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Greywater Reuse and Management for Urban Renewal Areas:

The Case of American Gibi, Addis Ababa, Ethiopia

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Master's Thesis

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June, 2020

Addis Ababa, Ethiopia

DECLARATION

I declare that this thesis is my original work and has not been presented in any other university, and all the materials and data sources used have been properly acknowledged as per the scientific guidelines of the university.

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CONFIRMATION

This thesis has submitted for examination with my approval as an advisor.

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GREYWATER REUSE AND MANAGEMENT FOR URBAN RENEWAL AREAS:

THE CASE OF AMERICAN GIBI, ADDIS ABABA, ETHIOPIA

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ABSTRACT

The water demand in Ethiopia has increasing from time to time, which implies to increase in wastewater. The previous GTP documents address that the plan of per capita water demand has increased to address the increasing need. On the other hand, the source of water for Addis Ababa become challenging. Hence, identifying more water source is very essential. Among them, the reuse of greywater can be one of the potential sources for some water requiring activities such as toilet flushing, gardening, construction etc.

Greywater reuse and management is a system that is applied as a solution for minimization of water usage for toilet flushing and gardening. This research is intended to show the conceptual design for greywater reuse and management by taking American Gibi, Addis Ababa as a case study. The area is considered as one of the urban renewal areas in Addis Ababa, where it is proposed to adopt the installation of greywater system integrated with the building design processes.

Data for the research were collected through observation, in-depth interview with the governmental officers, professionals of Architecture and construction. In addition, the research also used documents relating to greywater reuse and management studies and research as an input.

The result of the study showed that the amount of greywater produced in the area can fulfill the requirement for toilet flushing and irrigation for low water requiring plants. The research also showed that the study area has a chance to implement an integrated system of greywater reuse since greywater can be eco-friendly, cheap, easy and flexible to use.

Creating awareness to the users makes the system sustainable. The construction of greywater reuse systems should be combined with other techniques based on the available spaces. Attention should be given while to align the use of sanitary fixtures and piping systems to the other water supply and drainage networks in order to ease the reuse and recycling of greywater produced in buildings.

Key words: - American Gibi, Greywater, Greywater Reuse, Urban Renewal

TABLE OF CONTENTS

LIST OF ACRONYMS, ABBREVIATIONS AND UNITS

AAWSA	Addis Ababa Water and Sewerage Authority
CSA	Central Statistical Agency of Ethiopia
DWS	Department of Water and Sanitation
GTP I	Growth and Transformation Plan I
GTP II	Growth and Transformation Plan II
HRT	Hydraulic Retention Time
HWTS	Household Water Treatment and Storage
ICGS	Interior Customized Greywater System
LDP	Local Development Plan
MDG	Millennium Development Goal
MUDHCo	Ministry of Urban Development, Housing and Construction
UDME	Urban Design Manual Ethiopia
UNHABITAT	United Nations Human Settlements Program
WASH	Water, Sanitation and Hygiene
WIF	WASH Implementation Framework
WTP	Water Treatment Plant

D- Day

L - Liters

M^3 – Cubic meter

L/P - Liter per person

L/D - Liter per day

L/H - Liter per hour

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - INTRODUCTION

1.1 Background

Greywater is wastewater generated in households or any other buildings from streams without fecal contamination, that is all stream except for the wastewater from toilets. It is a system with numerous benefits. Besides reducing the wastewater entering the sewers, greywater can also help to reduce water usage by around 50%.

Addis Ababa is the capital and primate city of Ethiopia, located at an average elevation of 2500m covering 54,000 hectares of land. Due to rapid urbanization, the city is experiencing significant social, ecological, and demographic changes. During GTP-I period (2011-2014), the country has planned to provide access to safe water supply to 29,776,220 people of which was 27,140,044 for rural and 2,636,176 for urban. Of these, overall, 31,214,380 people **(**28,126,973 for rural and 3,132,978 for urban) have got access to safe water supply. This indicated that the plan was achieved by 104.8% of which 103.6% is for the rural and 114.8% for the urban (GTP – II, 2015).

Addis Ababa is haphazardly developed with substandard housings and poorly serviced neighborhoods particularly in the inner-city (UN-Habitat 2007). The rapid urbanization in Ethiopia involves the continuous and substantial movement of people from rural villages and homesteads to urban villages, small, medium, and large towns and to the capital city, as well as natural increase in cities and towns and the re-classification of previously non-urban settlements. The economic potential of urban areas also suggests that proper approach to growth can bring real change in the economy and the benefits of development can be more widely dispersed. On the other hand, rapid urbanization is creating mounting pressure on infrastructure, service provision and management capacity of governments. As this research indicates about the reuse of greywater, the core concept is to integrate greywater reuse system design within a household, a building and neighborhood.

However, it requires an integration of urban and architectural prototypes including the provision of space for the installation of separated pipes. Thus, the purpose of this study is to explore knowledge of greywater reuse as an optional use of water. Later, it will be placed on the selected case (American Gibi) through the relationship between the theoretical, technical and contextual perspective.

The case area 'American Gibi' is one of Addis Ababa's proposed urban renewal area that is currently cleared out and has a new land use made by the government. Where partial of the people from the previous settlement would re-settle once it is done.

1.2 Statement of the problem

The source of water supply to Addis Ababa is mainly from Legedadi, Dire and Gefersa dams after necessary treatment and ground water from Akaki & Legedadi well fields. There are also numbers of wells found inside the city that used as a source. In addition, different institutions dug wells inside of the city for their water demand. As per the report of AAWSA, 2009 surface water from Legedadi and Dire dam is treated at Legedadi water treatment plant having a daily production capacity of 195,000m^3 while that from Gefersa dam is treated at Gefersa water treatment works having a daily production capacity of 30,000 m^3. In 2017 about 1 in 2 people is an urban dweller and by 2030 about 60% of the population are expected to live in cities, partially contributing to an expected water consumption increase of 55% by 2050 (Alexander and Clark, 2017).

The water supplied for Addis Ababa return as a large volume of wastewater and contributes to the Akaki flow. Today, most of the springs are abandoned due to water quality deteriorations. In 2016 the daily production capacity of AAWSA has reached 601,000m^3 (Assabu G., 2019). Based on AAWSA the current water supply system has non uniform distribution with some areas getting water once in a week/two weeks. Water is highly concentrated in a few areas with a recorded water loss of over 37% due to inefficient water systems which are the major sources of water loss. Inefficient use and water loss at different points in the supply network has contributed to observe clear water poverty/scarcity. (Assabu G., 2019).

The total population of Addis Ababa city is 3,273,000 based on July 2015 CSA projection, although UN-HABITAT (2010) has reported a population size of 3.5 million although the 2014 AAWSA report has estimated the population served at 3.64 million. Based on the current population growth rate of 2.1%, the city's population is estimated to reach 5 million after 10 years.

On the other hand, the city government of Addis Ababa Housing Construction Project Office (AAHCPO) is engaged in the construction of condominium housing apartments (urban renewal) in ten sub-cities. The project used enormous amount of water. The project plan showed that the city targeting about 886,978 housing unit 2020 E.C.

It is therefore essential to reduce pure water consumption, by substituting fresh water with alternative water sources and optimize its efficiency. Among these utilizations of greywater is an alternative option. Greywater is easily produced from what consumers has already used without any payment.

1.3 Objective

1.3.1 General Objective

The general objective of the research is to introduce a suitable technique to apply greywater reuse for urban renewal areas.

1.3.2 Specific Objectives

The specific objectives of the research are:

- to investigate the existing practical of greywater management in the study area.
- to analyze the characteristics of greywater for the purpose of filling the demand in the case area (Household, Building and Neighborhood level)
- to elaborate the preferable greywater reuse technique in terms of American Gibi's context.

1.4 Research Questions

The research questions addressed in this work are: -

- What are the trends in the provision of grey water reuse system for urban renewal areas of Addis Ababa?
- What are the technical and spatial characteristics of individual users, buildings and neighborhoods in the case area and their challenges and opportunities for reusing greywater?
- In what ways could greywater reuse system be implemented in the case area?

1.5 Scope and limitation

As mentioned on the research objective above the idea of greywater reuse system is considered only on a specific case area which is American Gibi. Even though there is no detailed available data on the design of the housing units the researcher is obligated to use an estimation of produced greywater, room arrangement. The other limitation is the shortage of time and budget for experimenting the compared available techniques in the reuse of greywater which could be suitable for American Gibi.

1.6 Significance and Relevance

The study could be used as an input for other places of future urban renewal areas and also for individual households, apartments and neighborhoods. Even if the study is targeted on urban renewal areas it could also be implemented for other newly constructed buildings of different functions. The study focuses to develop ways of greywater reuse and management strategies which are relevant for: -

- Design consideration for greywater system for urban design.
- Spatial integration for greywater system within a household, building and neighborhood.
- Basis of future decision-making for the city government and other concerned organizations to develop policies and design guidelines.
- It also aims to contribute as an input for future researchers who want to study greywater reuse starting from an individual to a city level.

1.7 Organization of the document

This paper has three parts which are the introduction, main body and conclusion. The first which is the introduction contains problem statement, general and specific objectives, scope and limitation, significance and relevance.

The main body is the second part of the paper which contains literature review, case studies from different counties such as Ethiopia, Taiwan, Australia and Los Angeles and methodology. In the methodology data is collected from primary and secondary sources.

The last part of the research is the conclusion where is consists the result and discussion, conclusion and recommendation.

CHAPTER 2 – LITERATURE REVIEW

2.1. Introduction

2.1.1 Urban Renewal

Urban renewal refers to the redevelopment of urban centers, most often with an emphasis on the redevelopment of economic infrastructure. It is used to refer to multi sectored interventions, which are undertaken within specific geographic areas over a medium-term timeframe (Morontse, 2010). It entails the allocation of considerable resources to achieve redevelopment goals, it is all the undertakings and activities necessary to renew the neighborhood according to plan. Urban renewal is all about the improvements to the urban environment and infrastructure by the provision of more open space, community and other facilities; as well as the improvements to urban layouts, road networks and other infrastructure (Morontse, 2010). It also helps to improve specific areas of a city that are poorly developed or underdeveloped.

2.1.2 Greywater

Greywater is untreated wastewater that has not been mixed or contaminated by toilet discharge or unhealthful processing, manufacturing or operating waste. Wastewater from bathtubs, showers, bath room washbasins and clothes washing machines can be considered greywater. It does not include wastewater from toilets and in most cases kitchen sinks and dishwashers(Alexander and Clark, 2017).

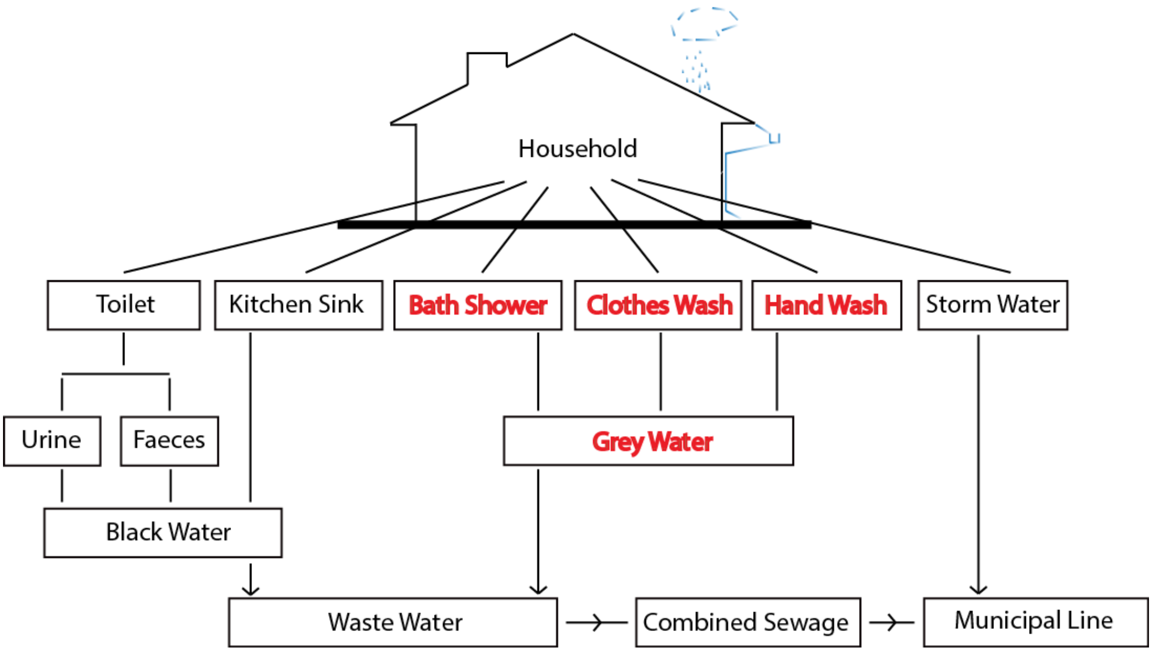


Figure 1.1 Hypothetical diagram for the effects of greywater produced from a household summarized from different literature.

2.2 Sources of greywater

Compared to clean water, greywater can be quite polluted, and its indiscriminate use may represent a risk to public health (ANQIP, 2011). Water demand in buildings can be reduced using greywater for certain applications like toilet flushing and irrigation. Such kind of process implies for cost saving if the main water supply is metered. This leads to extensive environmental benefits, and where greywater is used, reduced volumes of wastewater going to the sewer.

Being directly connected to a production process that requires intensive use of water, engineering, either in the building, has a fundamental role in preserving water resources. It is important to create new ideas which consider the rational use of water as something fundamental. In fact, drinking water is in many cases, badly used, or wasted, as in toilets, in streets and sidewalks washing, car-washing and irrigation and also for some other activities (ANQIP, 2011).

