basins, showers and bath tubs, laundry, kitchen sinks, dishwashers and general house cleaning. Wastewater produced during various functions in the household is different in character and pollution potential. Conventionally, wastewater produced in each of these functions is collected in one single pipe whereby each fraction regardless of its characteristics and pollution potential is combined in one single stream. In an urban setting, following collection, frequently this single stream of wastewater is conveyed through relatively long sewer lines into a treatment plant. In treatment systems, constituents/pollutants in the wastewater, i.e. organic matter, nutrients, pathogens among others like suspended solids, detergents, etc., are converted into CO_2, H_2O, N_2, sludge, etc. Those final products are discharged into the environment together with untreated fractions which had bypassed treatment, as liquid and gaseous products in addition to solid residue. In rural settings, they frequently travel shorter distances and are handled at locations close to their points of origin.

As opposed to the conventional combined collection of domestic wastewater of different characteristics coming from different units in the household, as is being exercised with current practice, the recent alternative for domestic wastewater management is segregated collection of wastewater at its source of generation. Within this context, two options of segregation have found interest by now: (i) separation into two streams as grey water and black water, and (ii) separation into three streams as grey water, yellow water and brown water in accordance with the recent sanitation concept Ecological Sanitation (ECOSAN). In both options grey water refers to all types of conventional wastewater inflow except that which comes from toilets. Independent of the choice of the type of segregation, grey water will always be generated whenever stream segregation is practiced. Black water refers to the fraction that comes from toilets, i.e. toilet wastewater containing human metabolic wastes, urine and feces. Yellow water is separately collected human urine while brown water is separately collected human feces. Benefits of segregated collection include production of grey water which is relatively easy to deal with for water reuse at many points of the water cycle, and the possibility of valorizing the remaining fractions for nutrient recovery, which may further be used as fertilizer, from yellow water, in addition to energy generation from brown and black water.

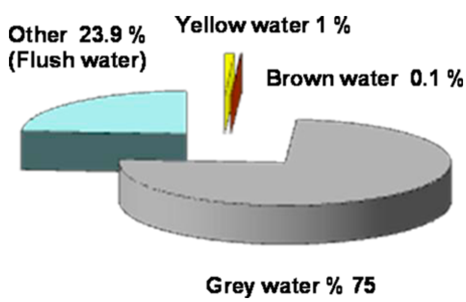

Fig. 1 Volume percentages of segregated streams (prepared based on Otterpohl et al. 2003)

With segregated collection, the aim is to process each stream to recover the valuable components rather than treating and discharging them into receiving water bodies or their equivalents. The recent sanitation concept called Ecological Sanitation (ECOSAN) specifically focuses on this and claims that domestic wastewater is not a waste to be discarded but a source to be revaluated. ECOSAN suggests handling each stream separately to process it for reuse for various final uses including irrigation water, service water, fertilizer, compost or energy sources, as dictated by their respective constituents and characteristics. It is based upon effective source control and closing of material cycles, especially water and nutrients.

Figures 1 and 2 indicate that characteristics of the three streams of ECOSAN are clearly different from each other and also from conventional domestic wastewater as outlined in Table 1. Figure 1 depicting volume percentages of ECOSAN streams shows that yellow water constitutes only 1 % of conventional domestic wastewater by volume while brown water is only 0.1 %. The figure also reveals that grey water makes up three fourths of conventional domestic wastewater volume.

