Modelling urban water cycle:
An approach for future urban water supply alternatives
Case study Accra, Ghana

Master of Science Thesis
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Abstract

Many cities throughout the world are growing rapidly and are facing water shortage. WHO data on water supply coverage 2006 shows that only 86% of urban population have an access to improved drinking water [WHO/UNICEF, 2006]. The same problem is also faced by Kpeshie area (a sub metropolis in Accra, Ghana), where running water is not always available and alternative water sources is often inaccessible. Ghana Water Company Limited (GWCL) has a limited capacity to fulfil the water demand. The new approach which involves the application of water reuse that promotes the multiple use of water from higher to lower quality needs should be promoted. In this study, four strategies on urban water management will be evaluated based on urban water balance principle using Aquacycle software. Future scenarios of population growth and Climate Change prediction are also assessed to obtain the most reliable and suitable alternate solution.

By quantifying the water balance of the component urban water cycle, various alternatives of both water inputs into and water outputs from urban catchments will be taking into account in order to making more use of the total water resources available in urban area.

Based on the model simulation, proposed alternatives would result to less imported water need to be supplied to the area, a reduction of waste water discharge and less storm water run-off output. Combination of household rain water strategy and cluster wastewater treatment is likely become the most promising options since it contributes significantly to the reducing amount of imported water by 52% under present situation. Population growth has significant impact to the water balance performance while climate change prediction has less affect.

Under present situation, wastewater treatment strategy is likely will reduce the nutrients load to the Kpeshi lagoon by 27% and 45% for Nitrogen and Phosphorus respectively. Nevertheless, the application of this strategy would still sufficient to meet current nutrients demand for existing urban agriculture.

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g	gram
Kg	kilogram
K	potassium
m^3	cubic meter
m^2	square meter
mg/l	milligram per liter
N	nitrogen
P	phosphorus
g/p.d	gram per person per day
Kg/p.d	kilogram per person per day
L/p.d	liter per person per day

GWCL	Ghana Water Company Limited
GIS	Geographic Information System
HHRWT	Household Rain Water Tank
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
WWT	Waste Water Treatment

1 INTRODUCTION

1.1 General

The traditional way of urban water management is designed based on a one way path, where water is extracted from natural environment, stored in reservoirs, send it to treatment and returns it to the environment once being used. Some of this water is used to transport waste through sewers to treatment plants before finally discharge into receiving water body. Meanwhile, the rainfall contributes to the storm water that is collected by drainage system for disposal into receiving water body

As the increasing demand of water sources in urban areas, traditional way of urban water management practice is shifted to the integrated urban water management. This new approach promotes the sustainable practices of water use, by considering the varying characteristics of water usage, in terms of quality and quantity. It involves the application of water reuse, which promotes the multiple use of water from higher to lower quality needs.

In this study, some approach on urban water management will be evaluated based on urban water cycle principle. The principle of this approach is to minimize the consumption of water supply by recycling the storm water and waste water, and consequently will reduce the discharged water to be treated. By quantifying the water balance of the component urban water cycle, various alternatives of both water inputs into and water outputs from urban catchments will be taking into account in order to making more use of the total water resources available in urban area.

Urban water cycle modelling is an instrument for investigating the use of locally generated storm water and waste water as a substitute for imported water alongside water use efficiency. Aquacycle is one of instruments program of urban water cycle model which performs a daily water balance with various water recycling options, which focus mainly to assess their effect on the amount of water used, storm water runoff and wastewater discharge. Aquacycle ‘stores’ storm water and waste water and utilize them as supply sources, according to the user’s specifications.

This research attempts to simulate the water balance, imported water, wastewater discharge and stormwater production of different strategies within Kpeshie area, Accra, Ghana, by using Aquacycle application. Since there is a water shortage within the study area at the present situation, finding alternatives for water sources would be a key factor to cope with this problem. Moreover, future scenarios of population growth and the effect of climate change are also taking into account to fully understand the performance of proposed strategies application.

1.2 Background

Rapid urbanization has led to very high population densities and thus requires more consumption of water and so the provision of urban water resources. The principal changes caused by urbanisation include the decreasing water quality which is caused by the increased demands on water supply, waste water management and drainage services. In area where freshwater is already restricted available and difficult to access, it requires other alternatives except from existing water supply company.

In addition to that, one of the major concerns of future water demand is whether there will be sufficient fresh water for the needs of agricultural and non agricultural users. Agriculture already accounts for about 70 % of the freshwater withdrawal and is usually seen as the main factor behind the increasing global scarcity of freshwater (*Bruinsma, 2003)*. Thus, freshwater as fundamental needs for human survival and socio economic development must be wisely managed. Reducing the needs for fresh water, through reuse and recycling would be one of the options.

Kpeshie is one of six sub metropolis that formed Accra Metropolitan Area which is the focus of this study. This area is considerably an urban area where land use is mainly intended for settlement with several parts for urban agriculture. Currently, the water management in the study area is very important as running water is not always available. Often, people have to fetch their water either waiting for water tank to come to their house or going to the nearest filling station. In many cases, these two alternatives are also run out of water and thus people have to go even further to find another water source. Due to the water shortage, inadequate infrastructure, improper maintenance and also population growth, new approach on water provision through improve of existing sources of water with more sustainable alternatives could be a promising alternative.

Water recycling helps to get the most from limited water supplies, by serving as a dependable water source. It also has various benefit as it gives an opportunity to fully reuse the resource potential in the wastewater, as it contains useful substances for some application (such as nutrients for agriculture). Thus, it leads to reduce water consumption and water treatment needs which means cost saving. And finally by reusing waste water more freshwater can be allocated for uses that require higher quality.

A comprehensive water balance system within the study area is needed to understand the urban water cycle, as means to evaluate the performance of each strategy and to estimate the least amount of imported water needed to sustain a sustainable life in the study area. In this research, the performance of water balance within present situation and the future scenarios of population growth and the effect of climate change are examined. The idea of using scenarios is to help people thinking about how things work therefore they can deal better with uncertainties in the future.

Assuming 4.4% population growth rate of present situation will remain the same in the future, the population of Kpeshie will reach to almost 1.5 million by the year 2030. With this

population growth projection it brings along increase in water demand. If the current water resources are not properly utilized, the water supplies system will likely collapse.

1.3 Problem Description

It is clear that water balance principle is the main key of understanding the urban water cycle. By quantifying the water balance for "what if scenarios" under different proposed strategies will help us to estimate the amount of potential water sources available in Kpeshie, and how to deal with uncertainties related to water shortage problem in the future.

In this research, the proposed alternatives strategies have been applied in some part of the world; however the applicability of them depends on the local situation. Community survey and cost and benefit analysis are needed to identify the practicability of the proposed strategies which is beyond the scope of this study.

1.4 Study Objectives

The objective of this study is to analyze the water balance system of each strategy of water resources alternatives, in order to obtain the proper approach for transforming the study area (Kpeshie) into an independent system, with the least amount of water input required from Ghana Water Company Limited (GWCL).