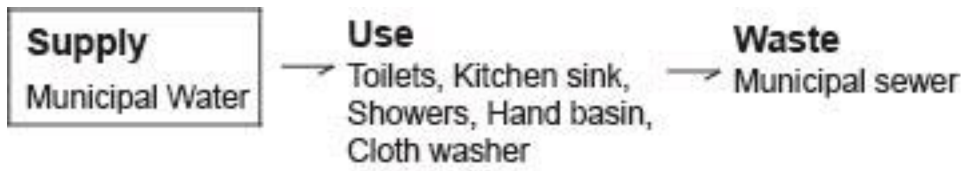


Figure 2.1 Water in residences with centralized systems without water recycling

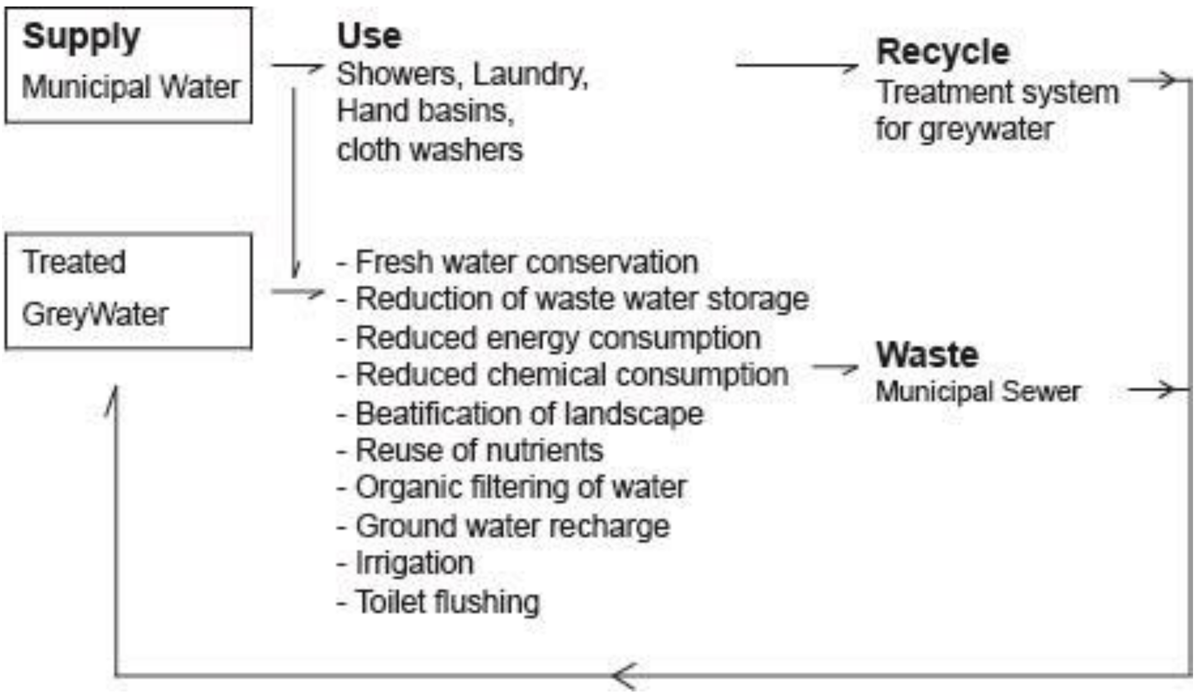


Figure 2.2 Water recycling in residences with centralized systems

Greywater volume within a household in low, middle and high-income areas with piped water reticulation may generate significant volumes per person per day. It is estimated that on average, typical greywater generation in Addis Ababa households with piped water reticulation may likely range between 40-60 lpcd (approximately 50% of total water consumption) (AWWSA). The table below shows that the typical residential end uses of water for generation of greywater for Addis Ababa.

Table 2.1 Estimation of residential end use of greywater (AAWSA, 2019)

Greywater	**Amount of greywater in percent**
Bathtub	3.3
Clothes washer	14.9
Shower	19.7
Faucet water	5.1
Total	**43%**

2.3 Advantage and disadvantages of greywater

Table 2.2 shows the main advantages and disadvantages of the use of greywater based on the research of Art Ludwig, 2008.

Table 2.2 Advantages and disadvantages of greywater (*Art Ludwig, 2008)*

Advantages of Greywater	**Disadvantages of Greywater (**including their solutions)
Reduced the use of freshwater – greywater can replace freshwater for some uses.	**Direct contact or consumption–** Avoid direct contact or consumption of greywater while cleaning filters and labeling of plumbing helps to differentiate the pipes.
Less strain on septic tanks or treatment plants – Reducing a septic system's flow by getting greywater out greatly extends its service life and capacity. For municipal treatment systems, decreased flow means higher treatment effectiveness and lower costs.	**Pathogen overload if not used within 24 hours.** **System overload –** if planed to increase users consider diverting greywater to the sewer while fixing the system
More effective purification– Greywater is purified to a spectacularly high degree in the upper, most biologically active region of the soil. This protects the quality of natural surface and ground waters.	**Breathing of microorganisms–** droplets from sprinklers (a device that sprays water) can evaporate to leave harmful microorganisms suspended in the air,
Reduced use of energy and chemicals – happens due to the reduced amount of freshwater and wastewater that needs pumping and treatment.	**Chemical contamination–**toxins from cleaner ingredients, but if used it could be avoided by diverting the pipe to the sewer.
Groundwater recharge – Greywater application in excess of plant needs recharges the natural store of water in the ground.	**Contamination of surface water**
Plant growth	**Contamination of groundwater or well**
Reclamation of nutrients – Loss of nutrients through wastewater disposal in rivers or oceans is a subtle but highly significant form of erosion. Reclaiming otherwise waster nutrients in greywater helps to maintain the land's fertility.	
Increased awareness of, and sensitivity to natural cycles–the greywater users, by having a reason to pay more attention to the annual progression of the seasons, the circulation of water between the Earth and the Sky, and the needs of plants, benefits intangibly but greatly by participating directly in the wise husbandry of vital global nutrient and water cycles.	

2.4 Application of greywater

It is essential that the quality of greywater is adequate for its reuse purpose. Separation of wastewater from its source helps to maximize the potential for waste water reuse, as different types of waste water (i.e. rainwater, greywater, urine, black water, and faeces) have different contamination level of pathogens and contaminations but also nutrients and salts where they are appropriate for different purposes. First they should be separated at the source level; it will create to retain high volume of relatively safe water (i.e. greywater and rainwater) that can be directly reused, whilst reducing the volume of waste water (i.e. black water) that must be treated before reuse. Since this study paper only discuss about the reuse of greywater of all the options considered as innovative approaches, it is necessary to separate the different types of greywater sources.

2.5 Greywater Reuse and techniques

2.5.1 Arba Minch, Ethiopia

System used and its technique

Greywater can be used in vegetable gardens throughout Ethiopia. The keyhole garden is specifically designed for increasing retention in water scarce areas, whereas the vertical garden with central gravel column is a space efficient technology particularly suitable for designed especially for the denser urban areas. Both gardening options provide improved nutrition to households and for this reason alone the technologies should be promoted across the country (ROSA, 2010). Figure 2.3 shows the application of greywater in Arbaminch by ROSA project, where the executing institutions are ROSA Arbaminch Team, Arbaminch Town Water Supply and Sewerage Enterprise (ARB), Arbaminch University (AMU), Jupiter construction micro and small enterprise Daylight construction micro and small enterprise.

Figure 2.3 (Right) Preparation of greywater tower in three steps: mixing soil, ash and compost, (Left) filling the gap(ROSA, 2010).

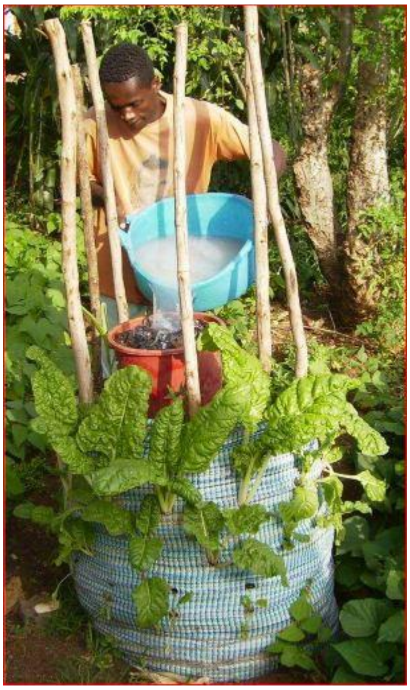


Figure 2.4 Pouring greywater into the tower(ROSA, 2010).

Keyhole garden is designed to be watered with greywater from washing or bathing, both to conserve water and reduce the labour burden of collecting additional water for irrigation. Water can be applied to the top of the bed or through the basket at the center, thereby watering the layer beneath. The basket is woven of reeds or thatching grass, which should help filter out some of the chemicals from soap and detergents. Kitchen scraps and manure can be placed inside the basket to help renew the nutrients in the soil. In addition, it is recommended to add manure or compost to the topsoil when it is no longer visible within the top layer. As the garden will sink over time because of decomposition of the layers of organic material, some soil should be added regularly to maintain the level of the garden.

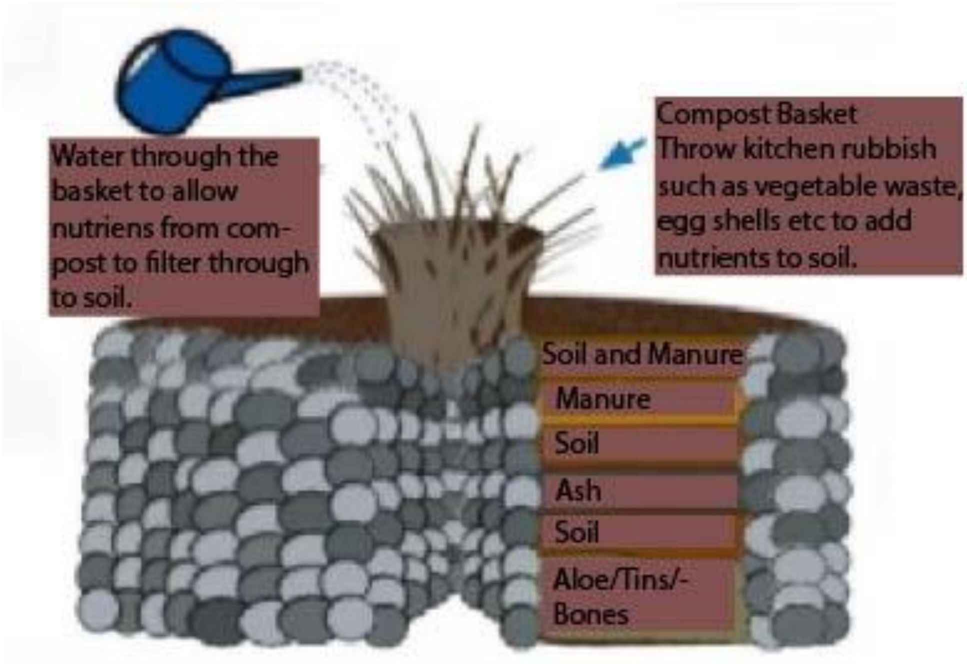


Figure 2.5 Keyhole garden(ROSA, 2010).

2.5.2 Taiwan's Experience

In Taiwan greywater distribution called conventional greywater reuse system (Juan, Chen and Lin, 2016)is used for a multi-story residential building. The system consists of three subsystems.

- Collection of raw greywater: lateral pipes are installed to collect greywater from bath, shower, and washbasin to central vertical pipes.
- Conveyance and treatment of greywater: collected raw greywater is conveyed through these separate vertical pipes to the basement for treatment. Treated greywater is then pumped to the top of the building to the storage tank.
- Distribution of treated greywater: treated greywater is then gravitationally conveyed from the storage tank to each family unit in each flat.

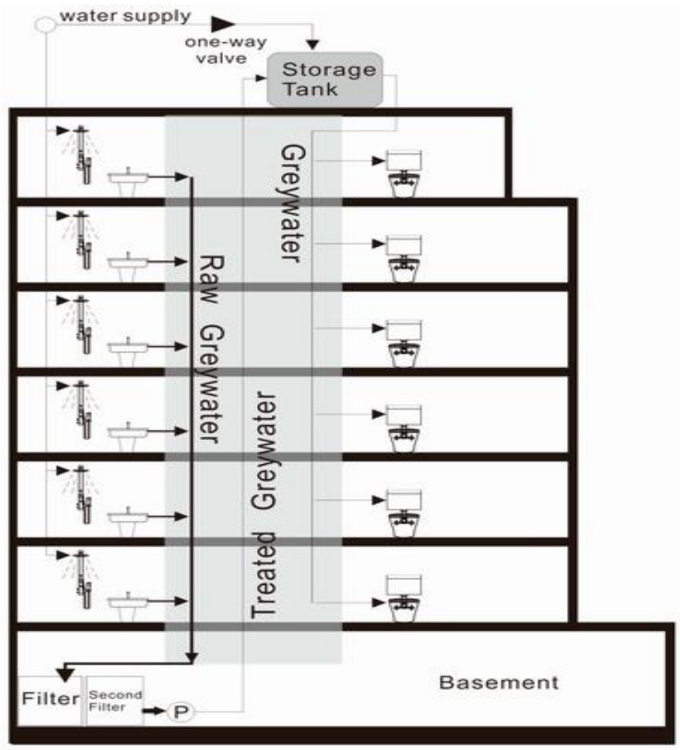


Figure 2.6 Greywater system in multi-story building

Interior Customized Greywater System (ICGS) Design(Juan, Chen and Lin, 2016)

- **Greywater treatment for indoor use**

The design is made considering the installation of appropriate greywater reusing system. The related functional areas are placed aliened which are the toilet, kitchen and balcony.