Figure 2 summarizes major constituents of wastewater fractions as percentages of each found in conventional domestic wastewater. It may be observed that yellow water with a volume of 1 % contains the majority of nutrients by far with over 80 % of nitrogen, and 50 % of phosphorus. Through segregation, majority of nutrients may be isolated in a very small volume, generating a highly concentrated stream. If yellow water is separated from the rest, the problem of nitrogen removal in the remaining 99 % of the volume can practically be alleviated. Likewise, the phosphorus problem becomes easier to deal with. Although potassium

Fig. 2 Percentage of nutrients and organics in segregated domestic wastewater streams (prepared based on Otterpohl et al. 2003)

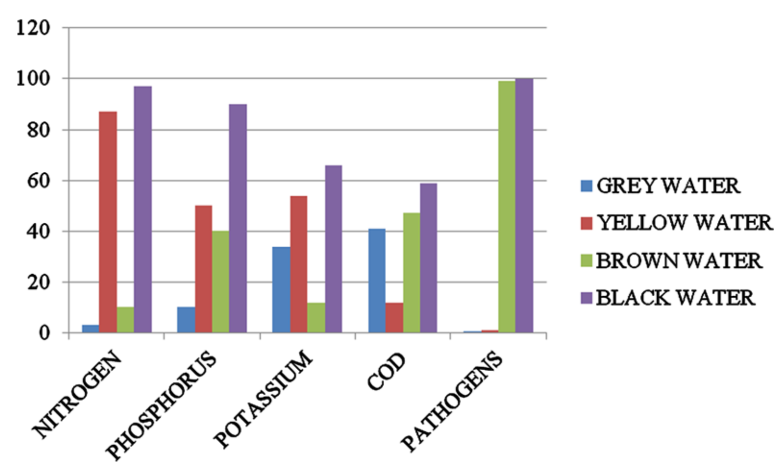

Table 1 Constituents and volumes of domestic wastewater and its fractions (Beler-Baykal 2012)

	Conventional	Grey water	Yellow water	Brown water	Black water
Organic matter	100 %	41 %	12 %	47 %	59 %
Nitrogen	100 %	3 %	87 %	10 %	97 %
Phosphorus	100 %	10 %	50 %	40 %	90 %
Potassium	100 %	34 %	54 %	12 %	66 %
Pathogens	100 %	Very low	Low	Very high	Very high
Volume	100 %	75 %	1 %	0.1 %	25 %

Table 2 Overview of constituents, products and possible final uses of segregated streams

	Significant constituents	Constituents to be revaluated	Constituents to be eliminated prior to reuse	Valuable products	Final use
Grey water	Organic matter	Water	Organic matter	Water	Irrigation
			Pathogens?		Service/flush water
					Water cycle
Yellow water	Nitrogen	Nitrogen	Pharmaceuticals?		Agriculture
	Phosphorus	Phosphorus	Hormones?	Fertilizer	Landscape
	Potassium	Potassium	Pathogens?		Green areas
Brown water	Organic matter				
	Phosphorus	Organic matter	Pathogens	Energy	Energy
	Pathogens	Phosphorus		Compost	Agriculture
Black water	Organic matter				
	Nitrogen	Organic matter		Energy	Energy
	Phosphorus	Nitrogen?	Pathogens	Compost?	Agriculture?
	Potassium	Phosphorus?		Fertilizer?	
	Pathogens	Potassium?			

is not listed as a pollutant, it is one of the major plant nutrients, hence one of the three main ingredient of fertilizers. In addition to high amounts of nitrogen and phosphorus, its high content of potassium with more than 50 %, makes yellow water an alternative fertilizer. Hence upon stream segregation, yellow water may be revaluated as fertilizer (Beler-Baykal et al. 2004, 2009, 2011a, 2011b; Ganrot et al. 2008; Kocaturk and Beler-Baykal 2012). The other stream which is significant in terms of nutrients is brown water with 40 % of phosphorus. Brown water is also rich in organic matter with almost half of what appears in conventional domestic wastewater and is a potential input for biogas production through anaerobic processing, and composting. Black water may be viewed as the combined collection of yellow and brown water together with flush water. As such, it contains over 90 % of nitrogen and phosphorus, nearly 60 % of organic matter and 70 % of potassium.

Moreover, nearly all pathogens reside in black water. It is a highly concentrated stream of pollutants isolating nutrients, pathogens and about half of organics, and its segregation saves the grey water from being polluted by these constituents to a large extent. Grey water on the other hand is relatively weak in terms of pollutants with the major one being organic matter. Regarding bacteriological quality, the greatest majority of pathogens by far are contained in brown water as most of those are attributed to human faeces. Pathogens in yellow water are low as compared to brown water and even lower in grey water.

