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Original Research

A Framework for Graywater Recycling of Household Wastewater

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Abstract

Water is a resource of increasing scarcity due to continual expansion of production. Many authors have focused on wastewater recycling for industry and municipal wastewater plants, but wastewater recycling at the community level still lacks a full discussion. This paper focuses on the issue involving only household wastewater recycling which is separated into graywater and blackwater by households. We propose a theoretical framework for analyzing the recycling of household graywater through a simple process that is installed in communities, as well as the re-use of reclaimed water for a variety of applications either in or outside the community.

There are at present no statutory regulations to govern the re-use of reclaimed water. Hence, piping and ducting systems for blackwater and graywater in households are not distinguished and a public ducting system for graywater is still not available in the market. In order to shed light on the dynamics of the household wastewater recycling system, we develop an implementation plan involving governmental policy, a community's construction of treatment plants, a household's commitment to recycling, control and checking up, and the education system in order to arouse the public to participate in this system.

Keywords: graywater, blackwater, reclaimed wastewater.

Introduction

Water is an important element in a complex and interdependent natural system and in general is seen as an essential input to human production and an effective tool of economic development. In view of the continuous growth in both population and human affluence in final products, a shortage of water resources is becoming a simple fact. For example, the water supply in Taiwan is estimated to be 170~193 x 10^8 m^3/year with a reliability of 85% in 2011, while total demand at present is 195 x 10^8 m^3/year, 200 x 10^8 m^3/year (estimated) in 2011, and 212~230 x 10^8 m^3/year (estimated) in 2036 (Taiwan Water Resources Agency, 2004). The water deficit is obvious and unavoidable in the future. To overcome the scope of such problems, there are two approaches to solve the water scarcity problem: one is to put forth efforts to change water consumption behavior so as to use water more efficiently to ensure the well being of future generations, and the other is to develop new water sources to expand the water supply.

Many authors emphasize that the efficiency of water utilization is an important concern in most developed countries and focus on the pricing of water utilities. For example, Garcia and Reynaud [1] present an econometric model to describe and estimate water supply and demand, eventually showing that "the optimal pricing scheme is characterized first by higher marginal prices and second by a lower fixed charge. However, moving towards efficient prices does not result in important direct welfare effects" (p. 1). Theoretically, the scarcity of water resources will push freshwater prices up and reduce water consumption on the ecological environment such as flowering, en-

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Table 1. The allocation of water consumption in Taiwan.

	2002		2011		2036 (projected)	
	Amount	%	Amount	%	Amount	%
Total consumption	195	100	200	100	212-230	100
Agricultural use	146	74.9	140	70	150	65
Industrial use	17	8.7	25	12.5	20-30	13
Domestic use	32	16.4	35	17.5	42-50	22

Unit: 10^8 m^3/year
Source: Taiwan Water Resources Agency, Ministry of Economic Affairs [7]

vironmental cleaning such as road cleaning, landscape aesthetics such as fountains, etc., but it cannot increase the supply of water resources. Moreover, household water consumption has not changed due to its inelasticity of demand.

The other approach to recreate adequate water supply becomes more important in achieving sustainable urban development. However, the development of a newly adequate water supply faces high challenges and strong opposition from environmentalists due to the limits of ecological conditions. For this case, the efforts of pursuing integrated optimal water resource planning in order to achieve the sustainable use of these natural resources becomes quite critical, based on the experience of many countries. Thus, recycling household wastewater and re-using the reclaimed water for non-potable purposes to increase flexibility for short-term water insufficiency may be an effective way to provide a guarantee for long-term water supply reliability without developing new water resources that damage the environment.

Reclaimed water re-use has become feasible in practice due to technological progress[1], and it is seen as an important role in satisfying human water consumption [2, 3]. Many countries facing a water resource deficit have started to regulate the re-use of reclaimed water from municipal wastewater treatment plants which receive all types of household wastewater effluents from toilet flushing, showering, laundering, etc. In such a central treatment plant, wastewater is recycled and returned back to households for re-use.

Many authors also focus on the application and the quality of the reclaimed water from municipal wastewater plants. For example, Abu-Zeid [4] focuses on the re-use of agriculture, municipal, and industrial wastewater as a new trend in developing additional water resources and discusses the characteristics and necessary treatments of municipal wastewater. In practice, household wastewater can be categorized into two categories: graywater and blackwater. Blackwater is the effluent coming from toilet flushing, kitchen sinks, or dishwashers, while graywater is derived from residential uses such as showers, laundering, bathing, etc. The major distinction between graywater and blackwater mainly lies at "(1) graywater contains nine-tenth of nitrogen than blackwater[2], (2) graywater contains far fewer pathogens than blackwater, (3) graywater decomposes much faster than blackwater" (extracted from http://www.greywater.com/pollution.htm). From a technical perspective, the recycling of mixed wastewater (the mixture of graywater and blackwater) is not economic and costly (please see a variety of discussions shown on the websites of http://www.greywater.com/pollution.htm).