The main objectives of this study can be presented as following:

- To identify the alternative water sources throughout the water cycle and its quantity that may be available for the possible end use demands, such as rainwater, storm water and treated waste water
- To simulate alternate water management scenarios on the water cycle for existing situation and future population growth and climate change scenario
- To investigate the relationship between the spatial pattern of demand, supply and storage capacity on the reliability of a range of alternative water sources
- To examine the material flows (nutrients) based on the application of water balance model

This study aims to find answers to the following research questions:

a. Do scenarios of water management reduce water demand and do they decrease the quantity of storm water and waste water that is discharged?
b. If so, how much is the decrease in the quantity of drinking water delivered to the study area?
c. What are the consequences of water management scenarios to the material (nutrient) flows?
d. What is the affect of population growth and climate change prediction to the water balance system?

1.5 General Research Methodology

The study of water balance in the study area is conducted by means of modelling using Aquacycle and the output of this model is used for mathematically comprehensive calculation of nutrient flow analysis. Data input for the model is obtained from desk study literature, field visits to the study area, key institutions (Ghana Water Company Limited, Ghana Statistical Services, International Water Management Institute, Water Resources Institute and Hydrological Department) and community surveys.

Aquacycle is a daily urban water balance model which has been developed to simulate the total urban water cycle and provide a tool for examining the use of locally generated stormwater and wastewater as substitutes for imported water. The modelling steps consist of (1) system characteristic, (2) data input (3) defining strategies (4) model simulation including sensitivity of future changes and (5) nutrient flow analysis.

Finally, the applicability of the proposed system is evaluated based on the water balance result from the model output. Since stakeholder analysis has not been conducted, only least consideration of social and economic condition during field visit is taking into account for the applicability of the proposed strategy. Furthermore, this study does not provide the prediction of water quality.

1.6 Outline of Report

This study report is structured as following:
Chapter 2, *Literature Review*, contains the concept of urban water cycle and basic principle of water recycles, including the alternatives strategies available within this principle. The consideration of applicability of strategies is also described herein.

Chapter 3, *Methods*, shows the method used for the model simulation, the data input, modelling site characterization including spatial description and water balance calculation. In this chapter, the nutrient flow and its calculation are discussed. In addition, basic principle of proposed strategies will also introduce.

Chapter 4, *Description of the study area*, describes the condition and situation of the study area, including the overview of water and waste water management, and water source related problems. The detail description of each cluster within the study area, satellite image and map is also presented.

Chapter 5, *Strategies and Scenarios*, includes the sketch model, the basic detail parameter and value of data input for each proposed strategies and scenarios

Chapter 6, *Result*, present the model result of proposed strategies under present and future scenarios. Graphs, tables of water balance performance for each strategy is shown in this chapter to illustrate the feature of the model simulation.

Chapter 7, *Discussion*, contains some discussion about the promising strategy that considered as the option to cope with water supply problem in the study area. The rationale of each strategy performance is also discussed, following the basic of Aquacycle concept.

Chapter 8, *Conclusion and Recommendations*, includes the conclusion based on this study and some recommendations for future research. As the main objective of this study is to analyze the water balance performance of possible alternative strategies of water resources within the study area, the applicability aspects should be further studied.

2 THEORETICAL FRAMEWORK

By being active in envisage its vision toward sustainable integrated urban water management for city of the future**,** SWITCH aims to bring about a change in urban water management in more coherent and integrated approach. The SWITCH Paradigm shift in water management is from conventional to integrated way, where all aspect of urban water system is considered.

This chapter describes the theories of urban water cycle and how it leads to the principles of integrated urban water management. This will give alternatives to areas where limited water source is in place, so that they will be able to self sustains their water demand.

2.1 Urban Water Management

2.1.1 Historical Background

Many cities throughout the world are growing rapidly and are facing water shortage. Urbanization has result to the increasing of water demand whereas not every country able to provide the water supply for their municipalities. WHO data on water supply coverage 2006 shows that only 86% of urban population have an access to improved drinking water [*WHO/UNICEF*, 2006].

The development of urban area resulted in the change of physical properties of land surface, due to the increasing paved surface area. And it has brought a change to hydrological cycle, such as pattern of surface water, lost functions of rainwater storage and infiltration, and accelerated transport of pollutant from urban areas. As a consequences, an essential approach with respect to centralized waste water system also take place, whereas the detention, retention and recharge approach during 1970 has shifted to the source of pollution control during 1980s and 1990s [*Niemczynowicz*, 1999]. At that time, water authorities in many countries found a positive correlation between poor sanitation and high mortality, and prompt to manage water supply, storm water drainage and wastewater disposal separately.

Since then, a variety of storm water handling and treatment methods have been developed, whereas it is understood that storm water should be handled locally [*Anderson*, 1996; *Mitchell, et al.*, 2003; *Niemczynowicz*, 1999; *Zaizen, et al.*, 2000]. Evaluation to conventional water supply and disposal methods, such as the reuse of storm water and waste water has been taken. These alternatives appear to offer many benefits. For example, less water is imported into towns and cities, and less storm water and wastewater are discharged. Thus, storm water and wastewater are being re-evaluated as resources to be utilized, rather than as waste products for disposal.

The wisdom of importing large volumes of high quality water into urban areas, and exporting even larger quantities of storm water and wastewater out of them, is now being reviewed. Consequently, approach to urban water management should be done in a more holistic. This new approaches and shifting paradigm for urban water management

emphasis on demand and supply side management, utilisation of non traditional water resources and the concept of fit-for-purposes and decentralization system [*Mitchell*, 2004].

Table 2. 1: Characteristics of 'old' and 'emerging' paradigms of urban water systems
(Adjusted from Pinkham 1999)

The Old Paradigm	The Emerging Paradigm
Storm water is a nuisance. Convey storm water away from urban area as rapidly as possible.	*Storm water is a resource.* Harvest storm water as a water supply, and infiltrate or retain it to support aquifers, water ways and vegetation.
Demand is a matter of quantity. Amount of water required or produced by different end-users is the only parameter relevant to infrastructure choices. Treat all supply side water to potable quality and collect all waste water for treatment.	*Demand is multifaceted.* Infrastructure choice should match the varying characteristics of water required or produced for different end-users in terms of quantity, quality, level of reliability, etc.
One use (throughput). Water follows one-way path from supply, to a single use, to treatment and disposal to the environment.	*Reuse and reclamation.* Water can be used multiple times, by cascading from higher to lower quality needs, and reclamation treatment for return to the supply side of infrastructure.
Bigger/centralized is better for collection system and treatment plants.	Small/decentralized is possible, often desirable for collection system and treatment plants.

The shifting paradigm has changed the 'old' one, from water disposal and treatment to conservation, recycling and resources [*Vlachos and Braga*, 2001]. Through decentralized system, water supply, treatment, sanitation, and runoff management systems would be highly integrated. This principle deem to collect, treat and reuse or dispose of wastewater at or near its point of generation and takes advantage of local hydrologic resources (e.g. urban rainwater/storm water harvesting and aquifer storage recovery systems) and uses all manner of wastewater treatment and reclamation/reuse systems. A combination of end-use efficiency, system efficiency, storm water harvesting, storage innovations, and reuse strategies would reduce water demand to levels below current demand. And problems raised by centralization of wastewater services (such as high investment and maintenance cost, overbuilt and resulting debt burdens for citizens, and affect the hydrology of water shed) is resolved by this new system [*Pinkham*, 1999].