Table 2 summarizes the significant constituents of each segregated stream together with valuable products which may be recovered from each and their probable final use. Yellow water may be used as fertilizer for agricultural and landscape purposes through direct or indirect routes due to its high content of plant nutrients. Organic matter in brown water may be converted into energy, or into compost to be used in agriculture. Black water is also a potential source of organic matter which can be used for energy production. The residue from this process is yet to be investigated in terms of its potency as a fertilizer. Finally, grey water is a good source of reuse water especially for water which needs not to be at the quality of drinking water. After the removal of organics, and control of pathogens, it may be returned to a wide range of purposes in the water cycle.

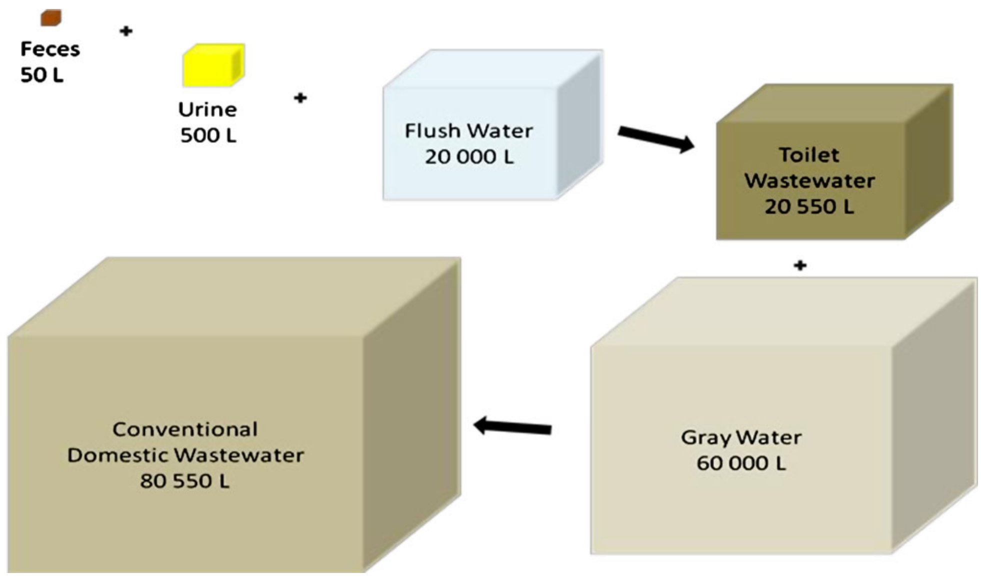

Fig. 3 Mixing and contamination in the conventional wastewater collection chain: (based on 220 l/person day total water use, 9 l per flush, 6 flushes/person day) (Beler-Baykal 2012)

Figure 3, drawn to scale in terms of volumes, illustrates how mixing the 0.1 % of human faeces (about 50 l/person/year) and 1 % of human urine (about 500 l/person/year) contaminates first 20 000 l/person/year of drinking water quality flush water to generate the highly polluted toilet wastewater, which in turn mixes with mildly polluted 60 000 l/person/year of grey water to produce conventional domestic wastewater to increase the pollutants in larger volumes significantly. Collecting and keeping streams separate will indeed prevent such contamination by isolating groups of pollutants in smaller volumes. In terms of water reuse, this will lend ease in handling, by replacing the larger volume and higher pollution potential mixed conventional wastewater with grey water which will have more limited pollution potential and a relatively smaller volume. Additionally, segregation will provide options of recovering other useful material, i.e. plant nutrients to be used as fertilizer and energy from what has been comprehended as a “waste”. Another issue here is the use of “drinking water quality” flush water to transport highly contaminated human excreta, which seems to contradict with the “fit for purpose” use.