In this paper we present a framework which describes the use of freshwater and re-use of reclaimed water in households, the recycling of wastewater and re-use of reclaimed water in a community, and the central distribution system of reclaimed water integrated with the harvesting of rainfalls handled by the government. This paper analyzes the use of reclaimed water and compares the relative advantage of our suggested system with the recycling of a municipal wastewater system. In section 4 we discuss how to implement this system. Under different institutional arrangements, how to design an incentive mechanism to encourage municipal effluent recycling is the main focus of this paper, and thus the policy planner must determine the contents of the criterion for compulsory recycling of graywater in the community and force the communities and inhabitants to follow. In Section 5 we offer a brief conclusion.

Water Supply in Taiwan

Taiwan consumes about 195 x 10^8 m^3/year of freshwater annually for all purposes (please see Table 1) in 2002. The island has faced a serious lack of freshwater even though the average annual amount of rainfall can reach

[1] Kurbiel et al. [5] have developed a technology to treat wastewater for industrial re-use and conclude that "it is possible to use reclaimed wastewater as an additional source of industrial water in regions of high water demand and poor natural resources" (p. 193).

[2] Nitrogen is one of the most serious and difficult to remove pollutants in the treatment process that affects our potential drinking water supply.

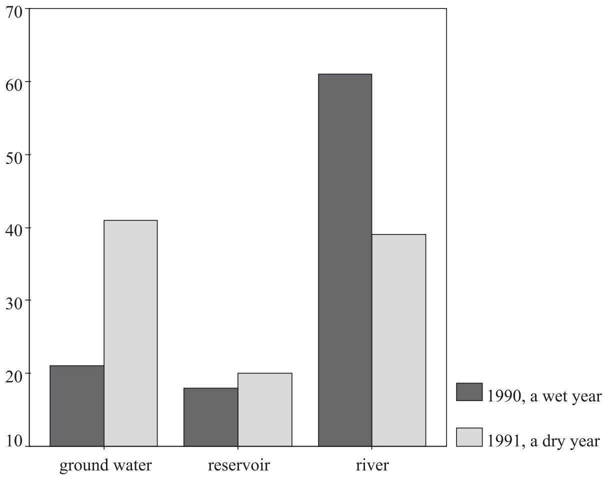

Fig. 1. Distribution of water supply sources. Source: Taiwan Water Resources Agency [7].

905 x 10^8 m^3/year (based on the annual average precipitation of 2500 mm), of which about 24% vaporizes, 71% flows into rivers and farther to the sea in a short time, and the remaining 5% infiltrates into the ground. Researchers suggest that effective soil conservation can help to facilitate water infiltration [6] and as a consequence in providing water conservation and improving water resource distribution. Taiwan currently faces a devastating problem where the cultivation of vegetables on steep slopes at high altitudes has resulted in increasing soil erosion. In rainy seasons, the exposure of soil to high intensity rainfall results in soil loss and reduces water infiltration rates. Due to an uneven time and space distribution of rainfall[3] as well as steep and short rivers and rapid flows[4], Taiwan frequently faces water deficits in some regions over some periods every year even though the average annual precipitation in Taiwan is very high, up to 2.500mm. Water shortages in Taiwan commonly happen in the long dry periods during February-April of each year. Rainwater is difficult to keep and preserve in the typhoon season during July-October due to the high sloping geographical land pattern.

Rainfall, rivers, and groundwater are traditionally considered as the main freshwater resources. Water supply depends on river intakes and reservoirs that account for about 60-70% of water consumption, with the remaining water supply from groundwater. The distribution of the three sources has varied over the years depending on the amount of rainfall (Fig. 1). Taiwan's government water policy points out that the source of water supply from rivers is preferred, while that from reservoirs is supplemented when a shortage of demand takes place, and eventually ground water is exploited when the shortage continues. Figure 1 indicates that ground water is over-exploited and provides 21% of the water supply even in a wet year, which is more than ground water infiltration. Thus, the over-exploitation of groundwater by excessive pumping has led to land subsidence and saltwater intrusion. The accumulated land subsidence depth in some coastal areas has been up to 2.5-3.2m (Chang Hwa Country and Pingtung County) over the past 30 years. Moreover, land subsidence is going on at the rate of 10-17.6 cm annually (Taiwan Water Resource Agency, 2004) [7].