2.1.2 Integrated Urban Water Management

As the increasing demand of water sources in urban areas, the integrated urban water management promotes the consideration of water supply, storm water and waste water as components of total urban water cycle. By quantifying the water balance of the component urban water cycle, various alternatives of both water inputs into and water outputs from

urban catchments will be taking into account in order to making more use of the total water resources available in urban area [*Mitchell, et al.*, 2001]. Within this new paradigm, decentralized approach on sewage treatment was introduced, where wastewater collected from individual or/and clusters homes are treated at or near the point of generation, and maximize its potential reuse opportunities [*Maher and Lustig*, 2003].

The principle of these components is to minimize the consumption of water supply by recycling the storm water and waste water, and consequently will reduce the discharged water to be treated. Some ways that can be implemented are through retention of roof rainwater, on site treatment of grey water and black water (toilet), storm water detention.

Harvesting rainwater and reuse waste water would not only protect the valuable natural water resources, take the pressure off some ground and river water extraction, but also reduce the energy used for treating and conveying water. Water recycling measures trigger a chain reaction of savings, as when using water efficiently means less amount water discharges and less energy and chemicals are required for water and sewage treatment and distribution [*Cheng*, 2002].

The ultimate objective of integrated water management is to achieve the sustainable, co-ordinated management of water resources within a region, with the objectives of controlling and conserving water, minimising adverse affects, and achieving specified water management and social objectives [*Marsalek, et al.*, 2001].

The adoption of Integrated Urban Water Management is introduced as an approach to the urban water cycle. This system includes the integration of storm water, groundwater and surface water use, re-use of treated wastewater, and recycling. It emphasizes the developments of technologies that reduces the use of treated water for sanitation and take advantage of rainwater as a resource that will lead to a fuller recycling and reuse of urban water [*UNESCO*, 2001].

Since urban water services includes the drinking water supply, treatment, reuse and disposal of water and storm water management, the interaction of urban water-cycle system and their boundaries (physical, temporal and spatial) need to be well defined [*Hardy, et al.*, 2005] .

2.2 Urban Water Cycle

As mentioned earlier, conventional urban water management is likely to use extracted water from natural environment stored in reservoirs and then treating it before and after use and returns it to the environment. Some of this water used to transport waste through sewers to treatment plants before finally discharge into receiving water body. Meanwhile, the rainfall contributes to the storm water that is collected by drainage system for disposal into receiving water body. Within this conventional way, used water and storm water were conveyed to a single treatment plant before discharging the treated effluent to a receiving stream.

Total water cycle integration is defined as the collective consideration of the water supply, storm water, waste water and ground water components of urban water service provision [*Mitchell*, 2006]. Components of a total water cycle within urban water management include: (a) re-use of treated waste water, (b) integrated storm water, groundwater, water supply and waste water management, and (c) water conservation approach through reduced water demand and recycling [*Marsalek, et al.*, 2001].

As the cities are growing, supplied food also increases. In order to meet these needs, a huge amount of water and nutrients are required. Following this, many environmental problems related to pesticides and fertilizer application; increased volume of water for irrigation; and run off from agriculture would not be avoided. Alternatively, waste water which contains of nutrients should be used for irrigation purpose. Data from FAO on 2002 shows that 70 % of total withdrawals worldwide fresh water is allocated for agriculture. And for this reason, urban water management shall deliver technology that makes re-use of urban water in agriculture possible [*Niemczynowicz*, 1999]. There are many advantages in using urban waste water for agriculture, some of them are:

1. Water conservation
2. Recycling of nutrients, thus reducing the cost for chemical fertilizer
3. Provision of a reliable water supply to farmers, particularly in low income dry areas
4. Prevention of pollution of canal and other surface water

However, these advantages have to be weighed against the disadvantages of using waste water for irrigation, which are mainly related to the presence of pathogenic micro organism. This health risk can be greatly reduced by treating the waste water before using it. However, many of existing technologies are considerably expensive for low income developing countries. A further disadvantage is that many of the conventional treatment methods remove the nutrient in waste water, thus reducing the economic benefits of the users (*IWMI*, 2002).

Another option is to capture rain water on the roofs and considered it as a valuable resource which can be a counter-measure against a shortage of water supply and runoff control. When it comes to water shortage where the demands exceeds the capacity of the high quality sources, and additional sources are not available or only available at high cost, the option that needs to be considered is utilization of lower quality to be substituted to serve for non potable purposes [*Sala and Serra*, 2004].

Storm water shall be considered as resources that can be reuse separately or together with grey water for indoor/outdoor domestic use. Nowadays a perceptive that rain water is important resources to recover the hydrological cycle for the purpose of sustainable development has been increasing [*Zaizen, et al.*, 2000]. Related to this, when urban sewerage and waste water are increased, it needs to be integrated with water supply system, as water recycle for non potable reuse might be an option.

2.3 Cyclic Approach in Wastewater Management

The cyclic approach in the wastewater management creates a paradigm shift from effluent disposal (wastewater is a problem) to water reuse (wastewater is a resource). It is important that the term reuse which connotes a resource be used in place of disposal which connotes a problem. The applications of this approach try to fully reuse the resource potential in the wastewater. It also suggests that rather than just manage the end effect, wastewater system should be integrated into natural processes, i.e. nutrient and water cycle. Conservation of resources and energy is the main intention of this approach.

The main resource contains in the wastewater is nutrients, which is also the interest of this study. The destination for nutrients in the wastewater is agriculture. This creates a close connection between wastewater management in the urban areas with the agriculture. The nutrients produced by wastewater management can be used for maintaining and improving the fertile top soil which in turn benefits the agriculture. Considering also the facts that the production of N fertilizers requires a lot of energy and the resources for the production P, K, and S fertilizers are limited, therefore wastewater becomes the most suitable alternative nutrient source for the agriculture.

In order to be able to fully reuse the resources in the wastewater and also to achieve a high hygienic standard, it is important to separate different wastewater streams. Furthermore, it is also necessary to minimise dilution so water can be saved and the waste can be handled easier. Because of the dilute characteristic of the wastewater produced in the conventional system, reuse of material and directing the wastewater streams to the advantageous place is limited.

2.3.1 Nutrients and Agriculture

Nutrient and Agriculture has a close relation, since agriculture has a responsibility to supply nutrients in the form of food for humans. Nevertheless, agriculture needs nutrient supply from the soil in order to be able to produce food. If the amount of nutrient in the soil is not enough, an additional supply of nutrient in the form of fertilizer is needed. On the other hand, nutrients also present in the wastewater streams produced by the communities. This means recycling of the nutrients containing in the wastewater is a potential source for agriculture.