An Appraisal of the Use of Grey Water as an Alternative Source of Water

Grey water constituting the largest fraction of segregated streams by volume is a combination of various types of wash water including those coming from wash basins, showers and bath tubs, dish washers, laundries and sinks, and it too may be separated in subcomponents. Those subcomponents also show differences among each other and combined grey water too as shown in Table 3. The least polluted among those seems to be the wash water coming from wash basins and showers/bath tubs and generally they get the first preference when reuse is considered. Diaper washing for example, increases pathogens significantly. Table 3 is prepared to compare characteristics of conventional domestic wastewater and different types of grey water. In terms of organic matter, grey water resembles weak-to-intermediate strength domestic wastewater with much lower concentration of nutrients and pathogens of that category. An analysis of Table 3 reveals that when reuse of domestic wastewater is intended, segregation of grey water from the rest with only organics as significant pollutants will allow reuse through milder treatment and decreased pathogenic risks as compared to conventional domestic wastewater; therefore smaller volumes and a smaller number of pollutants are to be handled. Particularly, a volume of 110–190 litres per person per day of grey water with only organics need to be treated, and pathogens are to be checked for, instead of 150–250 litres which would have to be treated for organics, nitrogen, phosphorus, pathogens along with others, in the case of conventional domestic wastewater.

Flush water constitutes about 1/4 of the household water demand and it is actually used to clean and convey human metabolic wastes which are highly contaminated with pathogens and nutrients down the collection line to its final destination. Frequently this is done using water with drinking water quality, which is a waste of high quality fresh water. Actually the use of drinking water for this purpose is highly questionable, especially in highly populated urban settings and water stressed/scarce areas. One very meaningful way of reusing grey water is to return it to household use as flush water. Flush water can conveniently be supplied from grey water which is about three times as much of the quantity needed for flushing. Even for cases when milder factions, i.e. the fraction from showers, baths and

Table 3 Typical characteristics of conventional domestic wastewater and grey water

	Conventional (Metcalf and Eddy 2003)			Grey water		
	Weak	Intermediate	Strong	Combined (Atasoy et al. 2007)	Bath&shower (Nolde 1999)	Bath&shower&washing machine with baby diapers (Nolde 1999)
BOD	110	190	350	90	50–100	150–250
COD	250	430	800	245	100–200	250–430
Nitrogen N						
Total N	20	40	70	9 (as TKN)	5–10	
Organic N	8	15	25			
Ammonical N	12	25	45	1.3		
NO_2/NO_3 N	0	0	0			
Phosphorus P						
Total P	4	7	12	7.3	0.2–0.6	
Organic P	1	2	4			
Inorganic P	3	5	10			
Total coliforms (in 100 ml)	10^6–10^8	10^7–10^9	10^7–10^{10}	13634	10^2–10^3	10^4–10^6
Fecal coliforms (in 100 ml)	10^3–10^5	10^4–10^6	10^5–10^8	3565	10^{-1}–10^1	10^4–10^6

wash basins are considered, the recycled water will still be sufficient for flushes. Hence if relevant infrastructure is in place, the entire amount of flush water may be supplied from grey water, saving 25 % of the high quality domestic water supply.

The Turkish megacity Istanbul constitutes a good example of an urban setting where benefits of using grey water for flushes could be significant. Istanbul pumps the highest portion of its water from 200 km away to supply water for 14 million inhabitants, treats it to bring it to potable water quality and then uses one fourth of its entire water for flushing to convey human excreta into wastewater treatment plants. High quality flush water could very well be replaced by grey water, especially in new housing complexes and settlements, specifically at this time where the megacity is scheduled to undergo substantial urban rebuilding (Beler-Baykal and Giresunlu 2013). Another very meaningful use of grey water is irrigation. Irrigation amounts to 70 % of the global water demand and is the sector which uses the greatest portion of water. This is probably a more significant area of reuse in rural areas, especially where agriculture is the predominant sector. The quantity of grey water is far from satisfying the entire need for this purpose but it still may contribute about 10–15 % of this on a global scale. In highly populated areas and water stressed regions, however, the contribution of grey water to meet the demand may be more critical.