To overcome the ever-increasing shortage of water supply, the construction of new reservoirs can be an effective tool, but there is opposition by environmental groups and local residents. In addition, seawater desalination, municipal wastewater re-use, and improvements in water utilization efficiency are also considered as effective tools to develop new water sources. Seawater desalination is one tool that converts seawater into freshwater for remote islands and coastal regions where water resource development is difficult, but unfortunately it is still not economical for investment. (Until now, Taiwan has installed 5 desalination plants on the outer islands with a total capacity of 6500 m^3 per day at an average cost of NT$ 40/ton, which is much higher than the selling price of potable water. Industrial wastewater recycling is also an effective tool to increase the water supply. However, the current industrial wastewater recycling rate is only about 30%, which is much lower than the government's target of 85%, as the cost of freshwater consumption is much lower than wastewater recycling. The government is targeting to arouse the public of water's scarceness and to be aware of the environmental concerns so that water consumption for domestic use can be reduced from 290 liters per day currently to 250 liters per day per capita in 2011 and to increase the recycling rate of industrial wastewater from 32% currently to 65% in 2011. We list all the possible approaches to increase the water source supply in Table 2.

In addition to the above strategies to increase water supply, many researchers argue that water recovery from household wastewater has been developed and proved to be efficient in production [8, 9] and has become increasingly popular in response to water shortages. In Taiwan, graywater is generated at about 120 liters per day per person (about 42% of the total daily water consumption of 290 liters/day/man). If household graywater is recycled completely and re-used for non-potable uses, then we can add a water supply of 96 x 10^6 m^3/year (about 3% of domestic use)[5]. Taiwan's government seems to neglect the importance of wastewater reclamation and re-use, and it mis-regulates the issues since there are no concrete policies shown in government documents. At present, wastewater reclamation and re-use is very low, less than 0.1% of the treated effluent generated, and only about 0.001% of total water consumption.

[3] Most of the precipitation is concentrated in the summer season (June, July, and August).

[4] Most rivers are steep sloped, where the upstream exceeds l/100, the downstream reaches 1/200~ l/500, as there are only 5 rivers having a slope milder than l/1000. In this case, these rivers cannot retain the precipitated water.

[5] This saving does not include hotel uses. If graywater recycling is regulated for both households and hotels, then the savings can reach 4.5%.

Table 2. The overall water resource supply in Taiwan.

Source of water supply	Status	Remarks
Rivers	Limited by geographical characteristics	The supply mainly depends on precipitation that is distributed over an uneven space and uneven time.
Reservoirs	About fifty (50) major reservoirs with total storage capacity of 22 x 10^8 m^3 have been installed. The following projects are under implementation: (1) Construction Project of the Paoshan Second Reservoir (2) Akongtien Reservoir Renewal Project (3) Pipe-Connection Project between the Nanhwa Reservoir and Kaoping Diversion Weir (4) Construction Project of the Hushan Reservoir	The construction of new reservoirs is opposed by environmental groups and neighboring residents. In the future, the construction of a completely new reservoir may become an 'impossibility' in Taiwan.
Groundwater	Land subsidence has occurred continually due to over exploitation of groundwater.	To avoid the ever-increasing land subsidence, groundwater recharge may be a solution in the future.
Seawater desalination	The government has installed five plants and plans to invest more on the outer islands in the future.	The cost is too high compared to conventional water supply from rivers, reservoirs or groundwater. Without subsidies from the government, the installation of a desalination plant is infeasible.
Industrial wastewater recycling	On average about 30% of industrial wastewater is recycled.	The recycling rate of industrial wastewater is expected to reach 85% by the government, but the industry is reluctant to improve the recycling rate, because of the low price of freshwater.
Water utilization efficiency	Annual water conservation through the voluntary conservation programs offered by industrial makers has reached 2 x 10^6 m^3/year. However, no evidence shows the performance of household water conservation.	The success of water conservation depends on the integration with public education to teach the public about the status of water scarcity and the ecological impacts of water over-consumption to change public environmental attitudes and behaviors.
Household Graywater recycling	No information about household graywater recycling is released. In fact, graywater is still a new, strange term for the public.	It requires an integrated system covering the rigorous treatment of graywater, water quality control, reclaimed water distribution, and appropriate management by linking the support of households, communities, and governments.

A re-use of reclaimed water for non-potable purposes has become more and more practical in view of economic analysis, because its scarcity drives the price up. Some authors (e.g. [5]) suggest that reclaimed water can be re-used in agricultural fields, even industrial use and wastewater re-use for agriculture has become a popular and widespread practice in some countries. Many authors also carry out preliminary studies on the development of reclaimed water for household uses [10]. Compared to neighboring countries, Taiwan's development on the use of reclaimed water is far behind[6]. For example, the major uses of reclaimed wastewater in Japan are for re-use in (1) the industrial sector (41%), environmental water and flow augmentation (32%), non-potable urban use and toilet flushing (8%), and seasonal snow-melting and removal (4%) [11]. In Taiwan, wastewater recycling from combined sewage (a mixture of graywater and blackwater) in a conventional wastewater plant is practiced in very few schools, and reclaimed water is re-used in garden flowering or for flushing toilets.

[6] In the past, raw sewage was directly re-used in farming without processing, but today households discharge the sewage into cesspools and eventually to neighboring rivers, thus leading to water pollution in rivers.