2.3.2 Nutrients and Wastewater

Wastewater is a natural resource since it contains nutrients from the human excreta. As mentioned earlier, the conventional wastewater management with its linear approach fails to make use of these nutrients. To overcome these limitations, a cyclic approach of wastewater management is introduced. This approach is basically based on the minimization of wastewater dilution and source separation of wastewater streams. However, there is a fundamental step in the separation of wastewater streams that is by identifying the different characteristics of the main components of household wastewater.

2.4 Wastewater Characteristics

As mentioned before, the fundamental step in the separation of wastewater stream is the characterization of the different wastewater streams. Here, the different wastewater refers to the wastewater produced by households, which is the focus of this study.

Table 2. 2: Wastewater from Households [Otterpohl et al., 1999]

Wastewater stream	Description
Blackwater	Faeces and urine with or without flushing water (wastewater from toilet and urinal)
Yellowwater	Urine with or without flushing water
Brownwater	Blackwater without urine or yellow water
Greywater	Household wastewater from kitchen, shower, washbasin, washing machine, etc (without faeces and urine)

The main components of the household wastewater are urine, faeces, and grey water. Urine and faeces are known as black water. Description about black water and grey water will describe further.

Basically, waste water may be disposed of in three ways:

1. Centralised, where sewage are channelled through sewer into a sewerage system and treated in a single large sewage treatment plant where it can be converted into a resource for selective reuse such as outdoor household garden watering, toilet flushing and irrigation crops. The treated effluent may also be discharged to rivers or oceans.
2. De-centralized through pipes into a local community small sewage treatment plant for local community reuse. A number of these local systems make up de-centralised sewage treatment.
3. On-site single domestic waste water management where the sewage or components such as grey water must be partially of fully treated for utilisation or reuse within the household scale.

2.4.1 Black Water

"Black water" is termed used for waste water generated from the toilet which is heavily and directly contaminated with human faeces and/or urine. According to research conducted by UNEP, black water contents of solid and significant amount of Nutrients. In average, each person excretes 4 Kg N and 0.4 Kg P in urine, and 0.55 kg N and 0.18 Kg P in faeces per year (*UNEP*, n.d.)

2.4.2 Grey Water

Greywater is waste water which does not arise from a toilet, and includes waste water from shower, laundry and kitchen. Volumetrically it has the largest fraction of the total wastewater flow, but has only a low nutrient content (*Ericksson*, 2002). The characteristics of grey water depend on some factors, e.g. the quality of water supply, type of detergents

used, and the activities in the households. It is often contaminated with human faeces; dirt and other material but in less amount than black water and are therefore less infectious than black water. It contains mostly of detergent, soap, dirt, and may be also some materials of the food residues.

Greywater is a great resource for high quality reuse of water. This water can be put to particularly good use in agricultural irrigation (especially in water scarce regions) but may also be used for groundwater recharge or discharged into surrounding watercourses. In the households, greywater can be reused for low quality water needs such as gardening or toilet flushing.

The nutrients in greywater are mainly inorganic and the amounts depend on the amount used in the households. Phosphorus and potassium are used in the detergents and their usage is reflected in the amounts of these elements in the greywater.

2.5 Climate Change and Water Recycling

Nowadays it is generally accepted that climate change is taking place. There are large of uncertainties as to when and where climate change will impact on agriculture. Study shows that some of the severest impacts seem likely to be in sub Saharan Africa.

Climate change will have a range of positive and negative impacts on agriculture. The greatest impacts could come from increased frequency of intensity of extreme events (*IWMI*, 2002). The most serious form is drought, when rainfall drop substantially below the long term mean in crop development. Such problems can be countered by investment in irrigation, but this option not always open to low-income countries.

It is understood that the key role of recycling is to reduce pressure on drinking water supplies by replacing it with recycled water where appropriate. The production of this recycled water is considerably almost independent of climate. Using this water can reduce reliance on highly variable rainfall and improve the security and reliability of water supplies in the face of future droughts, population growth and the potential impacts of climate change.

3 GENERAL DESCRIPTION OF STUDY AREA

3.1 Introduction

Ghana is a tropical country with an area of 238,000 km^2 and is situated on the West Coast of Africa (fig 3.1). It is bounded to the north by Burkina-Faso, the east by the Republic of Togo, the west by Côte d'Ivoire and to the south by the Gulf of Guinea. The country is divided into 10 administrative regions, including greater Accra. Accra Metropolitan is located on the East coast of Ghana; one of the 5 districts that make the greater Accra region.

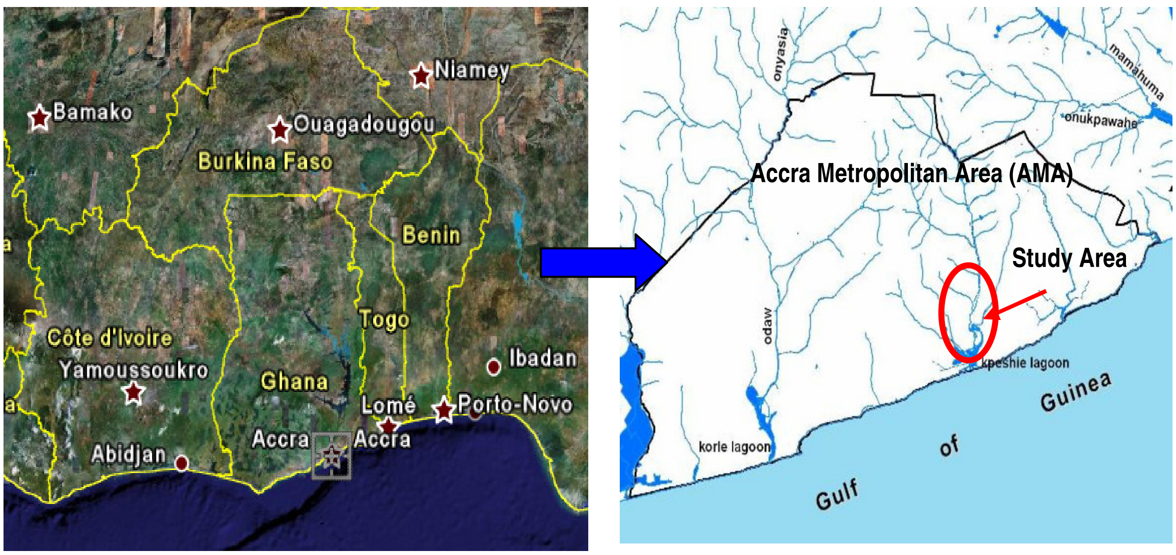


Figure 3. 1: Map of Accra-Ghana

The focus of this study will be in Kpeshie area, a catchment in the eastern part of Accra, which covers an area of 110 km2. This area is bounded on the east by the Military .Academy at Teshie and on the north by a line south of Madina and Ajirignano. It covers the eastern part of Accra, Ridge, Labadi and Burma camp areas. The area is part of Kpeshie basin which bordered on the east by Songo basin, Osu Klottey basin on the west, and Oduw and Sakumo basin on the north west and north East respectively. The Streams in the catchment generally flow from north to south, emptying directly into the principal outlet to the sea at Kpeshie Lagoon.

Based on 2000 census, Kpeshie sub metropolis population is up to 387.013. For the whole greater Accra, the population growth rate reach to 4.4 % with an average household size 4.6 (*Ghana Statistical Service*, 2000).