A number of technologies are available to treat grey water for reuse including high-tech compact systems like rotating biological contactors (RBC), sequencing batch reactors (SBR) and membrane bioreactors (MBR), as well as land extensive systems like constructed wetlands (CW). Table 4 prepared from information provided by Nolde (2007) shows footprints and energy demand for those systems. High-tech systems use smaller areas but are more costly and may necessitate trained personnel for effective operation, while climate sensitive constructed wetlands are much simpler and cheaper to operate if land is readily available. Superiority of the MBRs due to the high microbiological quality they offer is worth mentioning.

The choice of technology will be dependent on the final quality targeted which should be dictated by the final use as well as the location, availability of land, skilled personnel and budget. While in urban settings compact systems are preferred, CW are highly preferable in rural areas. In addition to cluster or common treatment, emerging package treatment systems which are installed under wash basins in individual houses have also been manufactured.

Physical and chemical treatment systems usually involve holding tanks, filters, and pumps. Basic grey water treatment and storage systems with activated carbon and/or clay filters and disinfection (e.g., chlorination, purification with ultraviolet radiation) can cost between $1000 and $5000 for a single family home while grey water systems incorporating high-tech biological treatment units like MBR can go as high as $10 000 (Allen et al. 2010). Comparable figures were also reported by Sheikh (2010).

Nolde (2005) indicates that for earlier cases of grey water treatment practice in Germany for a 70-person housing settlement in Berlin, a 15 m^2 plant in the basement was sufficient to treat grey water from showers, bath tubs and hand wash basins, and that similar observations were made elsewhere in the country. He reports that the payback time for a 400-bed hotel near Frankfurt was calculated to be

Table 4 Comparison of land requirement and energy demand for selected grey water treatment options (prepared based on Nolde 2007)

	Area requirement (m^2/person)	Energy requirement (kwh/m^3)
Constructed Wetlands (CW)	1–2	
Rotating Biological Contactors (RBC)	0.1–0.2	<2
Sequencing Batch Reactors (SBR)	0.1	1.5
Membrane BioReactors (MBR)	0.1	<1.5

6.5 years. Nolde (2005) summarizes typical grey water systems in Germany for a wide range of consumers including single-family houses, housing settlements, hotels and camping sites and provides information about the most typical grey water system in the country. The typical system handles 200–10000 litres of grey water per day originating mostly from bath tubs and hand wash basins. Most of those treat around 600 litres per day and require a land area of 0.81 m^2 and a height of 1. 88 m to save about 200 m^3 of water on an annual basis if operated at full capacity. Costs associated with those systems are reported to be about 5000 Euros including installation and operation costs of about 20–25 Euro per year. Nolde (2005) also indicates that with larger systems investment and savings potential will be improved, and due to experience acquired through the years, currently high treatment efficiencies can be guaranteed at lower costs.

Investigation of various scenarios made by Frohlich et al. (2003) to assess costs as they relate to segregated collection of ECOSAN streams have revealed that depending upon specifics of the cases, segregation may be more beneficial as compared to the conventional case. The authors have also concluded that benefits become more apparent as the population size served increases, especially with their 5000-inhabitant scenario.

Guidelines and standards constitute one of the priority elements of water and wastewater management and grey water is no exception. Although there are wastewater reuse standards in several countries at this time, there seems to be extremely limited water quality standards specifically issued for grey water reuse. The most specific one seems to be the guideline prepared by WHO (2006) which advises values for irrigation as 10^3 and 10^5 E coli/100 ml for unrestricted irrigation of crops eaten raw and restricted irrigation, respectively, for grey water reuse. The guideline also gives a value of 1 Helminth egg per litre for both categories. It has to be noted that the guidelines are issued only for irrigational use and values for reuse as flush water or service water are not included. Providing those limits will be more critical as grey water reuse becomes more widespread. Within this context, the final use should be considered important in setting the standards/guidelines.