The Framework

To avoid potentially catastrophic shortages of water supply in dry seasons, we propose:

(1) that municipal wastewater be re-categorized based on the quality of wastewater into (a) graywater and (b) sewage (blackwater) based on the rate of decay of the pollutant in each effluent. According to scientific data, household wastewater from baths, showers, non-kitchen sinks, and washing machines is categorized as graywater while wastewater from toilets and kitchen sinks is considered blackwater;

(2) to recycle the graywater immediately through a simple process installed at the community level; and

(3) to re-use the reclaimed water for non-potable use based on the demanded quality standard across a variety of applications.

According to [10], reclaimed water can be used for

(1) agricultural irrigation (crop irrigation and commercial nurseries),

(2) landscape irrigation (parks, school yards, freeway medians, golf courses, cemeteries, greenbelt, residential areas),

(3) industrial re-use (cooling, boiler feed, process water, heavy construction),

(4) groundwater recharge (groundwater replenishment, saltwater intrusion, subsidence control),
(5) recreational and environmental uses (lakes and ponds, marsh enhancement, streamflow augmentation, snow-making),
(6) non-potable urban uses (fire protection, air conditioning, toilet flushing), and
(7) potable reuses (re-purified water) (blending in water supply, pipe-to-pipe water supply).

In this paper we suggest that reclaimed water be used for household re-uses such as (C) toilet flushing and (D) household services such as car washing, flowering, gardening, etc. or (E) public services for communities such as fire protection, fountains, road cleaning, etc. or the irrigation of plants and grass growing in nearby agricultural fields, while fresh water be used only for (A) food and drinks and (B) potable water for showering, laundry, etc. (please see the framework in Fig. 2). Practically, it is a waste to use freshwater for agricultural fields when plants thrive on used water containing small bits of compost. In fact, the primary impetus to construct a reclaimed water distribution system comes from agricultural demand that consumes over 75% of total consumption [10].

In the framework the effluent from 'A' and 'B' is graywater which should be recycled and processed immediately before it turns anaerobic, but from 'C' and 'D' it is blackwater which should be delivered directly into the sewage treatment system, because it can contain a variety of viruses, bacteria, high levels of organic waste,

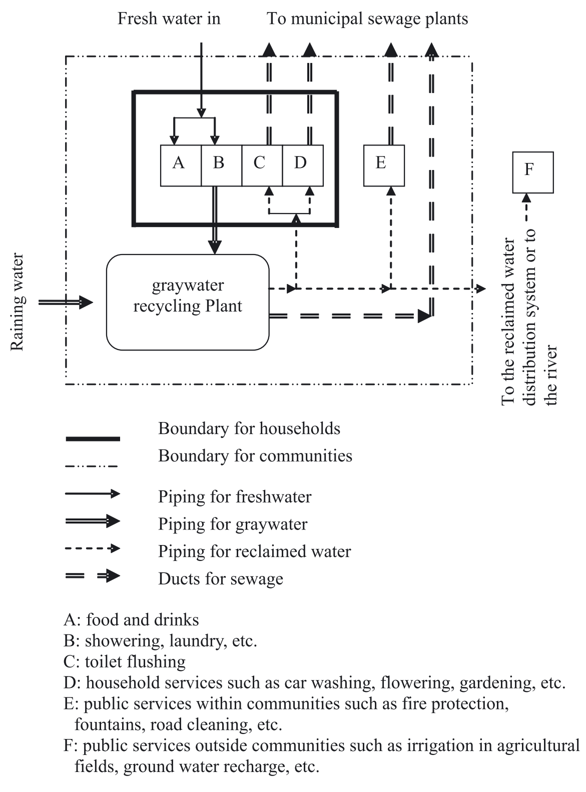

Fig. 2. Piping diagrams for wastewater reclamation and reuse

or harmful chemicals. The effluents (graywater) from 'A' and 'B' contain a portion of detergents, soaps, and mud and are easy to be treated by a simple treatment with the unit processes of neutralization, flocculation, sedimentation, filtration, softening, and chlorination so as to remove chemical and minor portions of sewage. We suggest recycling the graywater (the effluent from 'A' and 'B'), and to reuse the reclaimed water for 'C,' 'D,' and 'E' or to deliver the reclaimed water to the central distribution system of reclaimed water for 'F' external uses such as the irrigation of arbitral fields or for groundwater recharge, etc.

The quality of reclaimed water should meet the required standard for 'C,' 'D,' and 'E' (please see Table 3) or agricultural use and groundwater recharge (the impacts of the re-use of reclaimed water for agricultural use and groundwater have been studied by many authors and it may depend on the amount of reclaimed water, weather conditions, and other factors, but in general the negative effects are little if the quality of reclaimed water is under strict control [12-15]). The effluents from 'C,' 'D,' and 'E' are seen as blackwater and transferred to municipal sewage plants through sewage ducts for further treatment.