Kpeshie area lies in the coastal savannah of Ghana. The average annual rainfall is about 810 mm taking place mainly during two rainy seasons from May to mid July and from mid

August to October. Temperature variation throughout they year is minimal, with an annual average about 26.8 ^{0}C (*Ghana Geological Survey and Federal institute for Geosciences and Natural Resources*, 2006).

Savannah type vegetation mainly covers the study area. Grassland, clusters of shrub and scattered of trees easily be seen in the most part of the Kpeshie area. In the Kpeshie lagoon and Africa Lagoon, two lagoons which is the final point of wastewater and stormwater in Kpeshie, mangrove and dune vegetation are the main plants found. Irrigated vegetables and less irrigated cereal farm (cassava, maize, okro, yam are mostly dominated the agriculture area.

Land use of study area is mainly for settlement and farming land. However, due to urbanization and infrastructures development, the agriculturally used space in the urban areas mostly reduces in the future. This has been taking place along the Korjorn River and downstream Burma camp. Loss or removal of vegetation cover, hazard of drying condition and deterioration of soils are mainly caused of the land degradation. The La agriculture area has been converted into settlement and offices. And consequently, it has been modifying the catchment water system, including intermittent stream and Kpeshie lagoon.

From North to south of Kpeshie the topography decreases as the inlet Kpeshie lagoon is on the southern part of the area study. Burma Camp as the highest point of Kpeshie area is located 50 meter above the sea level. Most of agriculture land along the stream is in low land area of 20 – 10 meter above sea level. This area also considerably a flood prone area where drainage systems are small, become receptacle for solid and liquid disposal, or not even existed, and thus during storm events on rainy season giving rise to local flooding.

The Kpeshie basin mainly formed of Togo series and Voltalian system (Burma camp area), Dahomeyen system which covers the flat lying terrain to the south of Burma camp, and Accraian Series forms the Lagoon and river delta. Several sandy platforms are found in lagoon inlets and river deltas. They consist of unconsolidated sands and their surface is less than 5 meters above sea level (*Ghana Geological Survey) and Federal institute for Geosciences and Natural Resources*, 2006).

3.2 Overview of Urban Water Management in Study Area

3.2.1 Water Supply

Ghana Water Company Limited (GWCL) has been responsible for the provision of water supply for all purposes in Ghana. In Accra metropolitan area, the water is supplied from two sources, the Weija Waterworks and the Kpong Waterworks. The Weija Waterworks on the Densu River of the Weija dam is located 15 km west of Accra and The Kpong (old and new) waterworks on the Volta River downstream of the Akosombo Dam is located 54 km north of Tema (*IWMI*, 2007). Water supply for Kpeshie area is distributed from the Kpong new waterworks. Total water production from new Kpong is 164 000 m3/day with maximal (design) production up to 180.000 m^3/day (*GWCL*, 2007).

Since Accra's urban population is increasing at a fast rate, it has been resulted to the over use of the existing water supply system. And due to lack of water pipe network connections or suffer from dry pipes, some areas do not have connection to tap water. At the moment, the total water coverage of the urban water supply systems in Accra is 60 % of the total water demand (*IWMI*, 2007)**.** The other 40% of people not served, the resellers are all that are available. Water trucks make up a large part of the water distribution network. Based on the study conducted by London Economic on water consumption assessment in Accra, the average per capita consumption in Accra is 55 L/capita/day (*London Economics*, 1999). For overall water distribution system in Accra, the average leakage rate is up to 55 %, which consist of 25 % leakage of pipe distribution system and 30 % loss of commercial and illegal connection (*AVRL-GWCL*, 2007).

Apart from water provided by GWCL, there are many sources of clean water in Accra, such as bore wells and sachet/plastic bottle for drinking. The last alternative is become common and widespread around the city, which are sold by street vendor or shops. However, during dry season the alternatives water sources (wells) become dry.

3.2.2 Sanitation and Wastewater Treatment

In general drains and gutters are the most common form of sewerage, but some areas use separated system of black and grey water. The existing on site sanitation facilities for black water disposal in Accra are mainly bucket, pit latrines, open defecation, and water closet. In the study area, mainly Burma camp, it has combined sewerage system which channel it to the sewage treatment plant in Labadi Villas. Nevertheless, this treatment plant is no longer working.

In the separate system, the black water goes to septic tank as the conventional on site treatment. Since treatment facilities are not available, sludge from septic tank is collected in sanitary tanker and is emptied to dump site once they get full. It could be either released untreated to receiving water bodies or nearby drains or open spaces. The effluent from septic tank infiltrates or soaks to open drain. During the field visit, it is noticed that the sludge from septic tank in Burma camp was discharged in the open bare land close to old waste treatment plant.

Grey water is disposed off into bare ground, soak away pits, whilst others direct into nearby ditches or open storm water drains, which sometimes also receive overflows from septic tank. This sewage flows through open storm water drainage network, from where open space urban farmers use it for irrigating their crops. The sewage finally ends up in the river/sea without treatment. Within the study area, grey water from Burma camp is discharged to the small river within the camp, before finally end up in Kpeshie lagoon.

Based on Accra sewerage improvement feasibility study, it is recommended to set up combined treatment facilities that serve one catchment area. For this purpose, Accra has been divided into four areas for sewage treatment which consists of central area (served by the existing AWP), eastern area (Burma Camp), western area (Densu Delta) and northern area (Legon)). The new proposed treatment plant in Burma camp will be managed by AMA (which used to be managed by Military Defence) (*GWCL*, 2004).

3.2.3 Water for Agriculture

In general, there are two categories of urban agriculture practices in Accra, house hold gardening and open-space farm. The first one takes place on the plots around houses where farmers mostly plant vegetables. They use pipe-borne water and grey water (water from bathrooms and kitchens) for irrigation. Open-space farming take place on piece of land, some distance away from human dwellings which preferably along streams and drains, where farmers could access water easily for irrigating their land, except from rainfall and shallow wells (*IWMI, RUAF*, 2007).

With the limited supplied water to urban area and ground water is not accessible, the source of water for irrigation is mainly from waste water or sewage from cities drains. This source of irrigation is very necessary because of also the problems of insufficient rain and undetermined rain frequency among other factors. Some farmers take water from the stream of broken sewer lines (farmers around la villas) and use manual water fetching by water cans, some block the stream in order to impound the stream, pump it and channel it to their farm by using hose (farmers around the sewage lagoon on the Burma camp land). This practice however happened during dry season, when farmers use wastewater directly from drains and broken sewers without any dilution (*Keraita and Drechsel*, 2004).

In La farming area, along the small river some scattered farming land are existed. Within this area, farmers use pipe-borne water for irrigation and dugout the ground where they can store the water and use it later when the pipe water is not running. When they run out of water, farmers will use water from the river by pumping it and channel it to their land by using hose. For this purpose, farmers collected money to buy pump and hose and share it between them.

Since urban agriculture plays an important role in generating community economic growth in Accra, consideration on safe water use for irrigation has not been taking into account. Thus, either polluted or not, urban agriculture would take an advantage of the nearest water source available, during dry-season or annual irrigated farming.