In terms of grey water legislation, there seems to be a considerable variability between various countries. While some encourage grey water use, others have imposed prohibitions. Germany seems to be the leader in Europe followed by Australia. Domestic grey water reuse is legal in Germany, however it must be registered. It is mandatory to separate grey water in Tokyo, Japan for buildings with an area of over 30 000 m^2, or with a potential reuse capacity of 100 m^3 per day. United States does not have a national grey water policy but encourages the use of grey water, leaving regulation of grey water to states. About 30 of the 50 states have grey water regulations of some kind which vary considerably (Allen et al. 2010).

An investigation of grey water use in the USA shows that California is the state which leads in grey water use with 14 % of the households involved, which is followed by Pennsylvania (8 %), Florida (6 %) and New York (5 %). Recycled grey water which has undergone tertiary treatment and disinfection may be used for non potable uses of all kinds specified in California including irrigation, supply for impoundments, supply for air conditioning and others like toilet flushing, decorative fountains, fire fighting and even commercial laundries (Allen et al. 2010).

One other consideration for the segregation of grey water is due to concentration of the liquid phase in the sewer systems (or equivalent) and in treatment plants. As grey water constitutes 3/4 of conventional wastewater, flow rates will be diminished impacting with the transport system and concentration of the remaining fraction will increase impacting with wastewater treatment systems. This deviation from the conventionally expected case must receive attention and planning must be made to account for the reduction in volume and increase in concentration as the segregation of grey water becomes widespread.

Reuse of grey water calls for an integrated approach to water and wastewater management as it will be using "wastewater" to meet the demand of "clean water". When dealing with segregated streams, taking a holistic look at multidimensional issues associated with this approach is a major key factor in analysis, evaluations and making correct decisions.

Possible Use of Yellow Water in Agriculture as Fertilizer

World population exceeds seven billion as of present time and sufficient food for all is still one of the most significant

Table 5 Characteristics of fresh and stored urine (prepared based on Kocaturk and Beler-Baykal 2012)

Parameters	Units	Fresh urine	Stored urine
Ammonium	mg NH_4/l	344	5700
Total Kjeldahl Nitrogen	mg N/L	5700	5750
Potassium	mg K/l	1200	1200
Orthophosphate	mg PO_4–P/l	410	275
Total phosphorus	mg PO_4–P/l	415	300
COD	mg/l	7120	6950
pH	pH units	6.0	9.4
Electrical conductivity	mS/cm	14.0	33.8

problems on a global scale as indicated by the millennium development goals. In addition to fertile soil and water of adequate quantity and quality, fertilizer for production of food is one of the major requirements to fulfill those goals.

The richness of yellow water in terms of nitrogen, phosphorus and potassium makes it a viable candidate as an alternative fertilizer. It has been indicated that of the 135 million tons of yearly fertilizer demand on a global scale, 50 million tons may potentially be obtained from human excreta on a global scale, and one person's excreta will contain enough plant nutrients to produce about 200 kg of cereals per year (Wach 2007). These figures point at the fact that human urine may contribute significantly to the solution of food production issue and help out with poverty eradication.

Application of yellow water through direct and indirect routes is possible. If yellow water is to be used directly upon plants, it has to be stored for several months for hygienic safety (Hoglund 2001; WHO 2006). It is important to note that characteristics of urine changes during storage as shown in Table 5 (Kocaturk and Beler-Baykal 2012). The changes are especially noteworthy for ammonium, pH, electrical conductivity and phosphorus for agricultural purposes. Salinity is an important problem to be considered before direct application and dilution will most probably be needed. Pinsem et al. (2004) have recommended the use of urine at 20–30 % concentration for improved results. Additionally, occurrence, fate and impact of pharmaceuticals and hormones are still to be investigated.