The quality requirements of reclaimed water will affect the cost of the graywater recycling plant which may vary from simple-cost systems to highly complex and costly systems. Basically, it should be sophisticated enough to treat graywater so as to meet the requirements of the applications. When considering the quality of graywater containing 280 mg/l BOD5, 150 mg/l SS, and other residuals and the required quality standard for reclaimed water as per Table 3, a system for graywater treatment should at least includes filtration, grease separation, disinfection, and organic removal. In a graywater recycling plant, back washing is required to carry out and the backwash frequency depends on the quality of feeding gray water and the design of the system. Based on some practical cases, the removal sludge from the system should be discharged to a municipal waste water plant shown in Fig. 2 as the recovery rate of graywater cannot reach 100%.

To support the continuous supply of reclaimed water to the central distribution system, collecting catchments for rainwater can be equipped within the community. Theoretically rainwater may be pure and clean if it is not polluted when it passes through the air, which may contain various impurities such as NOx or SOx, especially in urban regions. To reduce water quality concerns, harvested rain from rainwater should be cleaned through the community's graywater recycling system. Rainfalls, however, vary across seasons and flush into rivers quickly. The available time is limited for rain harvesting, even though annual rainfall reaches 905 x 10^8 m^3, much higher than graywater production of 13.2 x 10^8 m^3. The relative proportion of rainwater inflow to the graywater recycling plant is limited unless an effective rain harvesting system is developed to collect and store the harvested rains. In practice, graywater is a reliable

Table 3. Quality standard for reclaimed water – some examples of applications.

Item for checking	For road spraying	For landscapes	For toilet flushing
Total bacteria count (no./ml)	Trace	Trace	Below 10
BOD(mg/l)	Below 10	Below 10	Below 10
pH	6.0-8.5	6.0-8.5	6.0-8.5
Turbidity (JTU)	Below 10	Below 5	
odor	Nil	Nil	Nil
appearance	Nil	Nil	Nil
Color	Below 40	Below 10	Below 40
C1-(mg/l)	Over 0.4	Pasteurization by ozone	Trace amount

Source: Taiwan Water Resources Agency (2004)

supply source while rainwater is limited by geographical and weather conditions.

Excessive reclaimed water beyond the community demand can be transferred to the central distribution system constructed by the government from the community when the consumption of reclaimed water is satisfied. From the central distribution system, reclaimed water can be delivered to agricultural fields or for other applications such as the artificial recharge of ground water [7]

This system in general can save the consumption of freshwater and reuse the reclaimed water for non-potable use. It not only benefits the conservation of scarce water resources, but also mitigates the environmental hazards in the community's environment arising from the traditional sewage treatment system that may become overloaded. In addition, this new system also is accompanied by the following benefits:

(1) *To reduce investment on municipal sewage ducts, treatment plants, and treatment costs*. Obviously, sewage flow will be reduced and decreased sewage flow[8] means higher treatment effectiveness and lower costs. The capital and operational expenditures arising from the investment on ducting/piping, septic tanks, and related municipal sewage wastewater plant will fall. The cost savings of a gray recycling system in a community is semi-quantitatively analyzed by comparison with the following case examples:

Broens, et al. [16] present a case study involving the operation of a reclaimed water plant for irrigation, which operates 4 UF (ultra filtration) units as pre-filtration and 1 set of an electrodialysis reversal unit, serving as a tertiary treatment installed in the WWTP (waste water treatment plant). This plant yields 20,000 m^3/day of reclaimed water from feeding input of 22,000 m^3/day WWTP effluent with 91% recovery rate. Another case presented by Haruvy (1998) considered a reclaimed water plant from a WWTP for 10,000 citizens through secondary treatment processes. The required quality of reclaimed water should meet the standard of BOD and TSS of 20 mg/l and 30 mg/l, respectively, adapted for irrigating most crops.

Consider a graywater recycling plant is installed in a community with a population of 10,000 citizens, then 1.200 m^3/day gray water will be produced based on the assumption of 120 liter per man per day of gray water production and 1.092 m^3/day reclaimed water will be yielded based on the same recovery rate of 91% as the technology adopted in [16]. The remaining 108 m^3/day of separated sewage is discharged through sewage ducts to municipal sewage treatment plants.

The cost for the conveyance of wastewater from the Tel-Aviv metropolitan area to the south by the Dan Region Treatment Plant is estimated to be 0.13 US$/$m^3$ [17]. As 1.092 m^3/day gray water is recycled in the community, the saving on sewage ductings/pipings can reach 142 US$/day if the distance between the community and the municipal treatment plant is the same as in [17].