Figure 2.7 – Floor plan, Taiwan(Juan, Chen and Lin, 2016)

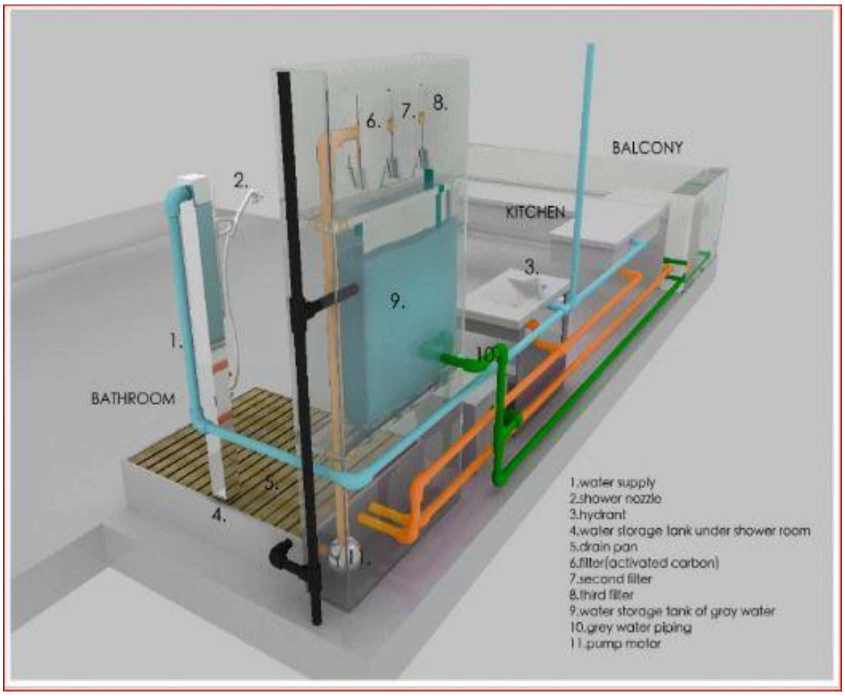


Figure 2.8 – Interior customized greywater system, Taiwan(Juan, Chen and Lin, 2016)

2.5.3 Australia Experience

A. Greywater treatment for indoor use

As an Australia's guide to environmentally sustainable homes suggested that in homes with access to a reliable rainwater supply, it is generally more economical just to use greywater outdoors and rainwater indoors. However, if you are unable to collect enough rainwater, treated greywater can reliably reduce indoor water use. The two biggest water usages of household activities are toilet flushing and clothes washing, where treated greywater could be reused. According to the guideline reusing treated greywater for toilet flushing can save approximately 50L of potable water in an average household every day and for clothes washer it can save approximately 90L of potable water in an average household every day.

In Australia even though wastewater from the kitchen sink and dishwasher can be classed as greywater it requires more complex treatment before reuse. Many states in Australia do not allow water from kitchens to be included in greywater for reuse, and permit greywater only from showers, hand basins and laundries. Greywater can be directly diverted from the shower or bathroom sink for toilet flushing as long as it is used immediately and not stored for more than 24 hours before reuse or disposal to sewer.

B. Greywater treatment for outdoor use

Greywater can be reused in gardens with little or no treatment. Subsurface irrigation systems, slotted drainage pipe or special drip lines, spread water evenly around the garden and are safer for untreated greywater.

Figure 2.9 Constructed wetland used to treat greywater from a housing development in Berlin, Germany (Nolde 2005)

Constructed Wetland

Figure 2.16 Constructed wetland systems (Allen, 2018).

Constructed wetlands are used to “ecologically dispose” of greywater. If there is a production of more greywater than needed for irrigation, a constructed wetland can help use up some extra greywater. Wetlands absorb nutrients and filter particles from greywater, enabling it to be stored for longer or sent through a properly designed drip irrigation system (though more filtration and pumping is also required). Greywater is also a good source of irrigation for beautiful, water loving wetland plants. If you live near a natural waterway and don’t have anywhere else to direct greywater, a wetland can safely clean and soak-up greywater, protecting the creek.

Constructed wetlands have been used with success in the past for the treatment of wastewater. In this process greywater is treated by soil filtration in reed-bed systems which reduce the organic load of the greywater. If properly designed, these systems would produce a clear and odorless effluent implies with being able to be stored for several days without the need for disinfection. The only disadvantage is that the high evaporation rate from the reed beds, especially in warm climate and the high space requirement. But in the other hand this way of treatment is simple, inexpensive and environmentally friendly. It also helps to provide food and habitat for wildlife, and it creates pleasant landscape.

The constructed wetland has been considered as the most environmentally friendly and costs effective technology for grey water treatment (Gross et al. 2007).

2.5.4 Los Angeles Experience

The used system and the project is called "Greywater-ready" New Construction**.** The practice below is adapted from (Allen, 2018) and it shows consideration of the use of future greywater system in mind, it is less costly and easier to install the future system. Architects, designers, builders, and developers can plan these "greywater-ready" buildings using a few basic design principals.

- Estimate how much greywater will be generated and how much of the landscape can be irrigated. Plan to access enough of the greywater sources so the landscape can be irrigated entirely with greywater.
- Create greywater accessibility points so that the greywater drains are accessible and able to be diverted into a greywater irrigation system. If greywater drains can't be accessed below the building (in a crawl space or basement), create an access panel in the wall (Fig 3.11) or a subsurface access point in the landscape (Fig 3.10) before greywater combines with any toilet water.
- Keep the greywater accessibility location as high in elevation as possible to allow for gravity-fed systems, and locate it so the greywater can access an irrigated portion of the landscape.
- If the future diverter valve location won't be easy to access for manual turning of the valve, make sure an electrical outlet is located nearby so an electronic actuator (operating device) can be connected to the diverter valve for remote switching.

Before closing up the walls, install a greywater pipe to the outside of the building with an access panel where the diverter valve will be located. The diverter valve direct greywater either into the pipe to the landscape or into the existing pipe to the sewer.

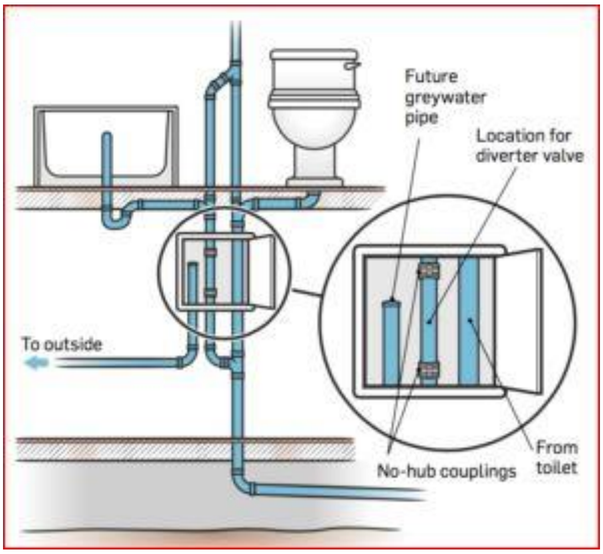


Figure 2.10 Illustration of installing greywater pipes(Allen, 2018)

- **Options for Slab-on Grade Construction**

Below is an illustration on how to install a dual-drain washer box. Plumb one drain conventionally to the sewer/septic and outfit the other drain with a pipe to the outside of the house. A 1″ flexible tube can be snaked through this pipe for a future L2L (laundry to landscape) system.

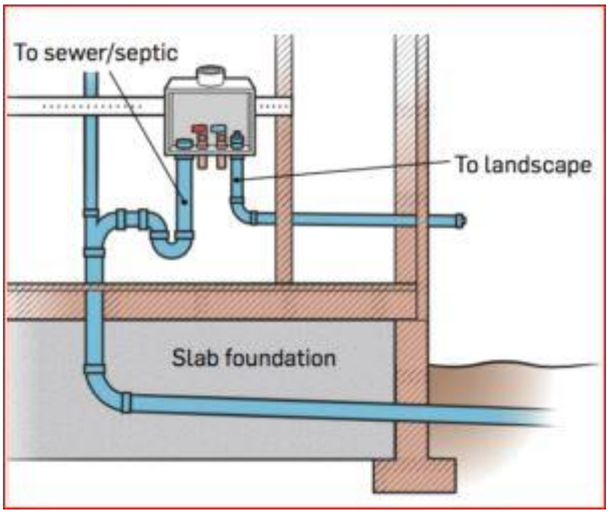


Figure 2.11 Illustration of installing greywater pipes(Allen, 2018)

On Figure 3.11 it shows on how to keep greywater pipe separate from the toilet pipe until outside the building. Locate an irrigation valve box above the location for the diverter valve for future access, the close-up of location for future diverter valve.

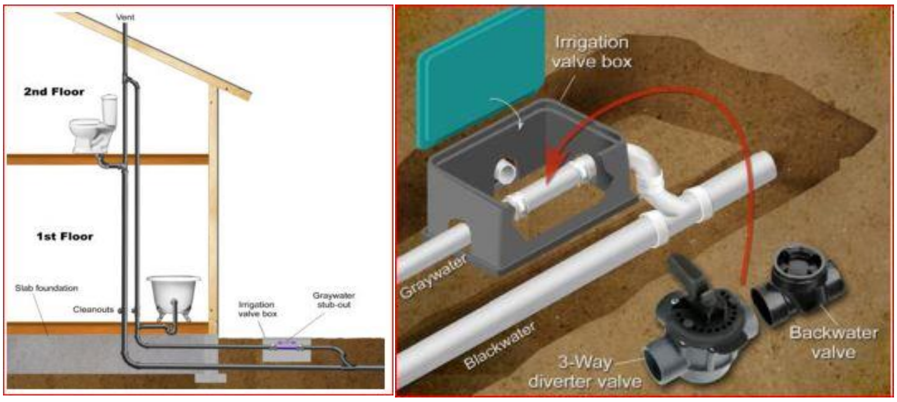


Figure 2.12on the left side illustration of locating an irrigation valve box above the location for the diverter valve for future access. On the right side is a close-up of location for future diverter valve. (Allen, 2018)

Table 2.3 Greywater accessibility chart (Allen, 2018)

Type of Building	Mandatory	Voluntary/Recommended
Single Family (1-2 units) with crawl space or basement **Multifamily Residential** (triplex, quadraplex, bungalow, patio homes, townhouses)	Minimum of one shower/bath, and laundry, on ground floor. All sources from 2nd floor and above.	All greywater sources from all floors. **Exception**: For homes with three or more showers/baths, one shower/ bath located in a less frequently used bathroom should be left off the system.
Single family (1-2 units) slab-on-grade **Multifamily Residential** (triplex, quadruplet, bungalow, patio homes, townhouses)	Minimum of one source of greywater (either shower/bath or laundry) on ground floor. All sources on 2nd floor and above	All greywater sources from all floors. **Exception**: For homes with three or more showers/baths, one shower/bath located in a less frequently used bathroom should be left off system.
Multifamily residential apartment building, student housing, mixed use residential	Rooms that generate high volumes of greywater, such as laundry facilities and showers in pool/spa area shall have an accessibility point. New construction should plumb with both potable	Showers, if on 2nd floor or higher. Bathrooms should be designed so greywater and blackwater pipes are naturally separate and drain through separate drains.

	and non-potable water lines to supply toilets so that toilets can be flushed with treated greywater or other non-potable sources of water.	
Commercial	Same as multi-family residential.	One laundry point of use to be offline and plumbed for potential filtering/recirculation to cooling tower.
New subdivision	All greywater sources except lavatory (bathroom) sinks shall be dual drainage plumbed to an accessible location outside the building.	

N.B. for all the cases under Los Angeles the 2nd floor represents the 1st floor and 1st floor represents the ground floor in Ethiopian context.

2.5 Comparison of greywater treatment technologies

As noted on Allen (2018) greywater treatment approaches range from simple, low-cost devices that route greywater directly to applications such as toilet flushing and garden irrigation, to highly complex and costly advanced treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps and disinfections units. There are several ways to treat greywater to yield hygienically safe water for reuse. In this study since the whole process of using greywater is new, it indicates the most used greywater source which originates from baths, showers and hand washbasin which is usually less polluted than from the kitchens and washing machines. The basic requirement or guidelines for greywater technology is listed below: -

- **Don't store greywater** (more than 24 hours). If you store greywater the nutrients in it will start to break down, creating bad odors.
- **Minimize contact with greywater.** Greywater could potentially contain a pathogen if an infected person's feces got into the water, so your system should be designed for the water to soak into the ground and not be available for people or animals to drink.
- **Infiltrate greywater into the ground, don't allow it to pool up or run off** (knowing how well water drains into your soil (or the soil percolation rate of your

soil) will help with proper design. Pooling greywater can provide mosquito breeding grounds, as well as a place for human contact with greywater.

- **Keep your system as simple as possible, avoid pumps, and avoid filters that need upkeep**. Simple systems last longer, require less maintenance, require less energy and cost less money.
- Install a 3-way valve for easy switching between the greywater system and the sewer/septic.
- Match the amount of greywater that an individual plant will receive with their irrigation needs.

2.5.1 Sources of Simple Systems

- **Washing machine**

Washing machines are typically the easiest source of greywater to reuse because greywater can be diverted without cutting into existing plumbing. Each machine has an internal pump that automatically pumps out the water- you can use that to your advantage to pump the greywater directly to your plants.

Laundry Drum

Figure 2.13 “Laundry drum” system (Allen, 2018).

This system is preferable because it is a cheap way of system and it avoids an irrigation process if the place has lot of concrete/patio between your house and the area.
Wash water is pumped into a “drum,” a large barrel or temporary storage called a surge tank. At the bottom of the drum the water drains out into a hose that is moved around the

yard to irrigate. This is the cheapest and easiest system to install but requires constant moving of the hose (flexible tube) for it to be effective at irrigating.