Related to fertilizer, some farmers apply it and some are not. Those who plants local/traditional crops such as cassava, plantain, maize and okro prefer to apply manure fertilizer instead of artificial ones. But the application of this fertilizer is also not in a regular basis, since farmers would apply it based on the leaves colour. If the leaves colour turn to yellow that means farmers need to add fertilizer. For vegetables-farming, the use of fertilizer is on regular basis, as it has shorter harvesting time compare to traditional crops. However, none of them conscious about the nutrient contents in the waste water they have been using. And when it comes to the preference of having adequate water in place or enough fertilizer, at the end all of them prefer to have water. Nevertheless, they are also concern about the needs of fertilizer especially for vegetables crops.

4 METHODOLOGY

This chapter consists of methods and technique that are used in the research in order to answer the problem statement and the sub questions stated in the research questions. Study literature in Delft will be described as well as one month field visit to Accra, Ghana.

4.1 Software for Urban Water Cycle

Aquacycle is simulation program on urban water cycle. The model system is conceptualized as shown in fig. 4.1. Aquacycle operates on a daily time step. This model account for cycle, which starts when water entering as precipitation or imported/supply water in order to meet indoor or outdoor water requirements. It then exits in the form of evapotranspiration, stormwater and wastewater.

Two system operate within Aquacycle are the rainfall-drainage system and the supply-waste water system. The inputs into rainfall-drainage system are not only derived from rainfall but also include contribution from piped water system through outdoor water use. In order to perform urban water balance, the rainfall-stormwater runoff system and supply-wastewater system need to be integrated into a single model framework, as part of urban water cycle system as being simulated by Aquacycle.

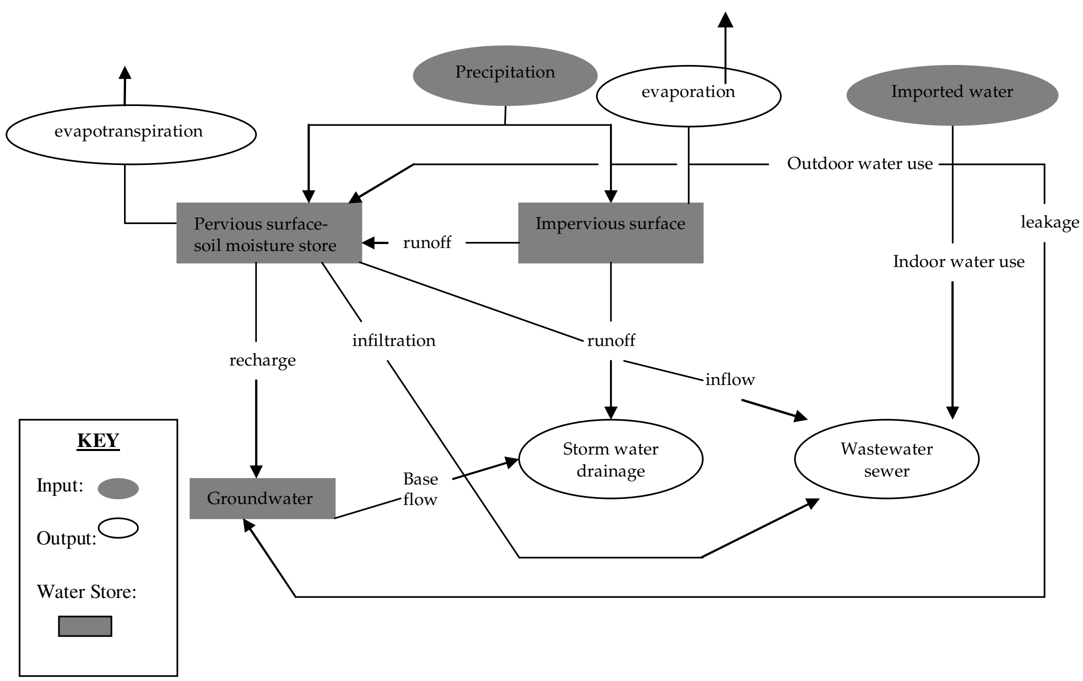


Figure 4. 1: Urban Water System as represented by Aquacycle:

4.2 Water Balance

The water balance analysis within the system is defined as the water inflow and water outflow of a system. The system is defined by the characteristic and size of the study area that will be counted in the model calculation. This water balances look at a closed hydrological system within the study area boundaries, which is further separated into clusters system. The equation of an urban water balance within each cluster is described as follows:

$$\text{Inputs} = \text{Outputs}$$

$$P+I + SI+WI = ET +D+ SR$$

With P: Precipitation, I: Imported water supply, SI: Stormwater Inflows, WI: Wastewater Inflow, ET: Evapotranspiration, D: Drainage, SR: Stormwater Runoff. All flows are expressed in cubic meters per year [m3/yr].

4.3 Secondary Data Collection

Literature review is including collecting baseline data related to application of water balance in different aspects of urban management and area study condition. This will generate background information, provide a basis understanding to work within boundaries, modelling site characteristic of study area (as shown in fig 4.2) and gather input data needed for structure the model. Some of generic data including indoor water usage profile, daily precipitation and potential evaporation series, site description (average block size, garden area, roof area, paved area, cluster area, open space) and nutrients concentration and loads are collected from literature review and were reviewed during the field visit.

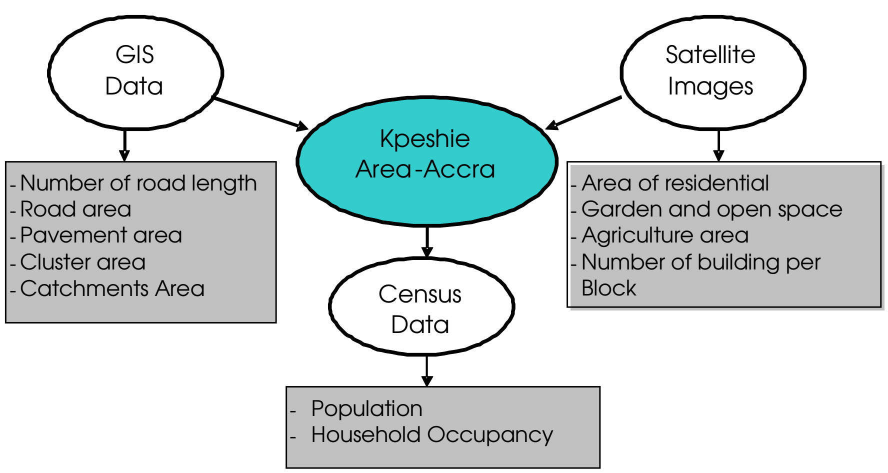


Figure 4. 2: Modeling Site Characteristics of Study Area

4.4 Field Visit

One month field visit was conducted on January-February 2008. This visit gave in-depth understanding about water sources problems and the condition of communities living within the study area. Due to detailed input data needed for running the model, the generated data and discussion with experts from Ghana Statistical Services, Hydrological Department, Burma Camp 49 Engineering, IWMI and other institution in Accra have helped to fill the data gaps which can not be obtained from literature review.