The operating cost of the tertiary treatment in the case of [16] is estimated to be 0.114 Euro/m^3, and in the case of [17] is estimated to be US$ 0.27 /m^3 for secondary treatment, and 0.17 /m^3 for additional tertiary treatment. As the quality of gray water inflow is in general easier to treat than municipal waste water (the combination of gray water and black water), the operating costs for a reclaimed water plant in community should be lower than a WWTP with effluent reuse. As to the infrastructure cost for the distribution system of reclaimed water, it should be lower than a WWTP

[7] Researchers argue that the re-use of reclaimed water for the artificial recharge of groundwater basins in supporting the groundwater level in order to avoid land subsidence has been proven to be more and more important even though this type of application at present still faces a wide spectrum of technical and health challenges due to some uncertainty with respect to health risk considerations [15].

[8] Some officials argue that a high concentration of wastewater flow may increase the difficulty in carrying waste to the sewage treatment plant, but others see this as not a problem if the sewer system is designed effectively with sufficient slope.

with effluent reuse because most of the reclaimed water will be consumed by the community, and thus a smaller piping/pumping system is required to distribute the excessive reclaimed water to agricultural fields or other applications while the distribution of reclaimed water recycled from a WWTP effluent needs a full scale of piping/pumping system for reuse.

(2) *To reduce the difficulty in finding a site for a new wastewater plant*. Due to less strain and need for septic systems, the expansion or new construction of a treatment system is reduced. The management of municipal wastewater treatment is a serious problem for most countries due to the existence of NIMBY effects. Inadequate administration on the public service of waste treatment systems may create serious public health problems that hamper social development. More recently, public administrations and many authors have realized that the most logical and practical solution to resolve the waste problem lies in recycling, including the recovery of secondary materials and the re-use of final products.

(3) *The reclaimed water in excess of community re-use may be distributed to central distribution system that may pump to a variety of applications*. The reuse of reclaimed water in any particular field depends on the quality requirement of reclaimed water such as physical, chemical and microbiological factors. Until now, the quality standard on reclaimed water for reuse has not been regulated in Taiwan. Even in the USA, the federal standard on wastewater reclamation and reuse has not been regulated [15]. They present a conceptual framework for trace organic compounds and their relative significance to human health risk by adapting from [18] and argue that physical, chemical and microbiological hazards and risks are the key factors to affect the criteria for the reuse of reclaimed water. Crook and Surampalli [19] have overviewed the water reuse criteria among some states in the US and compared these quality criteria and the Guidelines published by the US EPA. In general, the reuse of water recovered from graywater can substituted for fresh water for less sanitarily-demanding application and therefore a great amount of water resources can be saved and allocated for more important uses.

(4) *The installation of this system can reduce the uneven distribution of the water supply among different regions or different seasons, so that it can make the water supply be more flexible in solving the water deficit problem*.

Implementation

Four problems need to be solved to assure the implementation of this system:

(1) How to provide incentives to communities and households to separate wastewater and recycle the graywater,

(2) How to encourage the public (households, farmers, and industries) to use the reclaimed water and to support the implementation of this system,

(3) Who is responsible for the construction and operation of local treatment plants and related ducting systems, and

(4) How to prevent health/ecological risks.

At present, it is uncommon for households to separate wastewater and reuse reclaimed water and for the community to install and operate a graywater recycling plant. What needs to be established is a conceptual implementation plan of graywater recycling and re-use as a guideline related to the support of households, communities, and governments (please see Fig. 3). This implementation plan includes 6 steps, starting from the establishment of governmental policies that affect the household's consumption behavior, using reclaimed water for non-potable uses, encouraging the community to install and operate a graywater recycling plant, and controlling and providing check-ups to reduce the potential ecological or health risks in adopting the re-use of reclaimed water.

Step 1

Policy making: To assure the effectiveness of the framework, the government needs to reform water policy and develop a comprehensive mechanism whereby the public (households and communities) voluntarily participates in this system. The main job includes three policy-makings and one guideline for a policy formulating process:

1. *Pricing on freshwater and reclaimed water.* The reclaimed water can be used as a valuable resource and should be priced appropriately in order to avoid the over-consumption of freshwater. Many countries have considered incorporating appropriate policies to the beneficial use of reclaimed water in order to improve water shortages in the summer season when water resources become more and more scarce. The use of reclaimed water for non-potable uses and for irrigation in particular depends on the price attractiveness compared to freshwater [20, 21]. In general, the low price of freshwater will block the public (both industry and the community) to conduct wastewater recycling, but it also will encourage the over-consumption of freshwater. The cost savings for the reuse of reclaimed water needs to be large enough to overcome health hazards. As to reclaimed water recycling, it is a prerequisite to encourage the community to do graywater recycling where the net profit (subsidies from the government and/or the revenues of reclaimed water minus the costs) should be positive. A higher price of reclaimed water may attract communities to produce more reclaimed water, but also may damage a government's finances when excessive reclaimed water is sold to the government (delivered to a central distribution system).