For indirect application, yellow water will have to be processed more rigorously prior to reuse. So far, struvite precipitation and ion exchange/adsorption have been the most studied processes with promising results especially for nitrogen and phosphorus. Struvite precipitation has extensively been studied to show that it is successful for phosphorus removal from urine (Lind et al. 2000; Ganrot et al. 2008; Kabdasli et al. 2006) while it requires unreasonably large amounts of chemical addition for removing/recovering nitrogen. Both removal and recovery of nitrogen with ion exchange upon the natural zeolite clinoptilolite were observed to be successful. Additionally, promising results were obtained for phosphorus removal and recovery through the use of clinoptilolite (Kocaturk and Beler-Baykal 2012) which were supported by Allar and Beler-Baykal (2013).

The essential component of yellow water is human urine which is rich in nutrients and the highest portion comes from nitrogen with a TKN of 5500–9000 mg/l. In freshly excreted urine, nitrogen is to a great extent in the form of organic nitrogen most of which comes from urea. In time however, urea is hydrolyzed to ammonium and after about one month of storage, TKN is governed by ammoniacal nitrogen.

Clinoptilolite is a natural zeolite, more specifically an aluminosilicate. It is a natural ion exchanger which is highly selective for ammonium (Klieve and Semmens 1980). The success of removal of ammonium from wastewater through the use of clinoptilolite is well documented in the literature. Examples include Beler-Baykal et al. (1996), Beler-Baykal and Akca-Guven (1997), Beler-Baykal (1998), as well as the review prepared by Hedstrom (2001). Theoretical cation exchange capacities like 2.46 meq/g and ammonium exchange capacities like 30 mg NH_4/g (1.7 meq/g) have been reported (Beler-Baykal and Allar 2012). Among other uses, clinoptilolite is a natural material which is used in agriculture as a soil conditioner.

Clinoptilolite can also be used to remove and recover nitrogen in the form of ammonium from source separated human urine (Lind et al. 2000; Beler-Baykal et al. 2004, 2009, 2011a, 2011b; Ganrot et al. 2008; Kocaturk and Beler-Baykal 2012). In doing this, ammonium in yellow water is loaded onto clinoptilolite to exhaust the zeolite. Up to 93 % of nitrogen in urine could be transferred onto the ion exchanger. Meanwhile potassium and phosphorus are also transported onto clinoptilolite at levels which exceed 90 %. Thus the product to be used as fertilizer is clinoptilolite which is loaded with nutrients from human urine. It was reported that surface concentrations of 9.04–9.08 mg NH_4/g clinoptilolite upon loading and removals of 8.46–8.66 mg NH_4/g clinoptilolite from the surface could be attained in lab scale experiments (Beler-Baykal et al. 2011b). It has been shown that upon contact with tap water mimicking irrigation, up to 96 % of ammonium is released into the wash water through desorption and made available to plant use. Phosphorus is also released into the water and this amounts up to 99 % of the surface concentration. However, potassium could not be released into tap water due to the relatively high concentration of this ion which will not allow desorption (Kocaturk and Beler-Baykal 2012). Possibility of release of potassium into rain water with lower content of the ion is considered to be worthwhile.

The product, i.e. exhausted clinoptilolite, was applied to *ficus elastica* and grass in pot trials. The results of preliminary experiments have shown that the product was at least as successful as synthetic fertilizers (Beler-Baykal et al. 2011a; Kocaturk and Beler-Baykal 2012).

Additional Examples of Stream Segregation in Practice

The use of segregated streams has been getting more and more attention since the turn of the millennium. Examples of practice seem to increase day by day as full size applications in all continents, both in developing and in highly developed countries (Werner 2008), various African countries, India, China, Germany, and Scandinavian countries are just to name a few. More of the projects seem to be concentrated around rural areas and in the form of ECOSAN segregation with reuse in immediate vicinity in the former, as opposed to more being applied in urban and peri-urban areas as grey water/black water segregation and reuse of grey water in the latter.

German based GTZ and the SuSanA are examples of groups to take the lead in ECOSAN projects worldwide. The aim is to promote development and pilot application of sustainable recycling-oriented sanitation concepts in developing countries while contributing to the global dissemination and application of ECOSAN approaches and establishing state-of-the-art techniques both in developing and in highly developed countries (Werner 2008).

