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Recycling/reusing grey water and yellow water (human urine): motivations, perspectives and reflections into the future

Bilsen Beler Baykal

Department of Environmental Engineering, Istanbul Technical University, 34469 Ayazaga, Istanbul, Turkey, Tel. (90) 533 5795751; email: baykalb@itu.edu.tr

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ABSTRACT

Stream segregation is a recent domestic wastewater management approach which while providing pollution control offers a new approach to valorization of domestic wastewater as a source. Grey water (wash water from household use which excludes toilet wastes) and yellow water (human urine) are two of the streams which result from segregation of domestic wastewater at their points of generation. After proper treatment, grey water may be returned to almost any point in the water cycle to be recycled for a number of purposes, while human urine may be used as an alternative source of fertilizers for recycling nutrients. Only through recycling grey water for flushing, 25% of daily water use will be speared; while recycling nutrients in urine can provide about 30% of the fertilizer demand. Application of this technically and environmentally promising approach also requires economic and social acceptance to be claimed as a sustainable practice. Work undertaken so far reveals that this is a promising option also from the perspective economic and social acceptability. Recycling and reuse of grey water and yellow water may indeed contribute to more efficient use of water resources/pristine water, food security and sustainability for the current and future welfare of mankind.

Keywords: Domestic wastewater management; Stream segregation; Grey water; Yellow water (human urine); Recycling/reuse; Reclaimed water; Nutrient recovery; Fertilizers from urine; Technical and ecological/economic/social sustainability

1. Introduction

Sustainability has been one of the significant concerns on a global scale for the current and future welfare of mankind since the end of the 20th century onward. The term has embedded in it two significant concepts, namely controlled use of natural resources and control of environmental pollution, among others. It has been emphasized in the recent years that sustainability rises on three tiers or components, namely ecological/technical, economic and social.

As opposed to the conventional practice of combined wastewater collection and management, where domestic wastewater generated in different types of household functions are collected in one single pipe where all mix together, segregated collection and management of domestic wastewater has been suggested, both for controlling water pollution, and for revaluating this "waste" stream as a source of valuable material rather than disposing it as waste. Within this framework, domestic wastewater may be collected as two (black water/grey water) or three (yellow water/brown water/grey water) component streams.

Black water refers to the wastewater coming from toilet bowls while grey water refers to all wastewater excluding the one coming from the toilets. Yellow water is human urine separated at the point of generation, either from urine diverting toilets or from urinals, while brown water is mainly source-separated human feces again collected at the point of generation, that is, the toilet bowl. Stream segregation aims

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at valorizing each stream while controlling pollution through collecting, storing and processing each one separately, without mixing with or contacting each other [1,2]. Rather than being a technology, stream segregation is a domestic wastewater management approach. Clearly, it involves recycling and reuse as one of its main objectives.

It is a well-known fact that the world is facing a water stress and scarcity problem and the need for diligent use of natural water resources along with identification of alternative sources of water is obvious. Likewise, "food for all" and "global food security" are two major issues of our time which necessitate fertilizers. Stream segregation presents a viable contribution to both as it can provide an alternative source of water through reclamation of grey water and production of fertilizers from yellow water, that is, source-separated human urine.

Segregated streams/ECOSAN approach has been in the agenda to a large extent since the turn of the millennium and the amount of research and publications on the subject matter have been increasing fast in the last two decades [3–6].

The aim of this paper is to present an appraisal of grey water as an alternative source of water and yellow water as an alternative source of fertilizers to aid sustainability, addressing its three tiers, that is, technical/ecological, economic and social issues, and providing examples for each, mostly based on the experience of the Istanbul Technical University's research group on Segregated Streams and ECOSAN.

2. Stream segregation

Valorization of "wastes (using the conventional terminology)" of different types is an area which receives increasing attention in recent years. An important one of those is domestic wastewater. The conventional approach to domestic wastewater involves collection in one single stream which ends up in mixing of all components of wastewater stemming from the household, regardless of where it comes from or what its characteristics are, and conveying it through sewer systems to wastewater treatment plants where the contents are converted into gases such as carbon dioxide, nitrogen, etc., treated water with leftovers from treatment units, and sludge which needs further treatment. The alternative is segregated collection and processing of various streams where each stream is handled not as a waste in the classical sense but are taken as sources for generation of valuable material and possibly energy. This may be done either as two component or three component segregation where grey water, black water, yellow water and brown water are separated at the source they are generated as shown in Fig. 1, without coming in contact with each other. Black water refers to wastewater coming from toilets as a mixture of human urine, feces and most probably flush water and toilet paper. Grey water is all domestic wastewater with the exclusion of the part which comes from toilets, and contains wash water of different types. Yellow water is source-separated human urine while brown water refers mainly to separately collected human feces [1,7].

Grey water is the mildest fraction in terms of pollution potential and has organic matter and pathogens as pollutants to be treated. After proper treatment, grey water may be returned to almost any point in the water cycle. Yellow

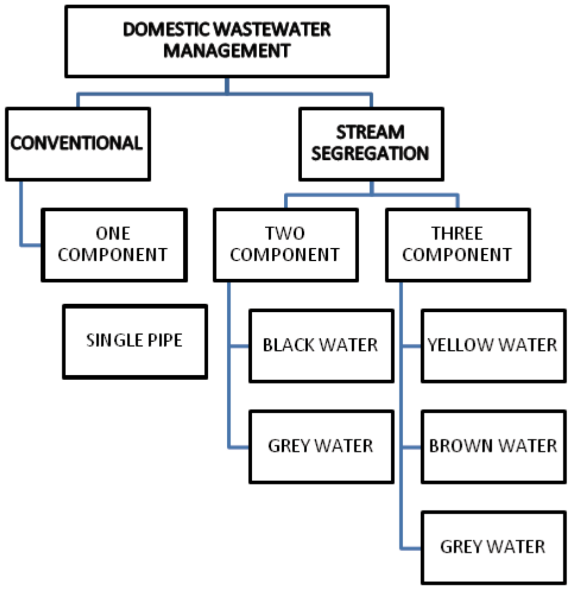

Fig. 1. Conventional domestic wastewater treatment and segregation options.