2. *To coordinate with others for the public concern*. During policy formulation, the policy planner needs to coordinate with public health agencies to present integrated health/water policies since the reuse of reclaimed water may affect public heath. A lack of coordination among governmental sectors may lead to a conflict of policy and make the public confused about water policies. The regulation system should be formulated through democratically-elected local authorities as well as through the participation of environmental groups and the public. A system to prevent conflicts among local municipalities or communities for the sharing of water resources is required since scientific water data itself cannot support the policy-making equitably. A close political, legal, and scientific interaction should be held and discussed through a discursive

Fig. 3. Implementation plan.

Step 1: Governmental actions		
Tasks	Objectives	Description
Policy making	To solve problem (1)	Analyze the price of freshwater and reclaimed water and determine an incentive mechanism for graywater recycling.
	To solve problem (2)	Coordinate with others for public concerns.
	To solve problem (3)	Regulate the size of community that needs to recycle household graywater.
	To solve problem (4)	Regulate the quality of reclaimed water for non-potable reuses.

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Step 2: Governmental actions		
Tasks	Objectives	Description
Construction of piping, ducting, and storage tank	To solve problem (3)	Connect the piping for reclaimed water from a community to a central distribution system, building a storage tank for reclaimed water, connecting sewage ducting from a community to municipal sewage treatment plants.

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Step 3: Communities' actions		
Tasks	Objectives	Description
To set up a graywater recycling plant and to build up an operation plan	To solve problems (1) and (2)	Analyze the project of the graywater recycling plant: size, quality of graywater, treatment process, capital, operation, maintenance, etc.
	To solve problem (2)	Analyze market characteristics: price of reclaimed water, quality of reclaimed water, users' acceptance, etc.
	To solve problem (4)	Analyze potential risks: water quality impacts, health impacts, environmental impacts, etc.

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Step 4: Households' actions		
Tasks	Objectives	Description
Households' commitment to recycle household wastewater	To solve problems (1) and (2)	Households are encouraged to separate graywater from blackwater and commit to reusing reclaimed water.

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Step 5: Communities/governmental actions		
Tasks	Objectives	Description
Monitoring and control	To solve problem (3)	Communities need to check the quality of graywater and reclaimed water continuously and governments should be responsible for the safety of the whole system.

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Step 6: Governmental actions		
Tasks	Objectives	Description
Public education	To solve problem (2)	Through appropriate education, the public is educated to be more environmentally-oriented and more participative in the system's operation.

approach as a basis for discussion and policy making through the adoption of an adequate water resource framework as well as from the development and management of water resources.

3. *To regulate the size of a community that needs to recycle household graywater*. Basically there are two approaches to regulate policies, either by a market-based mechanism or by command-and-control. The policy planner needs to determine the threshold size of the community which is feasible to produce reclaimed water through a technical analysis by maximizing total social welfare.
4. *To regulate the quality of reclaimed water for non-potable re-uses*. The quality of reclaimed water may affect the cost of graywater recycling plants and eventually be an important factor that affects both graywater use and rainwater harvesting. Chen and Chen [22] present a model to analyze the effects and the feasibility of a community so as to build up its wastewater plant and determine the optimal emission quality of the treated wastewater. Following this model, the policy planner can determine the optimal standard of reclaimed water to maximize the social welfare.

Step 2

Construction of piping/ducting/storage tanks. The use of reclaimed effluents and the construction of a piping system for reclaimed water distribution have received attention from both regulators and researchers. A central reclaimed water distribution system and rainwater harvesting collection point should be established by the government in which reclaimed water storage and delivery systems could be built as public utilities. Piping/ducting systems should be constructed and managed by the government. They should be laid out outside community boundaries for the purpose of reclaiming water from community graywater recycling plants and sending it to a central distribution system of reclaimed water or to agricultural fields.

For a place with limited rainfall or uneven rain distribution over time like Taiwan, a storage tank and piping system is required to store reclaimed water as a regular supply for non-potable use so as to ensure a supply during the intervening dry seasons. A series of rainfall attachment reservoirs for collecting and storing rainwater is needed. Rainwater harvesting systems to collect large quantities of rainwater are very complicated and expensive to install and require ample financial resources. Our proposed system asserts that rainwater harvesting be undertaken by communities if the price of reclaimed water is attractive enough to be an incentive.

Step 3

Communities need to set up graywater recycling plants and to build up operation plans and piping/ducting systems. Based on the technical analysis in Step 1, the government needs to regulate the community with a given population and a fixed area covering a series of housing estates in order to establish a graywater recycling plant or drop the price gap between freshwater and reclaimed water so as to encourage the community to set up graywater recycling plants. To coincide with governmental policies, the community must determine the appropriate treatment system for the quantity and quality of graywater based on the statutory standard (quality level). The piping/ducting outside households and inside the community must be provided by the community and marked with a distinctive color to identify the types of water. The community is accountable for paying the government for the treatment of sewage and the remaining nuisance (e.g. unpleasant odors) from the treated effluent, but it can charge a graywater treatment fee on the users (households). As the quality of graywater depends on the effectiveness of separation between graywater and blackwater that is conducted by households and may affect operating costs, a monitoring and control system of graywater quality should be conducted by communities through market-based contracts.