Laundry – to – Landscape

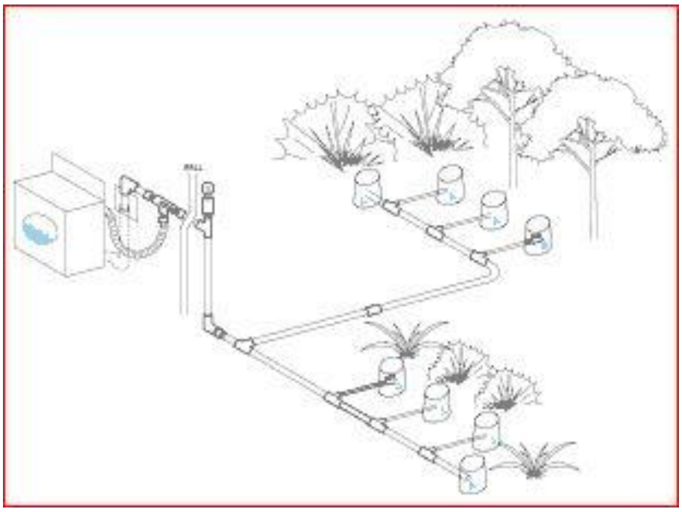


Figure 2.14 Laundry – to – Landscape system (Allen, 2018).

This type of system is introduced by Art Ludwig in 2008. It gives you flexibility in what plants are chosen to irrigate and takes very little maintenance.

This greywater system doesn't alter the household plumbing: the washing machine drain hose is attached directly to a diverter valve that allows you to switch the flow of greywater between the sewer/septic and the greywater irrigation system. The greywater irrigation system directs water through 1″ tubing with ½″ outlets directing water to specific plants. This system is low cost, easy to install, and gives flexibility for irrigation.

- **Shower**

Showers are another source of greywater- they usually produce a lot of relatively clean water. To have a simple, effective shower system considers a gravity-based system (no pump). This system is suitable for places which are located uphill from the house, and then will need to have a pumped system.

Branched Drain

Figure 2.15 Branched drain system (Allen, 2018).

The branched drain system was also invented by Art Ludwig in 2008. Greywater in this system flows through standard (1 ½" size) drainage pipe, by gravity, always sloping downward at 2% slope, or ¼" drop for every foot traveled horizontally, and the water is divided up into smaller and smaller quantities using a plumbing fitting that splits the flow. The final outlet of each branch flows into a mulched basin, usually to irrigate the root zone of trees or other large perennials. Branched drain system is time consuming to install, but once finished require very little maintenance and has high durability.

- **Sinks**

Kitchen sinks are the source of a fair amount of water, usually very high in organic matter (food, grease, etc.) kitchen sinks are not allowed under many greywater codes, but are allowed in some states, like Washington, Oregon, Arizona, and Montana. This water clog many kinds of systems. To avoid clogging using a branched drain system with mulch basins, organic matter collects in the woodchips and decomposes. Since bathroom sinks don't typically generate much water, they can often combine flows with the shower water. Or, the sink water can be drained to a single large plant, or divided to irrigate two or three plants.

Pumped system

Figure 2.17 Pumped systems (Allen, 2018).

This kind of system could be used for places where gravity doesn't contribute to transport the greywater uphill or if the land is flat and the plants are far away. In a basic pumped system greywater flows into a large (usually 50 gallon) plastic barrel that is either buried or located at ground level. Inside the barrel an effluent pump pushes the water out through irrigation lines (no emitters) to the landscape. Pumps add cost, use electricity, and will break.

Indoor greywater use

Figure 2.18 Sink positive toilet lid (Allen, 2018).

In most residential situations it is much simpler and more economical to utilize greywater outside, and not create a system that treats the water for indoor use. The exceptions are in houses that have water use and minimal outdoor irrigation, and for larger buildings like apartments.

There are also very simple ways to reuse greywater inside that are not a “greywater system”. Buckets can catch greywater and clean water, the water wasted while warming up a shower. These buckets can be used to “bucket flush” a toilet, or carried outside. As shown in figure 3.20 sink positive is a simple design.

Plants and Greywater

Low tech, simple greywater systems are best suited to specific, large plants. It is preferable to water trees, bushes, berry patches, shrubs, and large annuals. It’s much more difficult to water lots of small plants that are spread out over a large area (like a lawn or flower bed)

Below is a table showing the different ways of systems and comparison based on area requirements, cost, strengths and weakness.

2.6 Trends of water and sanitation infrastructure in Ethiopia

The government of Ethiopia is interested in provision of water, sanitation and hygiene services which is reflected way back in 1995 when a new constitution was prepared. In this constitution, Article 90 states that “To the extent the country’s resources permit, policies shall aim to provide all Ethiopians access to public health and education, clean water, housing, food and social security”. Similarly, Article 44 states that “All persons have the right to clean and healthy environment”. The inclusion of the right to water and sanitation in the national constitution signifies the political commitment of the government of Ethiopia to achieve the full coverage of both sanitation and drinking water.

The government of Ethiopia has finalized the Growth and Transformation Plan (GTP) in 2010 and started its implementation since then. GTP is a strategic framework to extricate Ethiopia from poverty so it becomes a middle-income economy by the year 2025. The government is committed to create a favorable “enabling environment” for the water, sanitation and hygiene (WASH) sector and has recently structured WASH implementation framework (WIF) which acts as the guiding document for the implementation of an integrated one WASH Program in the country. The government has also laid out ambitious plans for water, sanitation and hygiene through its “Universal Access Plan II” – which seeks to reach 98.5% access to safe water and 100% access to sanitation by 2015 (far more ambitious than the millennium development goal (MDGs)). As per the WIF, the major feature of the National WASH Program is that it has the leadership of four government Ministries (Ministry of Water & Energy, Ministry of Health, Ministry of Education & Ministry of Finance and Economic Development) who have pledged, through a Memorandum of Understanding to support an integrated WASH program that addresses the needs of individuals, communities, schools and health posts more holistically and reduces bureaucratic compartmentalization of services.

Depending on the UNICEF's official data the commonly accepted criteria for the effectiveness of water and sanitation services require that they be **affordable**, accessible to all which implies including children, the elderly and persons with disabilities, **acceptable** in addressing considerations arising from culture, religion and privacy requirements. To be **available** at home and at work in sufficient quantity and **of good quality** meaning that water must be free of harmful contaminants and that services must be safe to use. These criteria apply to water for personal and domestic use in which it should be sufficient to sustain life and health and meet basic needs for drinking, cooking and hygiene and to sanitation. The mentioned criteria do not address water for other uses such as agriculture or industry, nor do they imply that water should be free; usually it is not. The provision of water and sanitation services must be accomplished in a participatory, accountable and non-discriminatory manner.

A basic minimum standard of water supply is defined as a given quantity of potable water delivered within 200m of a household, at a minimum flow rate of 10 liters per minute. These requirements are designed to strike a balance between reducing the time and effort people have to spend collecting water, whilst still recognizing that shorter walking distances and high flow rates have cost implications. The minimum standard for basic water supply services is – the provision of appropriate education in respect of effective water use; and a minimum quantity of potable water of 25 liters per person per day or 6 kiloliters per household per month – at a minimum flow rate of not less than 10 liters per minute; within 200 meters of a household; and with an effectiveness such that no consumer is without a supply for more than seven full days in any year. (DAFGNSW, p-12, 2002).

Table 2.4 Percentage of water consumption in Africa (FAO 1998-2002)

Place	Agriculture	Household	Industry
Africa	85%	10%	5%
Water consumption of Ethiopia per sector in Billion m3/year			
Ethiopia	5.2040	0.3300	0.0210

Having the above data and the plan of rising the daily water consumption per a day per person for Ethiopia is 25 liters of water per person per day.

2.7 Greywater reuse and its gap in urban renewal areas of Addis Ababa

Demand for water and sanitation service far exceeds supply. As such, there is no excess capacity or back-up supply for water or sewerage in the city that would provide redundancy in the system. Water supply is derived from two sources: 40% surface and 60% groundwater, which are already under stress and failure of either source, would result in a crisis. Disruptions to water supply are generally handled by providing water using trucks. AAWSA has a fleet of 30-40 tanker trucks that can each serve about 130 households per day. In regard to wastewater treatment, there is no back-up plan in place other than direct disposal to water bodies. There is no contingency financing earmarked for water and sanitation, and minor maintenance and repair is covered by the AAWSA's budget. The estimated water leakage rate of 36.5% is high, especially considering that water scarcity is already a challenge for the city and is expected to worsen due to climate change and increased demand.

The use of water and sanitation infrastructure in the urban renewal areas will be applied in the same way as mentioned above in the policy. Some other factors inhibiting the achievement are the limited capacity of water bureaus in the country's nine regions and water desks in the 550 woredas; insufficient cost recovery for proper operation and maintenance; and different policies, standards and procedures used by various donors, miss use of potable water and some other problems are faced. But if properly applied an urban renewal is a second chance in creating opportunity to implement a well-managed settlement with integrated infrastructure if applied properly.

In Addis Ababa on December 2/2015, Ethiopia has set a goal to access 25 liter water per/day/person within one kilo meter radius from the base line 15 liter per/day/person with 1.5km. According to the ministry of water, irrigation and electricity will exert much effort to improve provision of water supply and improve drainage system in order to contribute for the plan of becoming a middle-income country. The GTP-2 goal is planned to benefit water supply and sanitation for millions of people in four regions.

2.7.1 Practice of water treatment within a household

On a study "Africa user research in water and sanitation" for specifically in Oromia region Gelan town and Aba Samuel village (Kebele), on household water treatment and storage (HWTS) says in Aba Samuel, almost all participants collected their drinking water from a water point (public tap) and/or backyard (private tap). However, some household were also using pond water. Because of availability water points are only certain hours, are not always operational, and lines are often long; participants who rely on public taps also reported collecting water from backyard or private taps. The study also mentioned that peoples were familiar with some water treatment products like Wuha Agar (or Water Guard) and Bishan Gari (a locally produced flocculent and disinfectant). As the villagers' perception tap water was considered "safe water" and that the water should not be treated because they presumed it had already been treated at the source, although stakeholders reported intermittent treatment. This kind of awareness exposed the society to diseases like diarrhea, common cold and typhoid/typhus.

Figure 2.19 Way of toilets arrangement in most condominiums of Addis Ababa

In most cases the shortage of water has been considered in housing areas and people tries to solve this by their own, for example by placing container and by reusing greywater produced from cloth wash for cleaning houses.

Table 2.5Dimensioning of different systems (Antoine Morel, 2005)

	Single household	Neighbourhood	Hole community
Wetpark		X	X
Constructed wetland	X	X	X
Ecomax	X	X	
Gaia-movement system	X		
Rota-Loo greywater system	X	X	

Table 2.6 Summarized pros and cons of the experiences of the different countries.

Countries	Name of Technique	Pros	Cons	Suitability for American Gibi
Ethiopia	Keyhole garden	1, Water scares areas 2, Does not require skilled person to prepare.	Topsoil gets affected through time	Low
	Vertical garden	1, Space efficient, 2, For irrigation	Only for denser urban areas.	Medium
Taiwan	Interior customized greywater system (ICGS)	1, Used for multistory buildings, 2, Allows well organized piping system 3, Pre consideration of integrating greywater system in a design.	Needs proper maintenance	High
Australia	Constructed wetland	1, Could be applied in gardens with little or no treatment. 2, Preferable for untreated greywater 3, For irrigation	1, Greywater is treated only outdoor 2, Require a bit more space than the other techniques.	High
Los Angeles	Greywater-ready New construction	1, Pre consideration of integrating greywater system in a design. 2, Less cost 3, Easy to install 4, For newly planned constructions.		High

The techniques used in Taiwan, Australia and Los Angeles are suitable for American Gibi because of their considerations of constructions. In American Gibi the construction for the housing units has not yet started. For this the Taiwan’s (ICGS) and the Los Angeles (Greywater ready new construction) techniques has the advantages of pre considerations of integrating greywater system. But out of these two techniques the (ICGS) is more suitable than the greywater ready new construction technique. This is because (ICGS) allows well organized piping system which considers multistory building units. The Australian’s technique (constructed wetland) is also suitable for American Gibi to be applied on the open space specifically green areas. The disadvantage of the ICGS technique is that needs a proper maintenance. But since this technique is implemented in side ones house the owner is responsible for it. This would have been a problem if it was a responsibility of a group of people. So both are applied for American Gibi, where (ICGS) are for indoor (within a household) and constructed wetland is for outdoor space and combining both to one another and function in an integrated way.

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Methodological framework

Using both qualitative and quantitative data approach, the research used three steps within the overall research process. First, literature is reviewed on the know-how of greywater reuse practice within a household, a building and neighborhood in Ethiopian and international context. Second, selected approaches or techniques practiced in Ethiopia and other countries were compared with each other and summarized. Third, contextual case study area (American Gibi) were analyzed and studied in detail from the collected data using observation, informal discussion, photo taken, documented data from different governmental offices. Then, conclusion and recommendations are developed.