water is the richest stream in terms of nutrients, that is, nitrogen, phosphorus and potassium, by far, therefore its use as fertilizer is recommended. Carrying the highest amount of pathogens among all segregated streams, brown water constitutes only 0.1% of domestic wastewater by volume, and contains about half of the organic matter therein. Therefore, it is a concentrated source of organics which may either be processed to produce compost or may be used as a source of biogas/methane upon processing under anaerobic conditions to contribute to energy generation from a waste stream. Black water contains all components that exist in yellow water and brown water so it is rich in terms of nutrients and organic matter, however due to the contribution of flush water to increase its volume, concentrations are much lower as compared with either one of those streams. The most abundant practice seems to revaluate black water for energy using anaerobic systems, frequently by using vacuum toilets to reduce flush water volumes which will in turn lead to higher concentrations to make anaerobic processes more favorable. A summary of characteristics of segregated streams based on Beler-Baykal [1,2,8] along with conventional domestic wastewater is given in Table 1 [8] while Table 2 [9] presents an analysis of pathogenic indicators in domes-tic wastewater and segregated streams of different types (Giresunlu and Beler-Baykal [9]). It may be observed that the lowest pathogen concentration among all streams investigated was found in yellow water.

Stream segregation provides a new approach towards domestic wastewater management claiming that domestic wastewater is not a waste to be discarded but a source to be revaluated. Within that context, domestic wastewater is separated into streams at the point of generation before they come in contact or mix with each other, kept separate throughout the entire time span and are processed further to be turned into beneficial recyclable products. It is a concept which has its basis in effective source control, closing of material cycles

Table 1
Characteristics of segregated domestic wastewater streams [8]

Stream	Fraction	Volume[a]%	Organic matter%	N[a] %	P[a] %	K[a] %	Pathogens	Constituents to be revaluated	Constituents to be removed	Valuable products	Final use
Grey	Wash water (all except toilet bowl)	75	41	3	10	34	Low	Water	Organic matter pathogens	Water	Flush water irrigation, and other water cycle uses
Yellow	Source-separated urine	1	12	87	50	54	Very low	Nitrogen, phosphorus, potassium	Pharmaceutical, hormones, pathogens	Fertilizer	Agriculture landscape Green areas
Brown	Source-separated feces	0.1	47	10	40	12	High	Organics, phosphorus	Pathogens	Energy, compost	Energy, agriculture
Black	Urine, feces, flush water	25	59	97	90	66	High	Organics, nitrogen, phosphorus, potassium	Pathogens	Energy, compost, fertilizer	Energy, agriculture

[a]% of conventional domestic wastewater.

Table 2
Pathogenic indicators in domestic wastewater and segregated [9]

Stream	Location	Source/specification	Total coliform	Fecal coliform	*E. coli*	Entero-cocci
			cfu/100 mL			
Grey water	Hotel	Wash basin/bath/shower	2.80E + 06	5.50E + 05	1.50E + 05	0
	University dormitory	Wash basin/bath/shower	1.79E + 07	3.20E + 06	2.60E + 06	0
	University building	Wash basin	2.69E + 03	8.70E + 02	1.00E + 02	3.50E + 02
Black water	University building	Toilet bowls	1.66E + 06	1.60E + 04	4.75E + 03	7.75E + 03
Yellow water	University building	Fresh urine	4.45E + 04	0	0	0
	University building	Stored urine (3 months)	0	0	0	0
	University building	Stored urine (5 months)	0	0	0	0
Conventional domestic wastewater	Municipal WWTP		1.15E + 09	2.00E + 06	1.05E + 06	9.40E + 06

and recycling, recovery and reuse, thus providing a pathway to sustainability using renewable sources from indispensible metabolic and daily routine activities of mankind.

3. Why recycle grey water?

Although about three fourths of the globe is made up of water, water, especially fresh water to serve almost all requirements of mankind, is a limited resource. Problems of water stress and scarcity across the globe is a well-known fact and communities are searching for ways to relieve this pressure. For long periods of time in history much of the attention has been devoted to quantity; however quality of water is also as important.

The challenge at this time is to provide sufficient quantity of water having adequate quality for prescribed purposes of use. This necessitates allocation of water to various demands by taking the "fit for purpose" approach as the focal point which advises to use the correct quality of water for the intended purpose in addition to sufficient quantity. A vibrant conclusion from this discourse is not to flush toilets with water of drinking water quality as is most frequently the case with current practice, especially knowing that flush water consumption accounts for 25% of daily domestic wastewater use, but to use grey water instead [10].

As may be observed in Table 1, grey water typically constitutes about 75% of domestic wastewater and may be returned to the water cycle and reused for many types of household use including flush water after a milder treatment as compared with treatment of conventional domestic wastewater for the same purpose. It seems very promising to use grey water provided and reclaimed on-site to spear the 25% which will be a significant contribution to relieving the stress upon natural water resources, especially in areas of water stress and scarcity. It is to be noted that although flush water demand is 25% of the daily use, the entire grey water from household is 75%. Various final uses include irrigation, car washing, firefighting, groundwater recharge, etc. in addition to flushing. If it is to be used for flush water only, collecting and treating light grey water, that is, the fraction coming from hand-wash basins, showers and bath tubs, will be sufficient as the latter typically constitutes 30% of daily use as depicted in Fig. 2 [11]. Benefits may be enhanced by using grey water for irrigation of gardens, car washing and even for general cleaning in and around households.