After analyzing the market, the community may sign contracts with households or with governments for the sales of reclaimed water. To ensure public health, reclaimed water quality must meet legal and health regulations and be performed in cooperation with community management. Thus, a monitoring system to indicate the quality of graywater and reclaimed water must be equipped and regularly checked. In brief, the community needs to develop an inspection and maintenance program for leaks and blockages within the community and ensure of the water quality received from households and delivered to households for re-use. To avoid health risks, the community needs to prepare some sign labeling on the piping of reclaimed water to warn of the contact hazard.

Step 4

Households' commitment and cooperation. The proper engineering of the suggested system itself cannot guarantee the successful operation of this system without households' support and cooperation. Environmental concerns and economic interests across households may generate debate and conflicts, and consequently may result in a reluctance to comply with governmental regulations. People are required to develop new values toward a pro-social value orientation that directs their eyes to the public interest of environmental sustainability and to foster the acceptance of a system to curb water consumption levels. However, some self-interested households may be reluctant to reduce their freshwater consumption if the price gap between freshwater and reclaimed water is not attractive. Through environmental incentives, such as subsidies to households for qualified graywater and extra effluent treatment charges on households depending on the concentration of pollutants, it may prevent households to discharge unqualified graywater to community graywater recycling plants.

Step 5

Control and regular check-up. In addition to households' commitment to a voluntary engagement in wastewater recycling, appropriate management is required on the system to develop new means to understand the interactions between economies and ecosystems, acting as a catalyst to help people identify the policy reforms necessary to maintain ecosystem integrity and to improve social equity for present and future generations. In addition, an education program to promote the reuse of reclaimed water also is required. In brief, these activities require the cooperation and support between communities and governments whose major tasks are described as follows:

1. Communities need to check the quality of graywater and reclaimed water continuously: Quality control on reclaimed water is a key factor to assure the success of the system, including the monitoring of bio-organics growth and migration, which proposes a challenging task to a graywater recycling plant [23]. To reduce the health hazards and ecological hazards that stem from the presence of a variety of human-associated micro-organisms and the potential for growth and/or persistence of these organisms, a management system to control the quality of reclaimed water delivered to the central system must be monitored. Such a complex system requires different indicators for the quality of gray water and reclaimed water to yield a comprehensive picture of the system dynamics to prevent the occurrence of contamination of humans and the environment and to prevent the attack of pathogenic microorganisms within the plant due to human contact.
2. Governments need to be responsible for the safety of the whole system in which users need not bear unacceptable risk and consider what level of risk control should be attained through the regulation on the quality of reclaimed water, how to guarantee the effectiveness of the regulation, and to evaluate the users' acceptability of the targeted level of risks. To reduce the public's concern about the re-use of reclaimed water, transparent information about the reclaimed water's quality should be delivered by the community and must be released to the public through an integrated participant management system.

Step 6

Public education. Communities and households play a very important role in bringing about effective solutions for water resource conservation through decentralization, meaningful participation, and cultural autonomy within communities. In order to reduce conflicts and show compliance between the goals of water conservation and the interests of local communities, public education about the objectives of water reclamation and their important role in environmental protection and planning should be sketched and implemented to make the public aware of the environmental crisis and stimulate the public to participate in the water reuse system, which will affect future environment and economy. Through public education that promotes environmental values and beliefs about water resources, the public's habitual change in favor of water resource conservation can be achieved. Moreover, the role of public education is to promote the adoption of water-efficient tools, recycling processes, or related technologies since they can reduce environmental impacts. Eventually, all related actors, including households, communities, and governments, can perform a respectable job toward the goal of a sustainable society by adopting the suggested system.

Conclusions

The recycling of graywater and the re-use of reclaimed water are a part of the fundamental solution to many ecological problems and have a positive impact on ecological sustainability. The major contribution of this paper is to present a framework showing the different uses of water with different qualities and suggesting an implementation process of the integrated system. In this paper we discuss each phase of the six-step implementation process to assure the success of the suggested household wastewater recycling system in which the technical/engineering sector is given and seen as easy to be analyzed, such that it receives less attention in this paper. This system can reform current faulty water management systems and reshape the position of water resources relating to the environment, as the current water management system has resulted in many negative effects such as damage to the environment, a failure to provide water to the public in droughts or to distant indigenous communities, and an ignorance of non-economic purposes. This system can be introduced and adopted as the master plan of water conservation for communities and it can also be extended to apply to office buildings or public organization buildings like schools, because a technical analysis assures that it has no undesirable impact on the environment nor on public health.

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