However, the main data used for this report comes from secondary data, either from research report, Institution data base, and also personal communications. General survey related to wastewater use for agriculture was also conducted, by interviewing 10 farmers in the area study and field visit to the agriculture site. Moreover, rough estimation of unit block characteristics (size, water usage, etc) that had been estimated based on study literature was reviewed.

4.5 Spatial Scale

To model a various strategies, three spatial scales are used within Aquacycle as shown in fig 4.3. These are unit block, cluster and catchment. In this study, unit block represents a single household, where water management operations can be managed. Cluster is a group of unit blocks that forms a local neighbourhood. It can contain a number of land uses such as settlement and urban agriculture. The cluster can be used within the model to represent the spatial scale at which community water services are managed. Catchment is made up of a number of clusters.

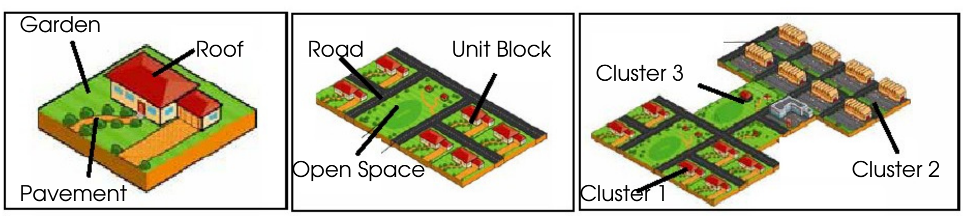


Figure 4. 3: Spatial Definitions in Aquacycle

4.6 Clusters Description

Since the basis of this study was to investigate comprehensive alternatives of water sources to achieve an independent waster system in study area, the boundary of the system in Kpeshie is limited to area where most of inhabitant is concentrated, including scattered urban agriculture/open-farming. In this research, the unit block is referred only to housing.

Based on satellite image, GIS map and field visit, the area is divided into four clusters (fig 4.4). This clusters delineation is due differentiation of contours, drains outlets to the

nearest stream and land use (settlement and urban agriculture). The detail description of each cluster is explained below:

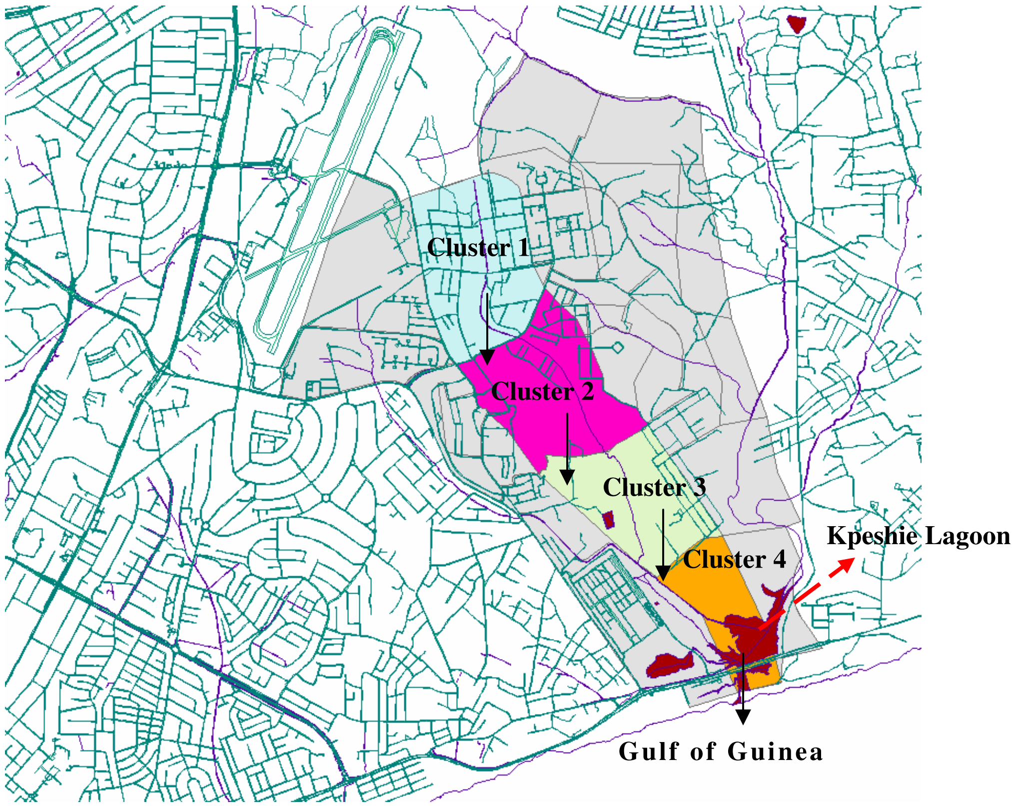


Figure 4. 4: Arrangement of four clusters

4.6.1 Cluster 1 and 2

Cluster one and two are covering some part of Burma camp area which mainly consists of settlements, offices and open bare land. The size of cluster one and two is about 140 ha and 130 ha respectively. With total population around 5600 persons (cluster 1) and 2300 persons (cluster 2), these two clusters are the most populous area within Burma camp. Housing condition is a mixture of old and new buildings, where the entire occupants are the military family and relatives. The housing is arranged based on clusters following regimen military section.

The existing wastewater system combines both black and grey water and channels it from cluster one to cluster two before finally discharge into the sewage pond in cluster 3 and ends up in the Kpeshie lagoon (cluster 4). In both clusters, open drains serves as storm water conduit.

Water supply in Burma camp area is one of the facilities that are provided for the military residents. The water is supplied from GWCL distribution pipe from the Kpong network and Oponglo. It is partly a direct pressure supply from the city mains and partly by gravity feed from the 2 reservoir tank 5000 and 4000 gallon, located in the northern part of Burma

camp. The tanks are, however situated at too low level to enable all the greater Burma camp to be supplied by gravity from these tanks. Due to water shortage and limited water supplied from GWCL, water is not running every day. Therefore, most household fills up their water tank once water is running, to be used for the following days. Many times people have to choose another alternative – calling water tanker, when both water sources (pipe water from GWCL or reservoir tank) fail to supply their water demand. And in some way, the water tankers service would only come provided some customers called them in certain period of time.

4.6.2 Cluster 3

This cluster is located downstream of cluster two, which is also still part of Burma camp. This area is a mixed area of Burma camp housing, new settlement and urban agriculture. Most of the area is covered by bush and trees and open bare land.

This area is where the sewage from Burma camp was treated before the treatment plant broken in 1981. However, even though the treatment is not working, the sewage still flowing through the pipe and some of it infiltrate to the ground where the rest goes to sewage pond (use to be the final pond before sewage was discharged to the lagoon).

Around the plant there is about half hectare land being cultivated by one farmer who also use to be the caretaker of the plant. Maize, cassava, corn and plantain are the typical plants in this area. Basically it is rain-fed farm but sometimes he uses water from broken sewer for irrigation. During dry season or when there is no sewage flows from Burma camp, he would left his farm dry. He never applies fertilizer to his farm and he also does not aware that the waste water he has been using contains of nutrient.