Stream segregation and grey water reuse integrates domestic wastewater management and domestic water supply, through recycling up to 75% of the wastewater back into the water cycle, thereby using it as an alternative means of water supply. This is especially crucial for countries/(urban) areas which are already suffering water stress/scarcity. Indeed, the reuse of grey water is a practice to help relieve the stress on fresh water resources and to use pristine water for more worthy purposes.

4. Recycling grey water

4.1. Technical aspects

Grey water is the stream which will be produced regardless of the type of segregation applied. Both two-component and three-component (ECOSAN) segregation will yield grey water. To be able to make use of the benefits of recycling grey water, first it should be segregated from the remaining segment at the source where it is generated and a separate line of piping will have to be installed for this purpose leading to the separate collection tank intended for collecting raw grey water. Further piping must be provided for conveying reclaimed grey water from treated grey water tank to the location of the end use.

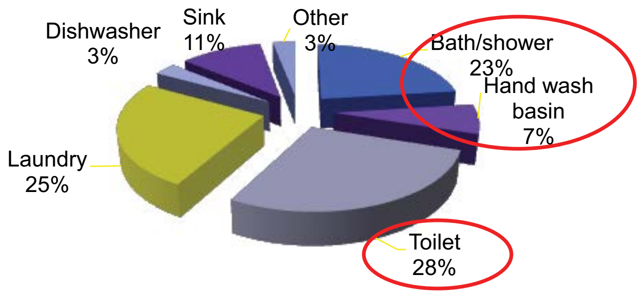

Fig. 2. Daily domestic water use [11].

Typically, grey water contains lesser amounts of pollutants as compared with conventional domestic wastewater with organics and pathogens as constituents to be treated before being recycled [12], and much lower levels of nitrogen and phosphorus in comparison with the conventional one. It is to be noted that characteristics of grey water vary greatly [13] and it is desirable to assess the characteristics of the specific grey water to be treated.

Frequently a treatment system with biological activity is employed to remove organic matter followed by at least one unit for disinfection to eliminate pathogens. Organics removal may be done in a range of treatment options including compact systems such as membrane bioreactors (MBRs), rotating biological contactors, sequencing batch reactors or constructed wetlands if land is available and affordable. Physicochemical systems may also be an option depending upon the characteristics of the specific grey water to be handled. When MBR is used for treating organics, commonly with ultrafiltration membranes, there is the further benefit of pathogenic elimination. Additionally, UV disinfection and chlorination are used as common methods for disinfection.

Currently, standards and/or guidelines specific to grey water and its use for different end uses is not common except a number of countries as exemplified by Australia and Germany [14]. Frequently standards and guidelines for general reuse of wastewater are considered for this purpose. However, as grey water is acknowledged in more and more communities and countries, it should be expected to have specialized grey water and final use limits in place. This would enhance the benefits of grey water reuse through a more efficient implementation of the "fit for purpose" approach.

As an example, Table 3 presents characteristics of light grey water from a university residence hall at a downtown location in the Turkish megacity Istanbul as averages throughout a monitoring period of an academic year [14]. The dormitory collects from wash-basins, showers and bathtubs and recycles reclaimed light grey water for flushing toilets. An ultrafilter MBR unit is used for reclamation followed by disinfection before reclaimed grey water is fed to flush water reservoirs.

Table 3
Raw and treated grey water quality and flush water limits [14]

Parameter	Unit	Raw grey water	MBR treated grey water	Flush water limits[a]
COD	mg/L	198	<30	
BOD	mg/L	67	3	5–20
SS	mg/L	139	5	10–30
VSS	mg/L	94	2	
TKN	mg/L	6.09	1.22	
NH_4–N	mg/L	0.64	0.09	
Total P	mg/L	1.78	0.97	
PO_4–P	mg/L	0.75	0.51	
Total coliforms	cfu/100 mL	1.16E + 07	0	10
Fecal coliforms	cfu/100 mL	4.82E + 06	0	
E. coli	cfu/100 mL	2.11E + 06	0	1–10
Enterococci	cfu/100 mL	0	0	

[a]Ranges compiled from Australia, Berlin and WHO, based on Giresunlu and Beler-Baykal [14].

It may be observed from Table 3 that in this particular light grey water, concentrations of physicochemical parameters including organic matter and nutrients are not high however pathogenic indicators show that these parameters need care. The table also lists the range of flush water limits compiled from Australia, Germany and WHO guidelines for flush water [14]. Table 3 reveals that raw grey water is not to be used without treatment to comply with the limits, however, the quality of the effluent from the MBR/disinfection system is more than enough for recycling as flush water.

4.2. Economic aspects

Many examples from literature and practice show that reclamation of grey water is technically possible and will contribute to sustainability of water resources. The second tier of sustainability refers to economics. There are several examples in the literature as well as in practice including housing complexes, hotels, dormitories, etc. to show that grey water recycling especially for flushing toilets is reasonable in terms of costs. This is supported by an appreciable number of building installations for grey water recycling for flushing toilets, indicating that costs were perceived as affordable by consumers as well as constructors.

As an example, an analysis of costs for MBR treatment of grey water in Istanbul for households and hotels reveals that expenditures and payback periods are reasonable. As Fig. 3 shows, both the capital and operating costs level out for 200 units both for households and for hotels for MBR treatment at 200 Euros and 10 Euros, respectively [15,16]. Corresponding payback periods were found as a little over 2 years and 1 year for households and hotels, respectively. Up to 100% additional costs may be assumed for piping and other expenditures taking the investment cost up to 400 Euros and payback periods less than 5 years and 3 years, respectively. This estimate was confirmed by various users of grey water recycling in Istanbul, actually with shorter payback periods.

It is important to keep in mind that economic affordability of grey water recycling is one of the main concerns of consumers as will be discussed in the next subsection. It is important to realize that acceptances towards this practice is about 4 to 9 times higher if the system is installed for free as compared with installation under self-funding, indicating the critical role of subsidy/incentives as economic instruments for encouraging grey water reuse.