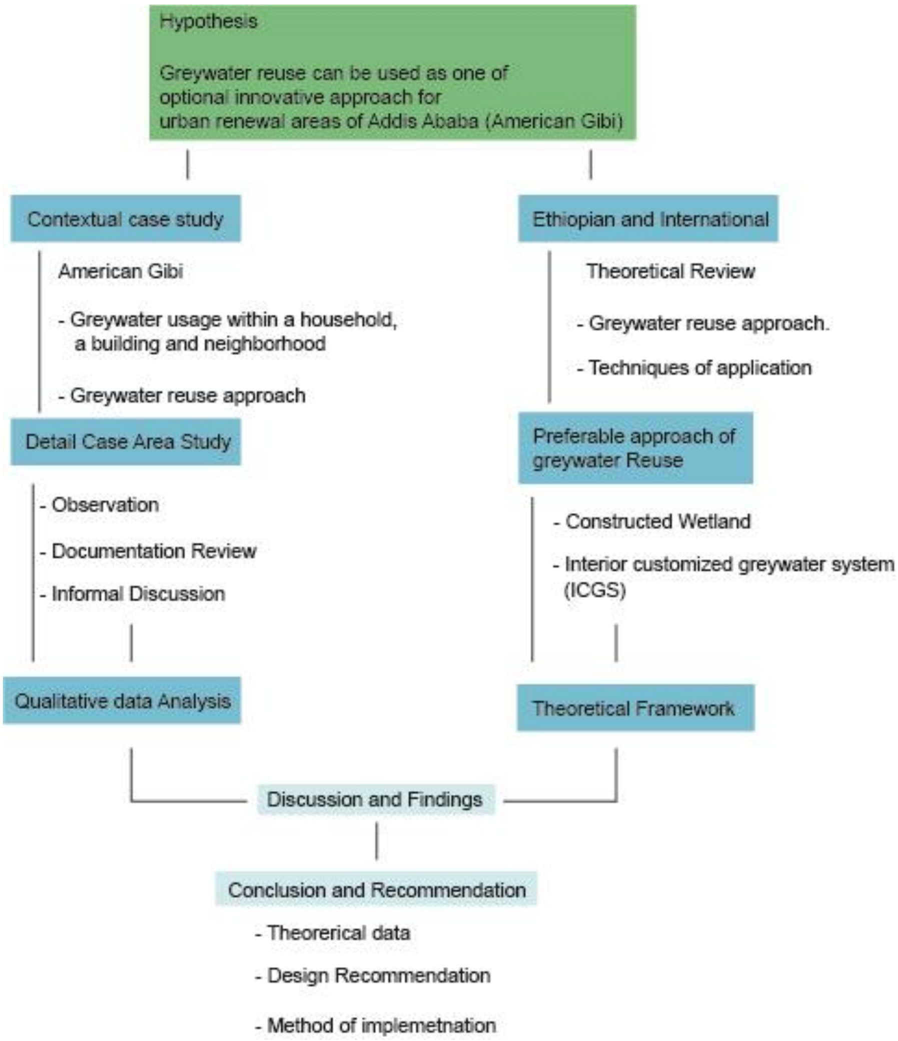


Fig 3.1 Methodological Framework Diagram (Author, 2020)

3.2 Case area description

The study area, American Gibi is located in Addis Ababa, Ethiopia, Addis Ketema sub city. American Gibi is well known for travel agencies of Umra travelers who predominately came from Wello area and other parts of the country. The travelers usually sell their belongings in order to reach Mecca – Medina, at least once in their lifetime. If they lose the chance to travel, they will be forced to stay in the area and this situation results increase in density.

Figure 3.2 American Gibi in 2015 at a level of 800ft (Google earth)

Figure 3.3 American Gibi in 2018 at a level of 800ft (Google earth)

The majority street side building height ranges from G+2 to G+5 while the internal (off main road) part of Piassa is largely occupied by G+0 residential houses. Since the concept of the renewal and the LDP is to extend the commercial corridor, the height should be compatible with those classical buildings. The allowed height is G+3 up to G+5. The American Gibi street side building height should be equal or greater in G+1 up to G+2 with the proposed condominium housing. This will help to secure the privacy of the housing from noise and visual interruptions.

The LDP propose the majority of the blocks containing 32-40 housing units with the majority of one bed room type considering the low- and middle-income groups of society. Since the existing density of the site is more than 200 housing units per hectare, the proposed condominium housings are not highly densified. On average, the new proposed settlement is 210-250 condominium houses per hectare. The proposed condominium housings, as much as possible, are arranged in a mixed income category manner in order to keep up the social mix which at last guarantees healthy and peaceful environment to the inhabitants.

The proposal also considers public and green spaces between the condominium houses for social functions, which is going to be enclosed by the condominiums.

3.3 Data types

3.3.1 Primary data

Field observation helped to have a pictorial understanding of the proposed design in place, even though the site is cleared out as shown on fig 3.2 and fig 3.3. In addition to that it clarifies the landscape so that it would be easier to identify a place to install the reservoir and creates know how on placing a piping system on the ground. But it is elaborated based on the secondary data. Physical site characteristics were like water source, soil, vegetation and climate.

3.3.2 Secondary data

From Addis Ketema’s sub city and Google map, the landscape and topographic figure were taken and the information about the way of the previous water supply system was gathered from AAWSA.

From the previous settlers, the society uses water from neighboring villages by sharing water pipe lines. Since the case area was originally used as a temporary residence there were no planned utility services. But through time the population becomes highly outnumbered which implied to high demand of water. Because of the loss of planned piping system, the society were forced to install water line from the available neighboring lines. Water is distributed on a shift basis through piped system. As for the knowhow of greywater reuse, informal discussions were made with peoples who are living nearby, because the original settlers are living in different places and difficult to reach them. So, the nearby peoples mentioned that people used greywater for house cleaning, toilet flushing, car washing, shoe shining and the likes. This shows that the society used greywater with no organized system but to optimize the usage of pure water.

3.4 Data collection methods

Quantitative and qualitative methods are used to analyze the collected data from primary and secondary data sources. Brief descriptions of the data are presented below. The tool that is used for primary data is personal observation of the current status and availability of utility services, photographs and the tool for secondary data used were interview and informal discussions with the sub-city officers, relevant documents from different concerning professionals.

Water supply and sanitation guideline of Addis Ababa, books, and journals were described based on countries experiences, technical parameters, spatial information, and professional’s perspectives.

In this section the gathered data and is discussed based on the written documents (formulas). Calculation based on the production of greywater and black water to estimate the reuse of greywater with in a household, a building and neighbourhood. This helps to realize the characteristics of greywater in the purpose of filling the demand of water.

Calculations are based on an estimation of 2 flushes per person per day. The following volumetric flow rate for blackwater below is for an estimation of 2 people using the facility. Which means that: -

Water flush per person per day = water (per flush) * 2 ….……………….……...….. (1)

Blackwater per person per day = Water flush per person per day + Urine (per person per day) + Faeces (per person per day) ……………………………………….…… (2)

Table 3.7 Blackwater volumetric flow rates

Volumetric flow rates (Q)	Blackwater	Total (L/d)	Total (L/h)
Per person	9.86	9.86	0.41
Total into system	19.72	19.72	0.82

According to several studies, the hydraulic retention time (HRT) of ten hours is accurate and can be used to calculate the volume of the two tanks needed.

V = Q * HRT……………………………………………………………………… (3)

Where,

Q = Volumetric flow rate

HRT = Hydraulic retention time, 10hours

In order to account for any changes in population or an increase in usage, a safety factor will be used. The original volume calculations are the minimum volume needed to handle the specified flow rates. For these purposes, a minimum of a 45 % safety factor will be used.

Volume of tank = Volumetric flow rate (Q) + Volumetric flow rate (Q) x 0.45… (4)

Due to the nature of the facility, the number of people using the facility will begin to increase as development is made. It is uncertain as to the approximate number of people who will be using the facility on a daily basis, and therefore, it is necessary to calculate the volume for varying number of uses. The volumes presented for greywater and for blackwater will help when determining what size tanks to purchase.

Using the above wastewater volume calculating method the researcher estimates the people leaving per condominium is calculated bellow. Since the majority of the housings are one bedroom types and the estimated people living are three. And if there are going to be 32-40 households per one building then the whole building will have 120 persons by taking the maximum people within a household three.

Table 3.8 Greywater volumetric flow rates for 120 peoples

Volumetric flow rates (Q)	Greywater	Total (L/d)	Total (L/h)
Per person	25	25	1.08
Total into system	3000	3000	125

Table 3.9 Blackwater volumetric flow rates for 120 peoples

Volumetric flow rates (Q)	Blackwater	Total (L/d)	Total (L/h)
Per person	9.86	9.86	0.41
Total into system	1183.2	1183.2	49.3

The result shows that there will be production of 1250 liter per hour of greywater from 120 peoples, which means that 10.42 liters of greywater is produced per hour per person.

The greywater produced is going to be used for toilet flushing and constructed wetland. As described on table 3.4 the amount of water needed for flushing per person per day is 8.56L, where there is a difference of 1.86 liters of greywater between the required and available amount for flushing. This left over could be applied for constructed wetland in order to grow different kinds of vegetation or plantation.

3.5 Data analysis

Different software like AutoCAD2007, AutoCAD2017, and illustrator, Excel and Revit were used. Some data are analyzed based on related reference books which are documented as PDFs by different authors. This research also considers the contextual case studies and theoretical frame works.

The characteristics of greywater to contribute in filling the demand for the case area can be high first by creating awareness to the society by the society. The only difference is that the usage of the produced greywater will be in an organized way and that it will be stored purposely in a specified place to be used not only to home cleaning and toilet flushing purposes but also for green space. And by using the case area’s advantage where it is a newly planned construction, installation of necessary pipes is easy. In order to have an organized system every housing unit has its own piping system connected within the building and then within the neighborhood. This is because if the system begins within a household, the owners feels responsible and maintain every move whenever it is needed. This implication contributes positively for a single building and the group of buildings to the whole neighborhood. With this sequence the system will have longer life time.

Once the information about the previous application of greywater and analyzing the characteristics of greywater in terms of the case area the next is to develop ways and schematic design for greywater reuse by setting up adaptive techniques. These took place based on the literature review and the comfort ability of the case area.

Table 3.6 Summary of Research Methodology (Author, 2020)

Research Question	Method	Output
- What are the trends of greywater reuse system for urban renewal areas of Addis Ababa?	- Observation - Informal discussion - Documented data	- Practiced approaches and ideas. - Availabilities of pre-requisite of greywater.
- What are the technical and spatial characteristics of individual users, buildings and neighborhoods in the case area and their challenges and opportunities for reusing greywater?	- Observation - Informal discussion - Documentation Reviews	- Internationally used practices and theories.
- In what ways could greywater reuse system be implemented in the case area?	- Documented data	- Internationally used practices and theories preferable for American Gibi.

The selection of literature review area depends on availability of information, similarity of slum neighborhoods as well as applicability of the lessons to the contextual urban area, also by their ability to provide an input to this study in terms of their being under active service of greywater treatment for urban renewal areas.

The AAWSA office's data were used in terms of its policy and design regulations. But for this study the billing system were needed in order to estimate the amount of greywater produced per person. Since it was impossible for the office to reveal the previous settler's information the researcher used owns approximate usage of household greywater production for the calculation purpose of the proposed condominium houses of American Gibi. But the estimation is consulted by the AAWSA officers.

Calculating the volume of tanks for the sanitation system (nguyen, huong, Turgeon, *Scott, and Matte*, *Joshua. 2010)*

In order to determine the volume of the tanks needed to handle the greywater and blackwater independently, it is necessary to estimate the volume that will be entering. Estimated usage per person per day for greywater is as follows.

Table 3.3 Greywater usage breakdown

Water use	Volume (L)	Description
Bathing	20	
Hand washing	5	1.5L per wash about 4 times a day.

As proposed for the American gibi there are going to be one-bedroom housing majorly. So, the estimated usages for three people using the facility, the volumetric flow rate for greywater is as follows. Three peoples are taken based on the previous settlement collected data by the sub city.

Table 3.4 Greywater volumetric flow rates

Volumetric flow rates (Q)	Greywater	Total (L/d)	Total (L/h)
Per person	25	25	1.08
Total into system	75	75	3.13

Similarly, the estimated usage per person per day for blackwater is seen below.

Table 3.5 Blackwater usage breakdown

Type	Total (L)
Urine (per person per day)	1.1
Faeces (per person per day)	0.2
Water (per flush)	4.28

3.6 Data Presentation

Site characteristics – characteristics of the site is based on the topography would be taken from Nortech of Addis Ababa recent edition, Google earth and on-site observation. Topography map, proposed building design and land use map, proposed number of populations from different sources like Nortech for the topography, Addis Ketema sub – city for the proposed design land use map. Three categories of maps are shown below describing the previous settlements and the newly planned land use map.

A, Previous LDP

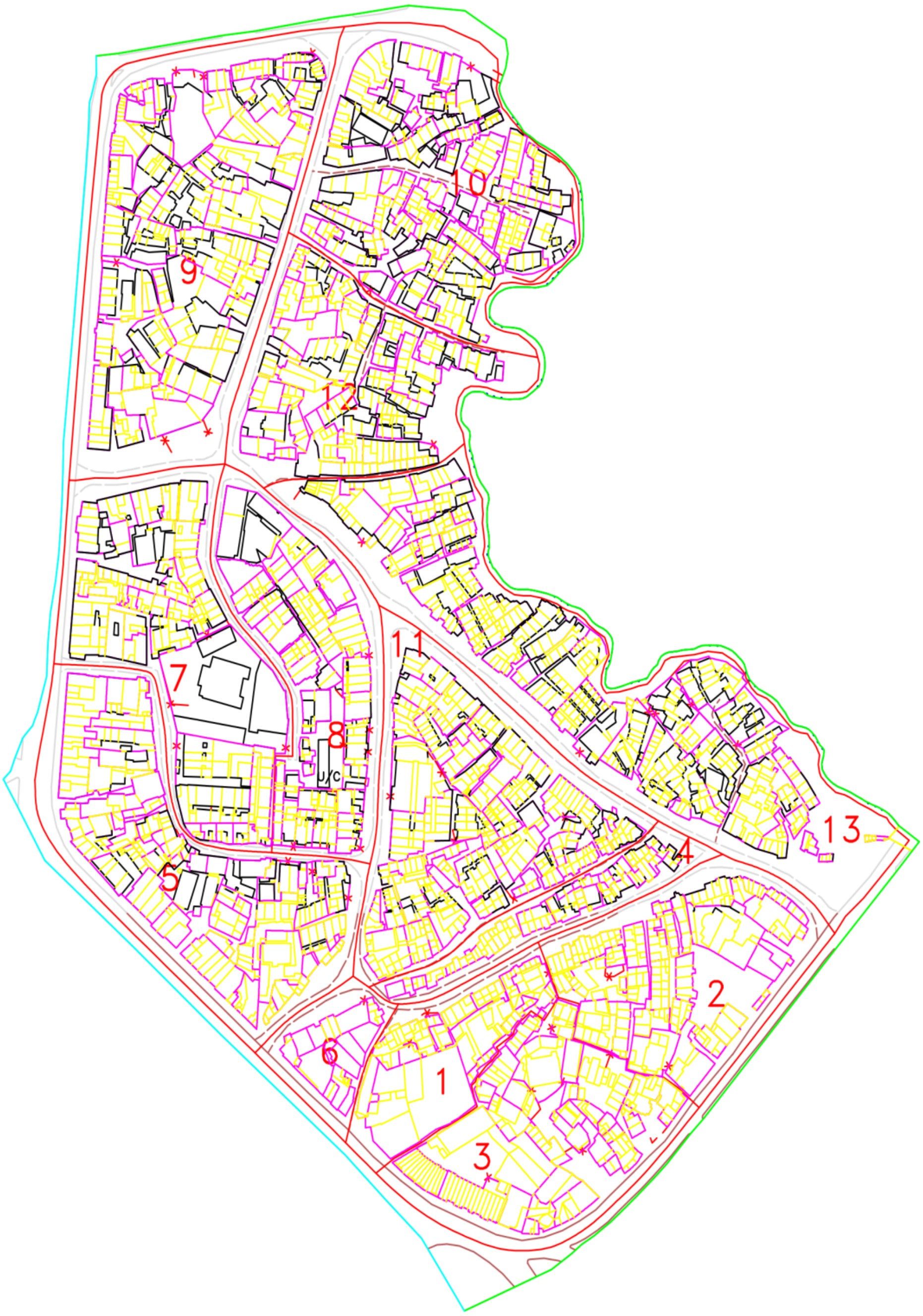


Figure 3.5 Previous settlement of American Gibi (Addis Ketema sub city, 2018), Scale 1:500

The figure above shows the previous settlement of American Gibi, where the pink represents the parcel, yellow represents the plot and the black represents the buildings with the block numbers. The green color stands for the green space. As seen the plots are not placed in an organized way, rather it is informal.