In addition to those mentioned in the preceding sections, the following is a short list of specific examples of segregated management of domestic wastewater and reuse of valuable products from segregated streams from around the world (Werner 2008; Oldenburg 2003; Oructut 2013):

- Arborloo simple low cost pit laterines for ECOSAN practice in Zimbabwe
- Public ECOSAN toilets in Bengalore also in Tamil Nadu, India with the use of urine and excreta based compost for agricultural purposes
- Urine diverting toilets (UDT) in Benin and large scale promotion in Durban, South Africa with 60 000 UDTs
- 1.1 million UDTs installed by 2007 in 17 provinces of China
- China–Sweden ERDOS eco-town project ECOSAN practices in an entire functioning modern town with urine-diverting dry toilets and collection systems for multi-storey buildings, decentralized grey water collection and treatment and compost from faeces and urine for agricultural reuse
- ECOSAN separation in Tsighua University, Beijing, China with separate collection and reuse of grey water, yellow water and brown water
- Mobile eco-toilets (urine-diverting composting toilets) in Beijing for public spaces, construction sites and green Olympic games of 2008
- Grey water treatment for reuse in Oslo, Norway
- 4 star hotel near Frankfurt, Germany recycling grey water for toilet flushing
- KwF and GTZ headquarters—large sized office buildings near Frankfurt equipped with sanitation systems based on the ECOSAN concept, both buildings separating streams for reuse of the products from each
- Flintenbreite, Lubeck, Germany eco-settlement for 350 inhabitants separating grey water and black water
- Two five-star hotels in the heart of Istanbul, Turkey segregating grey water for reuse in flushes and garden irrigation

Concluding Remarks

Segregation of domestic wastewater streams is a relatively new concept in wastewater management which allows the use of each stream further. Within this context, grey water which makes up 75 % of conventional domestic wastewater yet contains only about 40 % of organics as the problematic priority pollutant, lends a milder water phase to deal with. Although pathogenic content of grey water is much lower as compared to the conventional one, measures should be taken to check hygienic risks. The possible use of a portion of grey water for toilet flushes will provide one fourth of the daily domestic demand from reclaimed sources rather than from water of drinking water quality, and this seems to be a sustainable choice. Additionally, grey water may be used for irrigation and as service water, or as ground water recharge, depending on case specific demands and requirements.

Yellow water, on the other hand, constitutes only 1 % of domestic wastewater by volume but carries majority of the nutrients therein. Segregation of this stream will first of all free the remaining 99 % of the wastewater from a large proportion of problematic nutrients on one hand, while helping with sustainable solutions for wastewater management by revaluation of what is conventionally comprehended as a "waste". The high content of nutrients makes yellow water a potential fertilizer through direct and indirect routes. Encouraging results have been obtained upon processing of yellow water with the natural zeolite clinoptilolite.

Promising results attained regarding the use of yellow water as fertilizer so far provide motivation for further work. Future research should be directed not only at improving recovery processes but also should consider other aspects as the impact of pharmaceuticals and hormones. Additionally, increasing number of full-size applications and their success will provide further motivation from the perspective of practice.

Although segregation of domestic wastewater necessitates infrastructure for source separation, the additional benefits of stream segregation include ecologically sustainable practices involving nutrient and energy recoveries from various streams. Avoiding mixing of domestic wastewater fractions deserves attention as a promising approach which will give way to the revaluation of a recurring line of what is conventionally comprehended as a waste, i.e. wastewater, as a resource. Integration of water and wastewater management with grey water at the focal point will contribute to the sustainability of scarce fresh water resources by helping with the solution of the water stress problem and conserve pristine water for the most worthwhile use; while the use of yellow water as a source of nutrients is a worthwhile practice which addresses both control of environmental pollution and revaluation of “wastes” by turning the “waste” into a profitable product that will also help the millennium development goals through contributing to food production.

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