Another point to consider is that the value of contribution to sustainability of resources, and positive implication on the environment is not reflected in these cost estimations. What may not be desirable as costs for this sustainable practice at this time may be very significant for future conditions where water may not available or reachable.

4.3. Social aspects

The third tier in sustainability is the social dimension which is also a key factor for the success of stream segregation in the large scale in the form of wide spread use, similar to any new implementation which challenges a conventional well-accepted one. Public acceptance and approval of the community to use reclaimed grey water in their daily lives is a precondition for effective use. Preliminary efforts in this respect have given motivating results as exemplified by the preliminary surveys in Istanbul [17]. Fig. 4 which summarizes some of those results shows that among all final use areas questioned, toilet flushing received the highest acceptance with 90% while car washing, firefighting, irrigation and industrial use were accepted by 70%–80% of the respondents. Approvals for growing and using products coming from plants irrigated with grey water went as high as 80%'s for irrigation of green areas, with maximum acceptance for landscape plants, and for industrial plants, with highest acceptance for cotton. Approval for food stuff irrigated with grey water was somewhat inferior to green areas and industrial plants but still received acceptances which reached 70%, with cooked vegetables receiving the highest percentage. Uncooked vegetables received the lowest approval as might be expected most probably due to hygienic concerns. It was also interesting and motivating to see that the number of

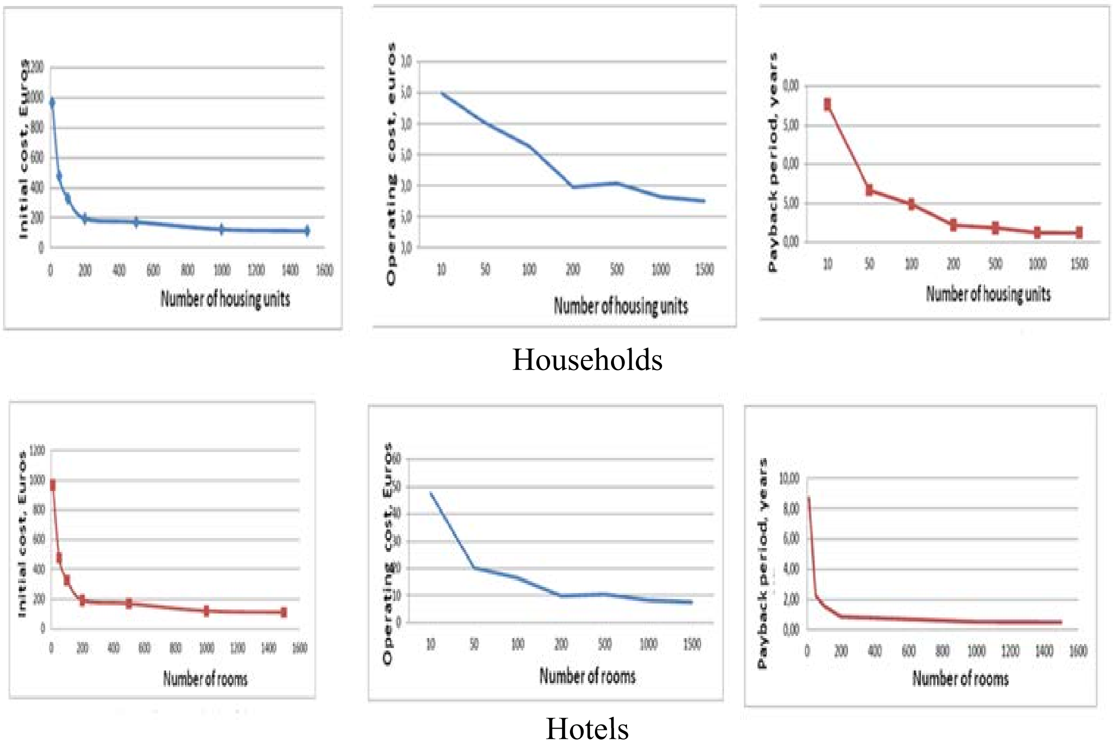

Fig. 3. Costs and payback periods for MBR treatment for households and hotels in Istanbul [15,16].