B, Proposed Urban Design

The figure below shows the proposed land use map. The urban design shows the new space division including the built-up area and floor area ratio.

Legend

1- Proposed housing area 1

2- Proposed housing area 2
3- Proposed housing area 3
4- Proposed housing area 4.

Figure 3.6 American Gibi's proposed urban design (Addis Ketema sub city, 2018)

Scale 1:250

Sub Arterial Street (SAS) is the city road which provided lower level of travel mobility than arterial streets, are called sub-arterial streets. Their spacing may vary from 0.5m in central business districts to 3 to 5km in sub-urban areas. Loading and unloading are usually restricted. Pedestrians are allowed to cross these highways at intersections. (Civilblog.org, 2015). For American Gibi it is proposed to be 25m. Principal Arterial Street (PAS) serves corridor movement having trip length and travel density characteristics indicative of substantial statewide or interstate travel. It also provides an integrated network without stub connections except where unusual geographic or traffic flow conditions dictate otherwise for instance international boundary connections and connections to coastal cities. For American Gibi it is proposed to be 40m.

C, Proposed Parcel Map

The figure below shows the parcel division design for the future prepared by Addis Ketema sub-city. It shows that almost all the blocking system is the same as before but in an organized way. This organization leads to an easy installation of the greywater system design with-in a household, buildings and the neighborhood.

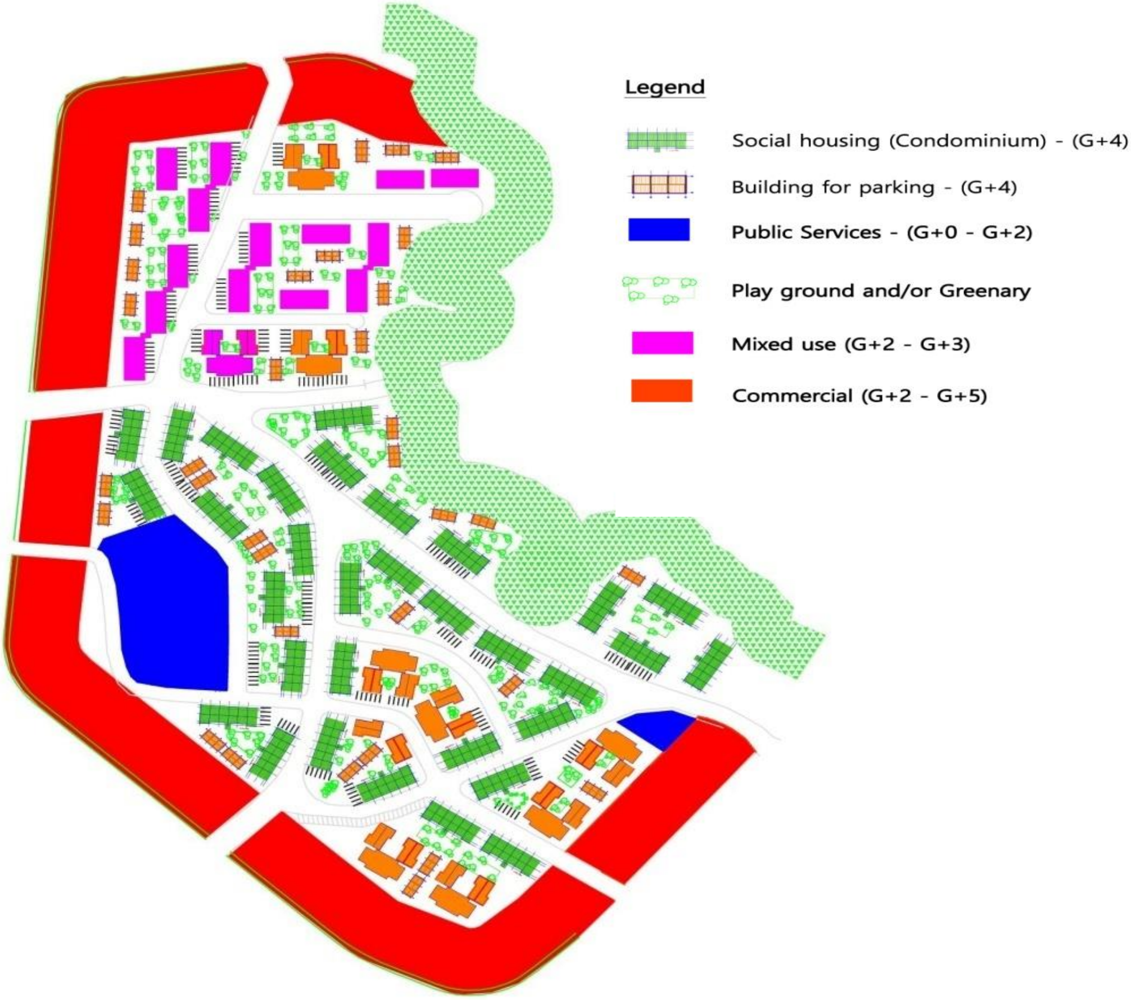


Fig 3.7 Parcel map, Scale 1:500

Table 3.1 Available space in American Gibi based on the proposal (Addis Ketema sub-city, 2018)

Available Spaces	Built up area	Floor area ratio
Proposed housing area 1	6727m^2	6391m^2
Proposed housing area 2	9881 m^2	9387m^2
Proposed housing area 3	4124 m^2	3918m^2
Proposed housing area 4	2556.7 m^2	2428.7m^2

Table 3.2Approximately estimated areas of condominium (Addis Ketema sub-city, 2018)

Type	Area	Remark
Studio	33 m^2 – 40 m^2	Including the communal space and based on the available space
One bedroom	46 m^2– 54 m^2	Including the communal space and based on the available space
Two bedroom	59 m^2– 67 m^2	Including the communal space and based on the available space
Three bedroom	72 m^2	Including the communal space and based on the available space
Total plot area	262 m^2, 280 m^2, 300 m^2, 316 m^2	Including the communal space and based on the available space

CHAPTER 4 –RESULT AND DISCUSSION

As discussed on research methodology combined the knowledge from the literature review and the data collected from the case area are synthesized to develop ways of greywater reuse and management for the proposed urban renewal area (American Gibi). This information includes starting from the source (household, building and neighbourhood level) until it is released to the municipal line. In addition to that the available greywater produced is calculated based on a formula and the case area's input 1of pure water.

4.1 Existing theoretical and practical knowledge on greywater

From the collected data the knowhow on using greywater was not intentional. But this caused by the shortage of pure water supply and the loss of organized water line to every household. Rather they were forced to install water line from the neighbouring settlers. Greywater reuse was implemented in terms of house cleaning toilet flushing, car washing, shoe shining and the likes.

Water is distributed on a shift basis in most of the sub cities through piped system. The goal of the supply of water estimation has not been accomplished rather the supply becomes less and less while the number of populations is ascending. As per the concerned stakeholders in AAWSA and Addis Ketema sub city there had been no water line provided for that specific area rather most individuals were forced to get water line from the nearest settlement.

Based on the collected data there is a clear gap between the supply and demand of water. But there is a chance of new construction process shortage and optimization of water supply could be applied using greywater reuse. Where still there will be a provision of shift basis water supply. Greywater reuse has been practiced in some parts of Ethiopia which makes it easier to practice it with some other technology.

4.2 Greywater reuse in terms of filling the demand for American Gibi

From the documented data (formulas) it is estimated that the production of greywater per person is enough to be used for toilet flushing and green area. Based on the proposed design most of the housing units contains studio than one bedroom, two bedroom and three-bedroom units.

As the calculation indicates the amount of greywater produced is higher than the greywater needed for toilet flushing. And since there is extra amount of greywater it could be set for the purpose of constructed wetland. In other words, 8.56 liters of pure water is saved from being used for toilet flushing. This indicates that per a single building with 120 peoples, there is a need of 1027.2 liters of water only for toilet flushing. The remaining amount of greywater, 1.86L could be used for greenery or vegetation purposes.

Table 4.1 Result of the greywater production per the proposed design

Type	Total (L/P)	Number of peoples
Water flush required per person per day	8.56	1
Required greywater for flushing for American Gibi	1027.2	120
Extra produced greywater which could be contributed to the constructed wetland	1.86	120

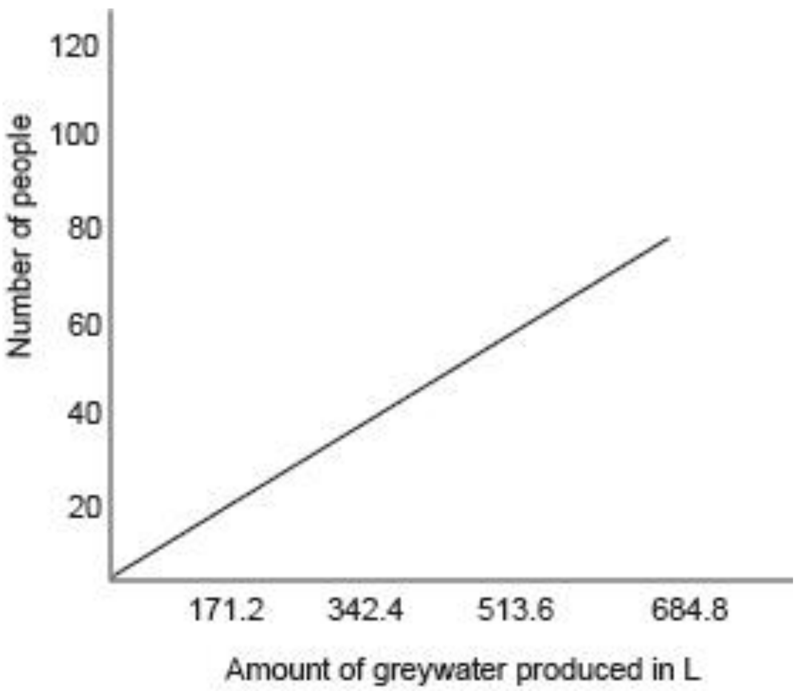


Fig 4.1 Direct proportionality of production of greywater and number of people (Author)

4.3 Discussion on the chosen preferable technique

The preferable greywater reuse system technique to be implemented is the constructed wetland and ICGS in a combined way. These techniques are discussed in detail on the literature review chapter. Both techniques work starting from a single household up to a building and within a neighbourhood. Where the ICGS works within a household and a building and construction wetland works within the neighbourhood. Two of the systems has an opportunity to be built on a newly construction space.

Below there are four figures showing the production of greywater and blackwater, green space available and location of the storage and treatment plant area. This is made based on the proposed design made by the municipality.

- **Ethiopia's experience in relation to American Gibi**

Keyhole garden and vertical garden are the two systems used in Arbaminch. From these systems the lesson learnt is that keyhole garden is used for places with water scares areas, where as the vertical garden with central gravel column is space efficient technology especially for denser urban areas. This system could be used for irrigation as similar purposes as Australia's experience of constructed wetland.

To generalize the both systems are simple, easy and cheap. There are also other systems namely laundry drum, laundry to landscape, branched drain, pumped system and sink positive toilet lid are discussed in addition to the experience of the international and local practices. The name of the system might seem different but they mostly had linkage with the local experiences.

- **Taiwan's experience in relation to American Gibi**

The lesson learnt from these experiences is to collect greywater and reuse it for multistory buildings. In the case of American Gibi the source of greywater is a single household and since the proposed housing projects are condominium, the greywater from the multistory building is also considered.

This system used three different steps in which to collect the greywater with vertical pipe, to treat it at the basement floor and pumped to storage tank located on top of the building and distributed with the force of gravity. To apply this in American Gibi, the site has an opportunity and challenges even though it would be costly to cart away. But as an option the cart away could be used for other purposes. It is also useful to manage space according to the BAR (built up area) and FAR (floor area ratio).

The other challenge is the installation of pumps are required in order to lift the treated greywater on top of the building storage tank, where it is an additional cost and depends on the power condition controlled by Electric power supplied.

This experience also reminds and considers the design integration of pre consideration of installing appropriate greywater reusing system. The basic point is to align spaces with related functions like toilet, kitchen and balcony.

- **Australia's experience in relation to American Gibi**

The Australia's experience is that the consideration of kitchen sink dishwasher as greywater but need a complex treatment which leads to high cost, labor, time etc. However, their experience helps to integrate rainwater and greywater usage for indoor and outdoor use consecutively. For places with long rainy season the greywater could be used untreated. But for places where rainwater is not available the treated greywater could be used. Greywater from shower or bathroom sink can be directly diverted to toilet flushing immediately and not stored more than 24hours.