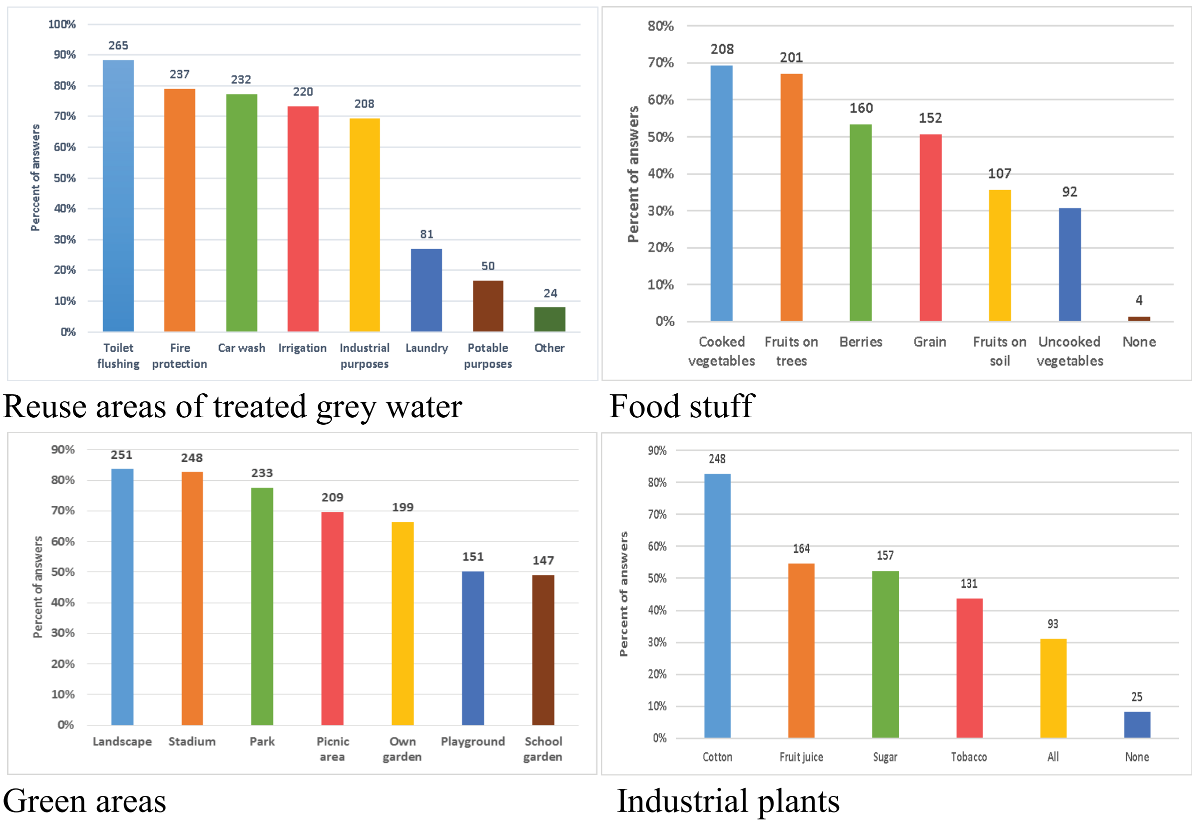

Fig. 4. Public acceptance for reclaimed grey water [17].

participants who said they would accept none of those final uses was very low.

The survey had also investigated the motivations and concerns of consumers regarding grey water reuse. It was observed that the three highest ranking motivations were “water savings”, “lower environmental impacts” and “lower water bills”, as opposed to the three highest ranking concerns as “not really sure if it is healthy “, “do not want to pay for system installation” and “not tested yet”, mostly implying health and economic concerns.

When asked about “willingness to install a grey water collection system”, 7% of the respondents said they are willing to pay for it and 17% said they will do it if they can afford, however when the question was shifted to installation free of charge, acceptances raised to 66%. With these responses, the survey had shown that acceptances towards grey water recycling was up to about nine times higher if the system was installed free of charge as compared with self-paid installation, pointing at the critical role of economic instruments for encouraging this new option.

5. Why recycle nutrients in yellow water?

Yellow water is mainly source-separated human urine and constitutes about 1% of domestic wastewater by volume, however it contains over 80% of nitrogen and over 50% each of phosphorus and potassium therein. Nitrogen and phosphorus are two of the topmost concerns in domestic wastewater and pose threats if they are discharged into the water environment, hence they have to be treated efficiently for pollution control and environmental protection. On the other hand, together with potassium which is not listed as a pollutant at this time, they constitute the three main ingredients of fertilizers which are indispensable for plant growth which includes food stuff with critical implications on food security.

Fig. 5 from Wach [18] reveals that about 35% of the global nitrogen, phosphorus and potassium demand for plant growth may potentially be obtained from source-separated human urine. It may be estimated that about 200 kg of cereals/year may be produced from urine produced by one person on an annual basis. This is a potential which cannot be neglected especially when considering that the phosphorus reserves of the globe are being seriously depleted [19,20] and that the energy which goes into the production of nitrogen fertilizers amount up to about 1% of the total yearly energy consumption worldwide [21,22].

With the current conventional domestic wastewater treatment practice, nitrogen forms which are readily available to plants are converted into nitrogen gas, in the nitrification/denitrification units and released into the atmosphere in a form which cannot be used by plants directly, while phosphorus is deposited in the treatment sludge which will need further treatment. To the most part, the potential is wasted with the conventional approach. However, clearly, the potential in urine is appreciable and should not be overlooked for sustainable food production and food security.

6. Recycling nutrients in yellow water

6.1. Technical aspects

In current conventional practice, urine is actually diverted by the use of urinals, mostly for men, but is not collected separately and therefore it is “wasted”. With the source separation in households, yellow water will be generated only in three component segregation, and urine diverting toilets (UDT) have to be installed for this purpose. UDTs have two compartments in the toilet bowl, where urine is collected from the front and feces, and possibly flush water and toilet paper, from the rear. Urine collected in the front must be transferred into urine collection tanks with separate piping and must be kept strictly separate to avoid cross-contamination. Thereafter it may either be used directly as fertilizer or may be processed further to produce fertilizers to be used indirectly. If applied directly, it has to be stored for hygienic safety. Although the amount of pathogens it contains is smallest among all segregated domestic wastewater streams and conventional domestic wastewater itself, a storage period of six months is recommended for inactivation based on the results of Hoglund [23] and WHO Guidelines [24]. In addition to storage, dilution may be desirable due to high salinity of urine, which is expected to increase about three times during storage due to urea hydrolysis. In addition to nutrients, human urine is rich in terms of organic matter and salinity and its characteristics change during storage. pH, salinity (measured as electrical conductivity),

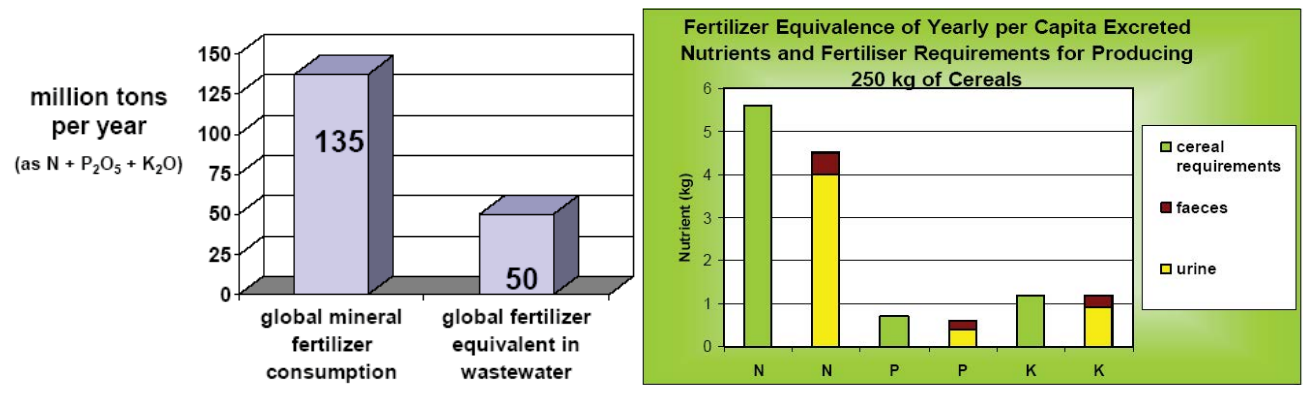

Fig. 5. Fertilizer potential of human excreta [18].

and ammonium are the constituents which are affected the most during storage time. Characteristics of fresh and stored urine are presented in Table 4 [25,26].

If urine is used indirectly as a "raw material" for production of fertilizers, it has to be processed. Although other possible options exist, three of the processes which seem to be more recognized are, struvite precipitation, stripping followed by absorption, and ion exchange/adsorption. In all of these processes, plant nutrients in urine, in the liquid phase, are concentrated in/upon a solid phase.

Struvite precipitation produces struvite as the fertilizer which is mainly a phosphorus fertilizer with a minute amount of nitrogen, upon the addition of an external magnesium source, while through air stripping followed by absorption in sulfuric acid, ammonium sulfate may be produced as the fertilizer [27–31]. This is strictly a nitrogen fertilizer. With both processes, high levels of recovery may be achieved for one of the nutrients; the other nutrient, however, is lost if those processes are applied only as single stages. Ion exchange/adsorption may be carried out by using synthetic [32,33] or natural [29,30,34–37] ion exchangers. Ion exchangers and products may vary depending upon the particular route and specific materials used. When the natural zeolite clinoptilolite is used as the solid phase, both nitrogen and phosphorus may be recovered using a single process.

Table 5 presents a lab-scale comparison of the three processes in single stage operation as well as in two-stage combinations [29,30]. The table provides quantitative justification that almost the entire phosphorus is recovered; however, nitrogen recovery is less than 10% if struvite precipitation process is used as a single step. The remaining liquid solution is very rich in nitrogen and if no further processing for recovery is applied, the potential from nitrogen is wasted from the perspective of revaluation, in addition to the environmental threat it poses. Applying a second stage will alleviate this discrepancy and up to 85%–99% of nitrogen can be recovered. Similarly, with stripping/absorption, almost the entire nitrogen may be recovered but phosphorus recovery is negligible when the process is applied as a single stage, however with the addition of a second stage for phosphorus recovery, recoveries as high as 92% could be attained. Ion exchange/adsorption is capable of removing both nutrients in one single process. When the process is employed in one single stage, up to 88% of nitrogen and almost the entire phosphorus may be recovered depending on the choice of operational conditions. Adding a second stage ion exchange/adsorption will improve the nitrogen recovery to 96%. Based on these results, it is clear that source-separated human urine may be used indirectly as a raw material to produce various types of fertilizers to be used for agricultural and landscape purposes successfully, returning the nutrients therein to plants in a short cut. This will not only lead to recovery of plant nutrients but also to the elimination of the salinity hazard, as well as providing a

Table 4
Characteristics of fresh and stored urine [25,26]

Parameter	Unit	Fresh [25]	Stored [25]	Fresh [26]	Stored [26]
pH	–	9.2	9.35	6.0–8.1	8.30–9.45
Electrical conductivity	µS/cm	27,850	34,500	13,000–22,500	31,600–42,800
Total COD	mg/L	4,260	4,830		
Soluble COD	mg/L	4,230	4,725		
Ammonium	mg NH_4^+–N/L	3,625	4,250	150–1,160	3,840–8,100
TKN	mg NH_3–N/L	8,525	4,875		5,640–11,413
Ortho-p	mg PO_4^{3-}–P/L	285	190		
TP	mg PO_4^{3-}–P/L	300	205	367–2,000 P	368–680 P
Potassium	mg K^+/L	1,225	1,225	1,300–2,400	1,010–2,530

Table 5
Fertilizers from source-separated urine [29,30]

Configuration	NH_4–N initial: 5,690–6,105 mg N/L	PO_4–P initial: 242–276 mg P/L
Ion exchange/adsorption with clinoptilolite (single stage) NEC	85%–88%	68%–99%
Ion exchange/adsorption with clinoptilolite (two stage)	95%–96%	87%–99%
Stripping/absorption $(NH_4)_2SO_4$	98%–99%	0–2%
Stripping/absorption followed by struvite precipitation	99%	83%–92%
Struvite precipitation MAP	3%–9%	98%–99%
Struvite precipitation followed by ion exchange/adsorption with clinoptilolite	85%–88%	98%–99%
Struvite precipitation followed by stripping/absorption	99%	98%–99%

means of pH control which may pose problems especially in the case of direct application.

Although the results have revealed that the processes referred to are indeed successful from the standpoint of nutrient recovery from source-separated urine to be used as fertilizers, the ultimate success of the product can only be appreciated by the demonstration of its benefit upon plants following actual application. Several observations were made with nutrient-enriched clinoptilolite from ion exchange/adsorption process to investigate this point and to compare the performance of the product with other fertilizer options using the landscape plant *Ficus elastica*, grass, barley, rapeseed oil and green peppers, all of which had given similar outcomes to show that the product had performed at least as good as commercial synthetic fertilizers, even better for almost all pot and greenhouse trials [26,29,36–38].