The other system used is constructed wetland which is used for outdoor use for irrigation. This could be applied on American Gibi where there is green spaces. In most experience from observing other condominium housing compounds, the green spaces are less treated by the users. But introducing constructed wetland contributes a very important role in producing productive green spaces which could be consumed either by the users inside the compound or the community from outside the condominium.

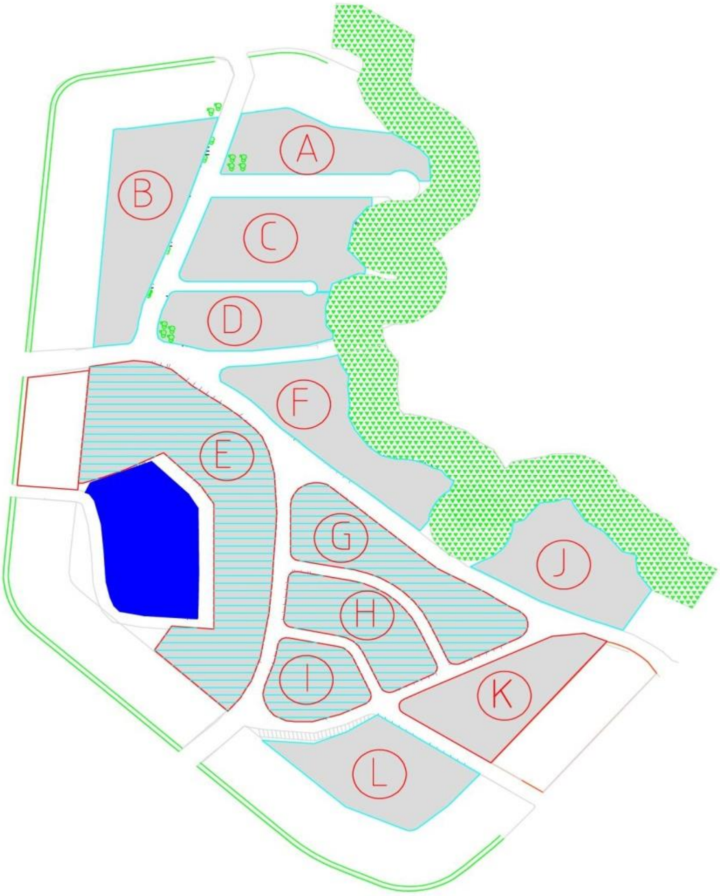
- **Los Angeles's experience in relation to American Gibi**

The experience used here is based on an easy and less costly with few basic design principals to install for future system. The integration of the design of architects, builders and developers are involved in order to plan "greywater – ready" builders.

From this experience the lesson learnt are how to install the necessary tools in order to differentiate and have separate piping system, how to control them easily. The optional ways of installation could be designed first by sanitary professionals and that it could be given space for the valve controller by the architect. Providing future spaces for piping so that one can determine the flow of greywater from the source to the landscape, to the treatment section, to the users or to septic/sewage of the municipal.

The other experience which could be adapted to American Gibi is that its recommendation of application of greywater system based on the type of buildings as shown on (Table 2.3) which considers single family, multifamily and commercial.

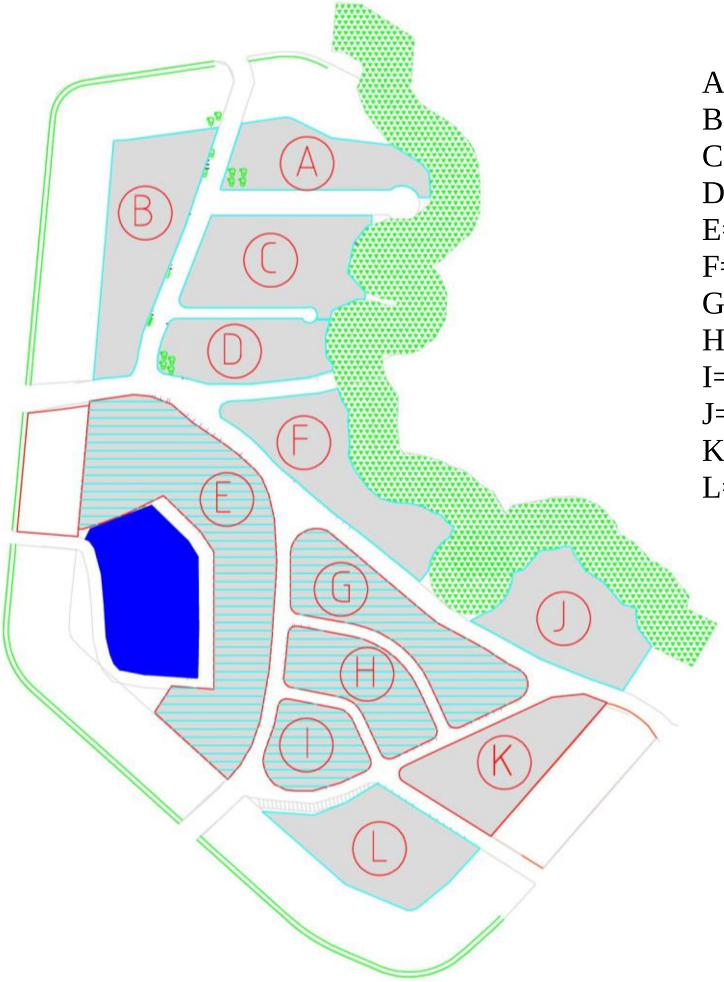
4.2.1 Greywater Production



A=15000L,
B=18000L,
C=18000L (Housing Area),
D=18000L,
E=33000L,
F=12000L,
G=18000L (Housing Area),
H=24000L (Housing Area),
I=12000L (Housing Area),
J=12000L,
K=21000L (Housing Area),
L=24000L (Housing Area)

Fig 4.2 Estimated greywater production in liters, Scale 1:500

4.2.2 Black water Production



A=5916L,
B=7099.2L,
C=7099.2L (Housing Area),
D=7099.2L,
E=13015L,
F=4732.8L,]
G=7099.2L (Housing Area),
H=9465.6L (Housing Area),
I=4732.8L (Housing Area),
J=4732.8L,
K=8282.4L (Housing Area),
L=9465.6L (Housing Area)

Fig 4.3 Estimated blackwater production in liters, Scale 1:500

The estimation is made based ontable 4.6. And it is made not only for the housing units but also for the other available functional areas for future studies.

4.2.3 Land use for Garden

Fig 4.4 Available greenery space, Scale 1:500

4.2.4 Design of greywater storage and treatment unit location

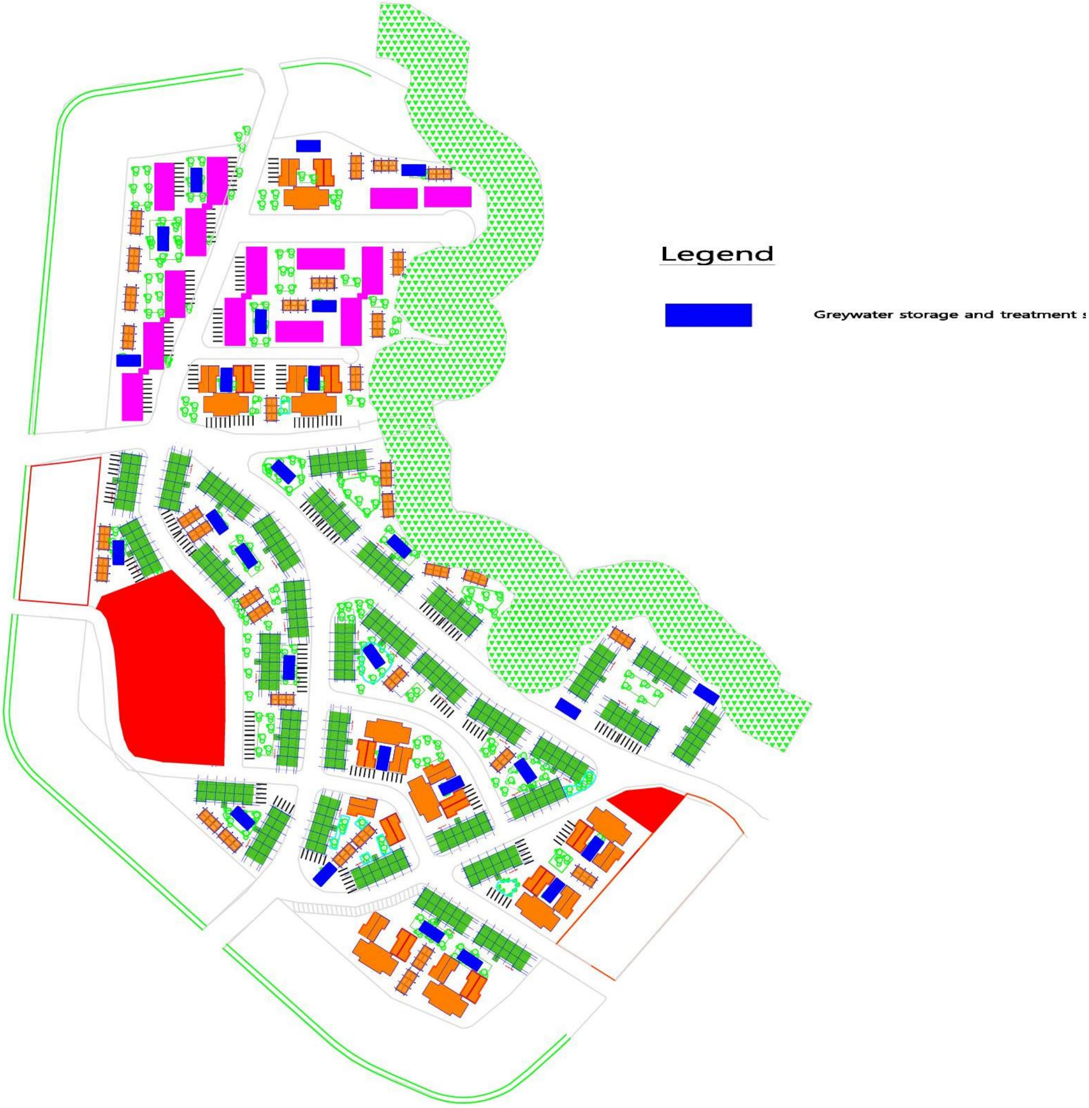


Fig 4.5 Greywater storage and treatment locations, Scale 1:500

CHAPTER 5 - CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In order to introduce the conclusion, the general and specific objectives are reminded below and interpreted based on the analysis made in the above chapters.

The general objective of the research is to introduce a suitable technique to apply greywater reuse for urban renewal areas. It is mainly to identify the planning and design gaps of greywater collection, storage, treatment, and reuse from spatial perspective. And identify the gap between the urban renewal areas and innovative approaches of water and sanitation provision specifically, greywater system in the case of American Gibi.

As discussed in the previous chapters the reuse of greywater could be applied both for existing buildings and a newly constructed building. One of the objectives of GTP II is to improve wastewater management system by 2025, using low cost technologies to be categorized under the middle-income countries.

In order to apply reuse of greywater for newly constructed areas, the Ethiopian water sector strategy allows implementing easily adaptable, implementable, affordable, sustainable, easily maintainable innovative ways.

Considering the opportunity of the case area (American Gibi), it would be easy to implement the different techniques of greywater system. As per the result the amount of greywater produced is 8.56L of water for toilet flushing. 10.42L of greywater is produced per person, where there is an excess 1.86L of greywater per person. Having this, it is possible to practice the constructed wetland and ICGS in terms of contextual conditions. In addition to that, as discussed, the characteristics of greywater, it could be used treated or untreated. But the way of application must be differentiated for both practices and additional pre-caution must be taken while using the untreated greywater.

The two techniques are able to be built with an easy step. And as the summarized comparison made between the different techniques, the constructed wetland and the ICGS are suitable in terms of their being able to be built for newly construction areas. The result also indicates that it is possible to build a sustainable greywater system on American Gibi.

5.2 Recommendation

Greywater reuse is one of the innovative approaches of optimizing pure water consumption and reduction of waste. It is recommended to apply the techniques with sufficient maintenance.

It is preferable to take care of the built system by the community themselves by creating awareness. It can be given through training, on how to use the system and do maintain with some time interval to increase its durability.

5.2.1 Proposed scheme for optional furniture alignment with in a household

Considering the third objective of the research the figure below shows the optional schemes that are suitable for the chosen techniques to be applied on toilets and bathrooms. The design shows how to use water supply and sanitary spaces including the way to install the assembled pipes of the system. The figure below shows proposed sample prototype design.