6.2. Economic aspects

Application of urine separation and further processing to produce fertilizers will necessitate installation of specialized UDT together with separate collection pipes and collection tanks for urine. Thereafter, urine either has to be stored for direct use or processed further to produce marketable fertilizers which will entail further spending. However, a holistic look upon this concept will reveal that in return to additional expenditures for urine separation and production of urine-based fertilizers (UBF), there will be revenues from the product, and reduction of treatment costs due to separation of nitrogen together with at least half of phosphorus upon yellow water segregation.

An analysis made based on the facts/data of a summer housing site of 480 households in Bodrum, Turkey, will be presented here as an example regarding costs of urine diversion and production of nutrient enriched clinoptilolite as UBF [39]. Located by the Mediterranean Sea in an area where seasonal population variations are pronounced, the settlement houses an estimated maximum of 1,440 residents in 78,000 m^2 total land of which 46,800 m^2 is green area strongly dominated by grass. The major aim was to evaluate potential self-sufficiency of on-site recoverable plant nutrients from urine to be used as fertilizer within the premises upon processing with clinoptilolite, and to estimate costs for such an application. The results revealed that nutrients which can be recovered from source-separated urine that can possibly be collected in the premises were self-sufficient and would cover the fertilizer demand of the entire premises. The suggestion was affordable in terms of costs with less than 1.7 USD per household per month extra expenditure, not taking into account the savings by eliminating existing nitrification/denitrification units in the current treatment plant, as separation of nitrogen by urine diversion will make the use of those units obsolete. With the elimination of the nitrogen treatment units, costs will almost break even and this seems to be acceptable by the residents from the perspective of expenditures. Table 6 summarizes the cost estimates [39]. An additional benefit with this practice is due to clinoptilolite itself which is commonly used for soil conditioning. Once again the value of contribution to sustainability of resources, food security and positive implication on the environment is not included in these cost estimations.

6.3. Social aspects

Public perception towards urine separation and UBF is probably more critical as compared with grey water recycling and based on several surveys undertaken, the psychological dimension is more apparent in this case. In general, the idea of using their own metabolic wastes (excreta), that is, urine, is unfamiliar, odd and undesirable to the community. For this reason surveys conducted generally start by questioning acceptance towards natural fertilizers and synthetic fertilizers before asking for approval towards UBF. The results revealed that as opposed to an acceptance of over 90% for natural fertilizers, approval for synthetic ones did not reach 50%. Approval for UBF was nearly 60%, which at least shows that preference for UBF was higher than synthetic fertilizers, even without supplying much information about UBF, which was perceived to be motivating [40].

Acceptance towards UDT was at the 60% level. Willingness to pay for UDT was around 30% which raised to nearly 80% if it is offered for free. Similar to grey water, the role of economic incentives were obvious with yellow water. The top most motivations for urine diversion and UBF were indicated as being economical and environmentally friendly. The top three concerns were observed to be possible bad odor, health concerns and psychological reasons [40].

Figs. 6–8 [41] present the results regarding acceptances of respondents towards using UBF for food stuff, green areas and industrial plants, respectively. It may be observed that approvals for direct use of urine are clearly inferior to indirect use in all cases.

Acceptances for using products from plants fertilized with UBF were around 55% for food stuff and green areas

Table 6
Cost of urine diversion and urine-based fertilizers [39]

Costs	Expenditure
Capital cost (2 UDT, 2 × 100 L tanks, column, pumps, piping)	2,500 USD/housing unit
Operating cost (clinoptilolite, electricity, chemicals)	5.7 USD/household per month
Typical actual fertilizer costs	4 USD/household per month
Additional cost in excess of expected market fertilizer cost (neglecting nutrient removal expenditure in the existing treatment plant)	1.7 USD/household per month
Production cost of NEC fertilizer	5.6 USD/kg N (market range: 2–11 USD/kg N)

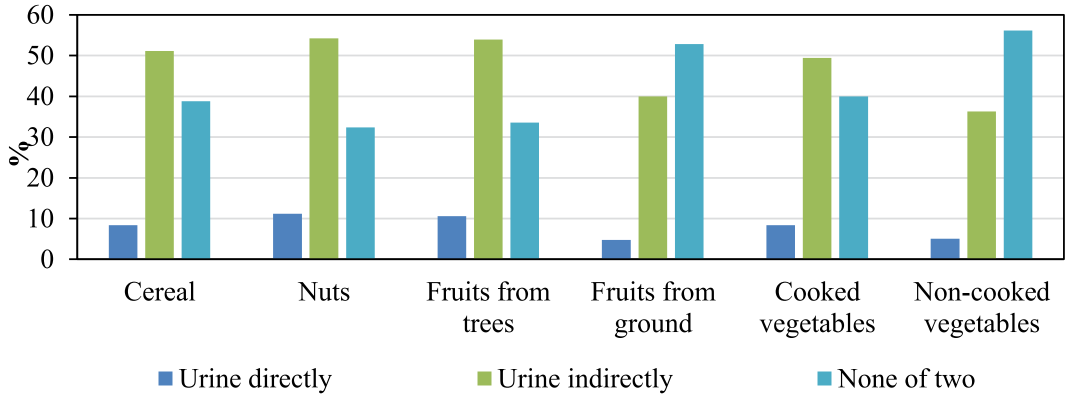

Fig. 6. Acceptance of UBF for various edible products (Allar et al. 2016).

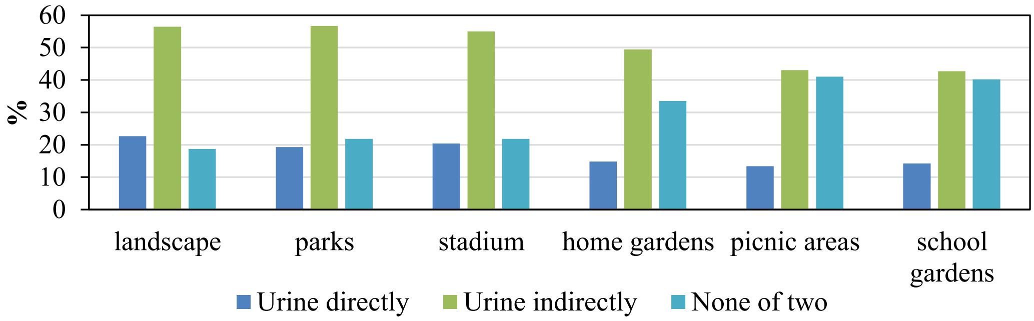

Fig. 7. Acceptance of UBF for various green area applications (Allar et al. 2016).

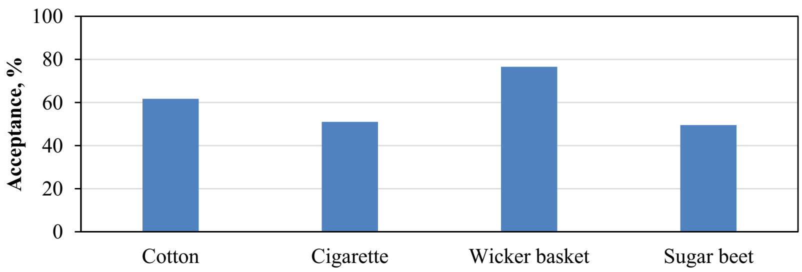

Fig. 8. Acceptance of UBF for various industrial plants [41].

if urine is used indirectly. In case of direct use, approvals could barely reach 20% for these two groups. Complete rejection (none of the two) is another meaningful indicator here which was highest with about 30%–55% for food stuff and about 20%–40% for green areas depending upon the product and location. Industrial plants received somewhat higher acceptance which was between 55% and 75%.

The results seem to be in line with expectances in that foodstuff which will not receive any further treatment, such as cooking for example, was accepted the least as in the case of uncooked vegetables such as salad greens and also those which had the highest chance to get in contact with the product such as strawberries. With green areas, locations which may imply higher chances of personal contact such as picnic areas and those which are to serve children received lesser acceptances. The higher approval for industrial plants is probably due to the fact that they will be processed further. These results are interpreted to imply hygiene as an important concern.

All in all, it may be concluded that health concerns seem to be an important factor in acceptance along with psychological reasons. Public opinion for acceptance towards using nutrients recycled from urine may be improved by supplying information and facts about this practice. Specifically, reminding people that what they give highest preference for as fertilizer is the excreta of animals while urine is the excreta of mankind and urine is the fraction which has the lowest amount of pathogens. Sharing success stories/presenting demonstrations of this practice together with economic instruments to subsidize implementation may also be helpful.

7. Further comments on recycling reclaimed grey water and fertilizers from urine

Stream segregation presents opportunities of wise revaluation of domestic wastewater. Obviously, grey water is an alternative source of water, especially for non-potable use, and may lead to a meaningful path towards "fit for purpose" use of water, and human urine is a valuable source of fertilizers to help combat with hunger and to contribute to "food for all". Both are renewable and dependable sources since they will be produced indispensably wherever and whenever mankind lives. Valorization of those streams will aid in sustainability of limited world resources and will prepare a better and more pleasant future for future generations. Moreover this will be achieved in short cuts due to closing of water, nutrient and probably energy cycles [2]. However, it is to be kept in mind that there are some current drawbacks or issues to be handled and investigated further for reducing probable risks which may come up from issues such as pharmaceuticals and hormones in urine [42], personal care products in grey water (Hernandez-Leal Zeeman). Also it is important to note that managerial aspects differ from the conventional water/wastewater management practice. As an example, water and wastewater cycles will have to be integrated for grey water reuse as a wastewater stream will be used as water supply, hence anything which may go wrong in the wastewater cycle may affect the water cycle directly. Likewise, fertilizers for agricultural production and possibly food stuff will come from another wastewater stream, any discrepancy of which may have implications on the food/agricultural production line. A holistic look upon the subject matter is another important aspect. Taking a holistic perspective is important not only for planning to make the most meaningful benefits and optimal arrangements for implementation but also for cost estimations. For example, although there will be higher expenditures at the beginning for segregation due to specialized infrastructure including separate piping, separate storage facilities and processing requirements, they may be offset by the revenues, for example, from fertilizers produced from urine. Awareness raising, supplying information to the public and providing success stories for this practice are yet other lines of action for effective implementation of stream segregation [43,44].

Two examples/comments upon the use of reclaimed products from segregated streams will point at the facts that (i) the quantity of water used for toilet flushing in the Turkish megacity Istanbul before 2015 was estimated to be equivalent to the quantity of water supply transferred from Buyuk Melen, which is about 200 km away, in the form of inter-basin transport, and (ii) nutrients from the excreta of one person have enough fertilization capacity to produce a loaf of bread per day.

8. Concluding remarks

Stream segregation is a promising alternative for domestic wastewater management to leave a better world for future generations by revaluating a "waste" as a "source" of valuable material and probably energy, while taking care of environmental pollution. Especially the potential in grey water as an alternative source of water to contribute to retardation of water scarcity and source-separated human urine as an alternative source of fertilizers to aid with the concept of food security and food for all are noteworthy. It is a doable practice promising technical/ecological, economic and social sustainability which for sure may be improved in years to come. It may be promoted through awareness raising and supplying information/facts about this approach, and through economic incentives. Definitely there is room for research about the subject matter especially for issues which need further research as in the case of pharmaceuticals, hormones and personal care products. Wider use of the concept in time and success stories will definitely invoke higher interest and willingness for this practice.

Finally, two messages at closure:

- Combat hunger and help food security through revaluating their own excreta
  - □ Recover nutrients and use them as fertilizer
  - □ Provide mankind with a loaf of bread a day
- Remember the concept of fit for purpose use
  - □ Do not flush toilets with drinking water
  - □ Use grey water instead

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