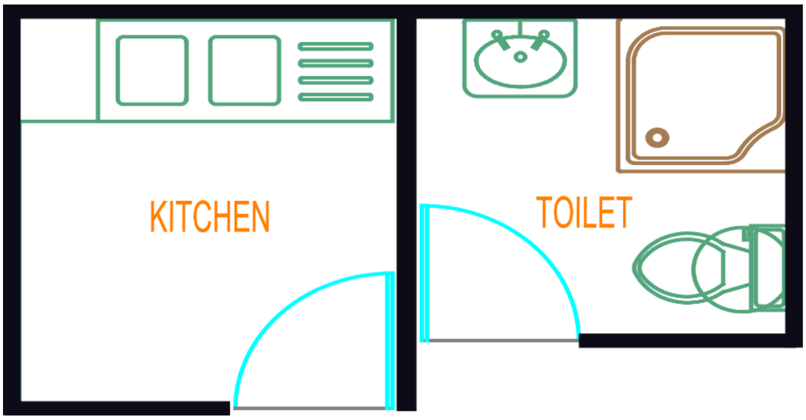


Figure 5.1Optional alignment one

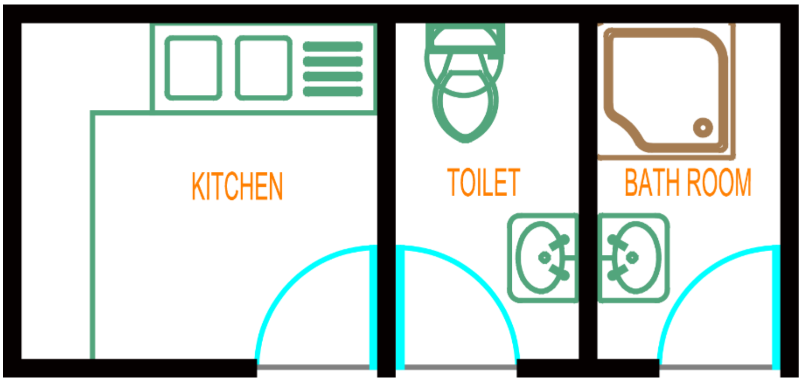


Figure 5.2Optional alignment two

Figure 5.3Optional alignment three

5.2.2 Proposed collection of greywater

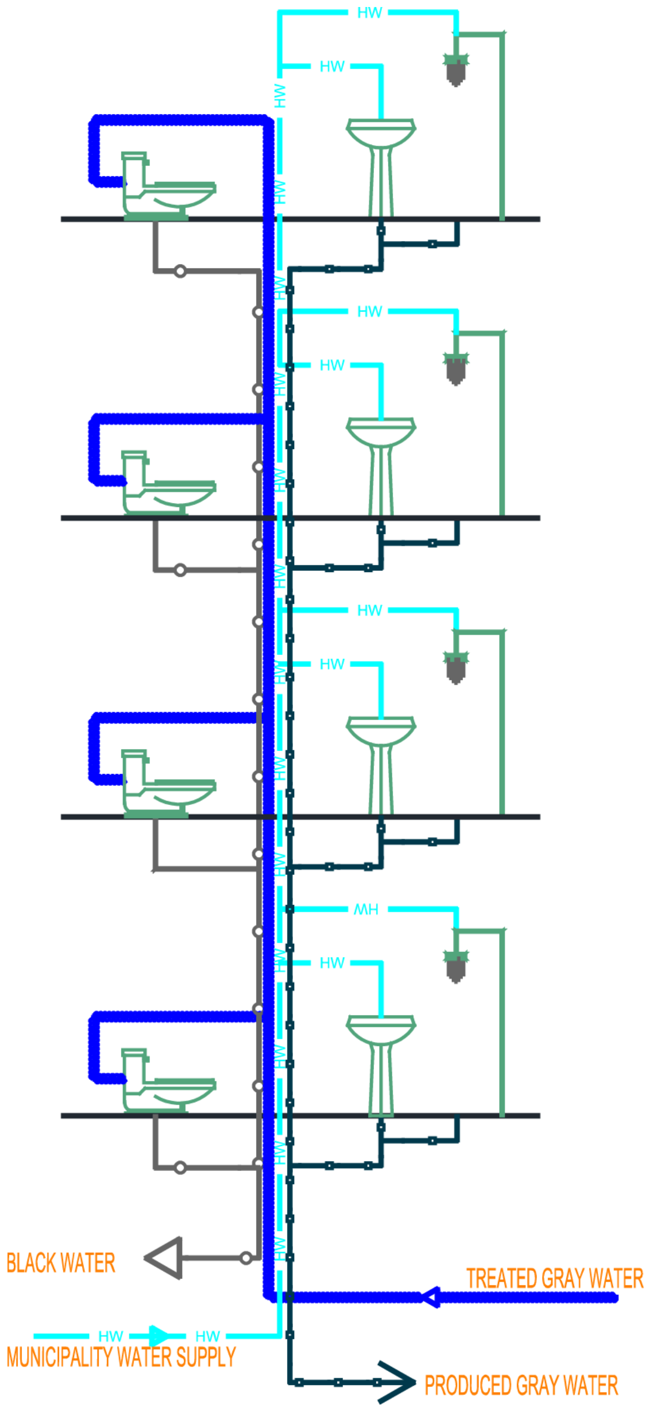


Figure 5.4 Schematic design of flow of wastewater and clean water

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ANNEX

Advantages of Greywater

- **Less strain on septic tanks or treatment plants** - Greywater, which comprises the majority of the wastewater stream, contains vastly fewer pathogens than blackwater and 90% less nitrogen (a nutrient that is a problematic water pollutant). Reducing a septic system's flow by getting greywater out greatly extends its service life and capacity. For municipal treatment systems, decreased flow means higher treatment effectiveness and lower costs.
- **Reduced use of freshwater** - Greywater can replace freshwater for some uses. This saves money and increases the effective water supply, especially in regions where irrigation is needed. Residential water use, on average, is almost evenly split between indoors and outdoors. Most water used indoors can be reused outdoors for irrigation, achieving the same result with less water diverted from nature.
- **More effective purification** - Greywater is purified to a spectacularly high degree in the upper, most biologically active region of the soil. This protects the quality of natural surface and ground waters. Topsoil is a purification engine many times more powerful than engineered treatment plants, or even in septic systems, which discharge wastewater deeper into the subsoil.
- **Reduced use of energy and chemicals** – happens due to the reduced amount of freshwater and wastewater that needs pumping and treatment. If it is possible to provide once own water or electricity, will benefit directly from lessening this burden. Also, processing wastewater in the soil under plants definitely encourages you to dump fewer toxins down the drain.
- **Groundwater recharge** - Greywater application in excess of plant needs recharges the natural store of water in the ground. Abundant groundwater keeps springs flowing and trees growing in intervals between rains.
- **Plant growth** - Greywater can support a flourishing landscape where irrigation water might otherwise not be available.
- **Reclamation of nutrients** - Loss of nutrients through wastewater disposal in rivers or oceans is a subtle but highly significant form of erosion. Reclaiming otherwise wasted nutrients in greywater helps to maintain the land’s fertility.

- **Increased awareness of, and sensitivity to natural cycles** - The greywater user, by having a reason to pay more attention to the annual progression of the seasons, the circulation of water between the Earth and the sky, and the needs of plants, benefits intangibly but greatly by participating directly in the wise husbandry of vital global nutrient and water cycles.

Disadvantages of Greywater

- **Pathogen overload** - Greywater systems are safest when reusing water that is fairly clean initially. ***Solutions:*** Greywater should not contain water used to launder soiled diapers or generated by anyone with an infectious disease. In both cases, greywater should be diverted to the septic tank or sewer. Also, don't store greywater; use it within 24 hours, before bacteria multiply.
- **System overload** - If you are having much more people and you are going to use a system designed for two, consider diverting greywater to the sewer for that time.
- **Direct contact or consumption** - Avoid direct contact or consumption of greywater while cleaning filters and labelling of plumbing helps to differentiate the pipes.
- **Breathing of microorganisms** - Droplets from sprinklers (a device that sprays water) can evaporate to leave harmful microorganisms suspended in the air, where people may breathe them. ***Solution:*** Don't broadcast greywater with sprinklers.
- **Chemical contamination** - Biological purification does not usually remove industrial toxins. Toxins will either be absorbed by plants or pollute groundwater. Many household cleaners are unsuitable for introduction into a biological system. ***Solutions:*** Divert greywater that contains chemicals so they poison the sewer or septic instead. Better yet, don't buy products that you wouldn't want in your greywater system.
- **Contamination of surface water** - Greywater needs to percolate through the soil, or else it might flow untreated into creeks or other waterways. ***Solutions:*** Discharge greywater underground or into a mulch-filled basin to contain it and slow its movement toward surface waters or groundwater. Don't apply greywater to saturated soils. Apply greywater intermittently so that it soaks in and the soil can aerate between watering. In general, greywater that is

confined subsurface or within mulch basins at least 50' (15m) from a creek or lake is not a problem.

- **Contamination of groundwater or well** - It is all but impossible to contaminate groundwater with a greywater system, as the treatment capacity of the topsoil is so enormous. Over 90% of plant roots and beneficial microorganisms are in the top few feet of soil, above most septic leach fields. However, if you have a poorly sealed well, greywater running over the surface could potentially pour into it. ***Solution:*** use crude adaptations of septic tank codes, which is call for 50' of separation between location of greywater application and a well, same as a septic. Probably half of this is sufficient.

Arizona administrative code title 18: environmental quality chapter 9. Department of environmental quality water pollution control R18-9-711. Type 1 reclaimed water general permit for gray water

- A type 1 reclaimed water general permit allows private residential direct reuse of gray water for a flow of less than 400 gallons per day if all the following conditions are met:
  - Human contact with gray water and soil irrigated by gray water is avoided;
  - Gray water originating from the residence is used and contained within the property boundary for household gardening, composting, lawn watering, or landscape irrigation;
  - Surface application of gray water is not used for irrigation of food plants, except for citrus and nut trees;
  - The gray water does not contain hazardous chemicals derived from activities such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photo labs or similar hobbyist or home occupational activities;
  - The application of gray water is managed to minimize standing water on the surface;
  - The gray water system is constructed so that if blockage, plugging, or backup of the system occurs, gray water can be directed into the sewage collection system or onsite wastewater treatment and

disposal system, as applicable. The gray water system may include a means of filtration to reduce plugging and extend system lifetime;

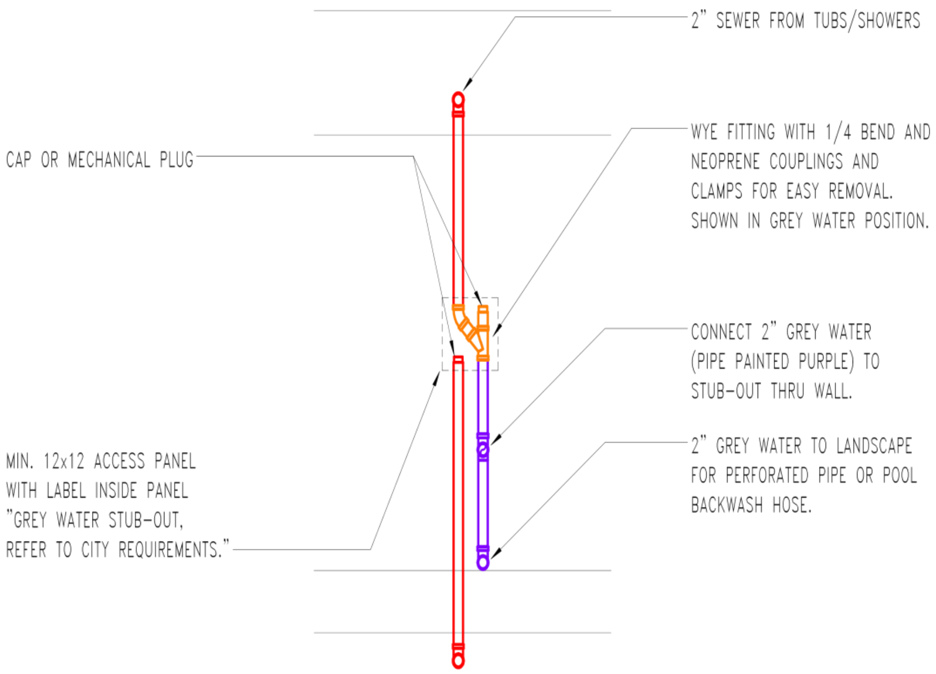
- Any gray water storage tank is covered to restrict access and to eliminate habitat for mosquitoes or other vectors;
- The gray water system is sited outside of a floodway;
- The gray water system is operated to maintain a minimum vertical separation distance of at least five feet from the point of gray water application to the top of the seasonally high groundwater table;
- For residences using an on-site wastewater treatment facility for black water treatment and disposal, the use of a gray water system does not change the design, capacity, Or reserve area requirements for the on-site wastewater treatment facility at the residence, and ensures that the facility can handle the combined black water and gray waterflow if the gray water system fails or is not fully used;
- Any pressure piping used in a gray water system that may be susceptible to cross connection with a potable water system clearly indicates that the piping does not carry potable water;
- Gray water applied by surface irrigation does not contain water used to wash diapers or similarly soiled or infectious garments unless the gray water is disinfected before irrigation; and
- Surface irrigation by gray water is only by flood or drip irrigation.

B. Prohibitions. The following are prohibited:

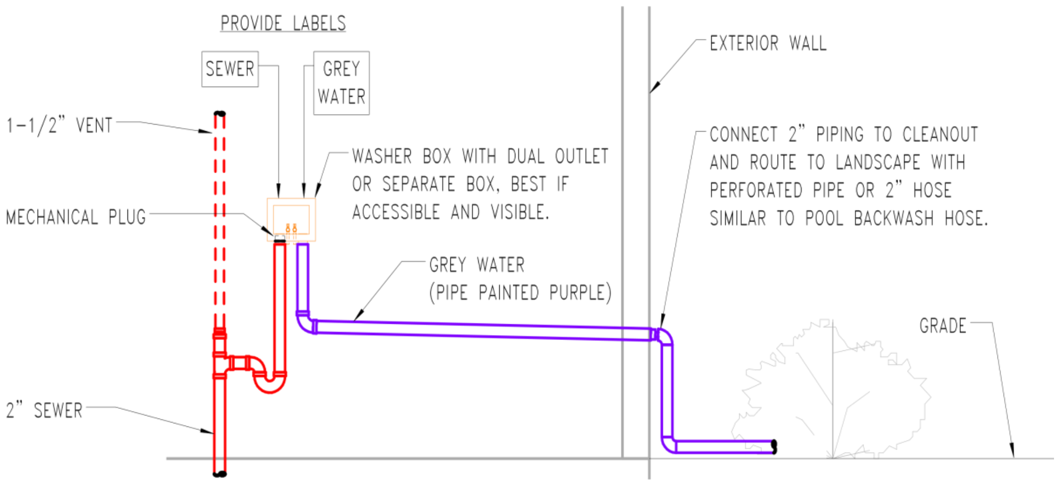
1. Gray water use for purposes other than irrigation, and
2. Spray irrigation.

C. Towns, cities, or counties may further limit the use of gray water described in this section by rule

WYE FITTING IN WALL - GREY WATER



WYE FITTING IN WALL - GREY WATER



WASHER WALL BOX - GREYWATER