Figure 4. 5: Sewage Pond

Figure 4. 6: Broken WWT Plant

About 500 meters from the plant there is an area known as Labadi villas where the sewage pond (as it intended as the discharge point of sewage) exists. Around this pond, some vegetables such as lettuce, pepper and union are cultivated, and farmers use water from the pond for irrigation. Other scattered farm lands are along the stream, from where farmers take water for irrigation. Based on interview with local farmers, it was understood that

most of them using the waste water for the irrigation due to lack of alternatives water sources.

Close to the sewage lagoon there is some new housing under construction. With the increasing population and the development of this area, it is predicted that the bush and agriculture area within this cluster will gradually be converted into new settlements.

4.6.3 Cluster 4

This area mainly consists of new settlements, International Trade fair centre and an open bare land. There is no sewerage system exists, thus wastewater is discharged directly to the stream. Since this is considerably new settlements and not part of Burma camp, there is no water distribution system within this area. As the consequence, people have to buy water from GWCL through water tanker. Based on the survey during the field visit, it is likely the open bare land will soon be converted into new settlements.

Figure 4. 7: Kpeshie Lagoon

4.7 Data Input

In this study, the model takes input from both six input files and Aquacycle default. This is due to the data limitation of the area study. The six input files are indoor water usage profile; climate data; unit block; cluster; catchment; and parameter and initial values. For each input of data description, availability and source is described below.

4.7.1 Indoor Water Usage Profile

The indoor water usage water profile contains data on domestic waster use with order from occupancy one to seven. Since there has not been any research for water usage profile in Accra, for this study the amount of indoor water usage consumption for additional house hold occupancy is calculated based on percentage increase of water usage consumption of similar study in Athens. The same indoor water profile is used for all clusters.

Based on estimation of percentage of water use per person per day in developing country (fig 4.8) and amount of daily average water consumption in Accra is 55 L/p.day (*London Economics*, 1999), indoor water usage profile is given as follow:

Table 4. 1: Water Usage Profile (L/day)

1	Household Occupancy	1	2	3	4	5	6	7
2	Kitchen Water Use	13.20	21.25	27.19	31.42	33.53	40.39	47.26
3	Bathroom Water Use	22.00	35.64	48.40	57.42	62.92	71.50	79.64
4	Toilet Water Use	12.10	19.84	26.02	31.82	35.45	40.05	44.53
5	Laundry Use	7.70	14.17	24.56	30.80	35.27	40.43	45.43
TOTAL		55.00	90.90	126.17	151.46	167.17	192.37	216.85

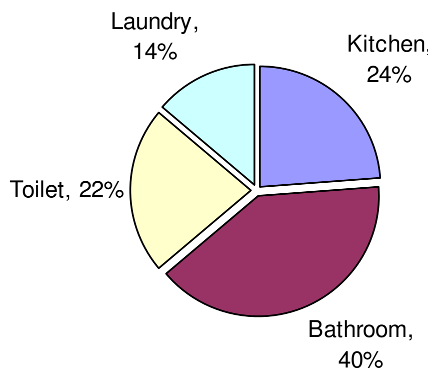


Figure 4. 8: Percentage of Water Use per Person per Day in Developing Country (*EMI*, 2007)

It is important to note that within this research the term of water consumption is used instead of water demand, as it likely reflects the real amount of water being used by the community in the study area to sustain their daily life. Thus, it is understood that the existing water supply system has the capacity to meet this amount of water consumption.

4.7.2 Climate Data

The climate data file contains historical daily rainfall and potential evaporation data series in unit millimetres per day. For Accra, historic climate data is available from 1970 to 2005 (*IWMI*, 2007).

4.7.3 Unit Block

Unit block data input contains details option selected for the unit blocks within each cluster being simulated. Unit block characteristic is homogenous within one cluster, but this characteristic may differ between clusters. Data input sheet for unit block is shown in Table 4.2 and detail unit block data input for each strategy and scenarios are shown in annex 1.

4.7.4 Cluster

Cluster data input contains details on the water options selected for each cluster within catchment being simulated. Within catchment, arrangement between clusters may be differ. Data input for cluster is shown in Table 4.3 and detail data input for each strategy and scenarios are shown in annex 2.

Table 4. 2: Unit Block Data Input

1	Supply garden irrigation with imported water? 0 or 1
2	Rain tank storage capacity in m3 >= 0
3	Rain tank exposed surface in m2 >= 0
4	Rain tank first flush in Litres >= 0
5	Domestic hot water from rain tank? 0 or 1
6	Domestic kitchen cold water from rain tank? 0 or 1
7	Domestic bathroom cold water from rain tank? 0 or 1
8	Domestic laundry cold water from rain tank? 0 or 1
9	Domestic toilet water from rain tank? 0 or 1
10	Domestic garden irrigation from rain tank? 0 or 1
11	Kitchen greywater for sub-surface irrigation? 0 or 1
12	Bathroom greywater for subsurface irrigation? 0 or 1
13	Laundry greywater for subsurface irrigation? 0 or 1
14	Wastewater treatment and storage capacity in m3, >= 0
15	Wastewater treatment and storage exposed surface in m2, >= 0
16	Treat kitchen wastewater? 0 or 1
17	Treat bathroom wastewater? 0 or 1
18	Treat laundry wastewater? 0 or 1
19	Treat toilet wastewater? 0 or 1
20	Toilet water from wastewater store? 0 or 1
21	Garden irrigation from wastewater store? 0 or 1
22	Wastewater storage overflow to sewer? 0 or 1
23	Wastewater storage overflow to storm water? 0 or 1
24	Unit block runoff draining to cluster stormwater store? 0 or 1
25	Supply toilet from a cluster stormwater store? Specify cluster number or 0
26	Supply garden irrigation from a cluster stormwater store? Specify cluster number or 0
27	Unit block wastewater draining to cluster wastewater store? 0 or 1
28	Supply toilet from a cluster wastewater store? Specify cluster number or 0
29	Supply garden irrigation from a cluster wastewater store? Specify cluster number or 0
30	Supply toilet from catchment scale stormwater storage? 0 or 1
31	Supply garden irrigation from catchment scale stormwater storage? 0 or 1
32	Supply toilet from catchment scale wastewater storage? 0 or 1
33	Supply garden irrigation from catchment scale wastewater storage? 0 or 1

0 = no; 1 = yes

4.7.5 Catchment

Catchment data input contains detail on the water options selected for the catchment within each cluster being simulated. Data input sheet for catchment is shown in Table 4.4, and detail catchment data input for each strategy and scenarios are shown in annex 3.

Table 4. 3: Cluster Data Input

1	Cluster scale stormwater storage capacity in m3, >= 0
2	Cluster scale stormwater storage exposed surface in m2, >= 0
3	Cluster scale stormwater storage first flush in m3, >= 0
4	Road runoff to cluster scale stormwater store? 0 or 1
5	Collect stormwater from upstream slucters? 0 or 1
6	Cluster scale wastewater storage capacity in m3, >= 0
7	Cluster scale wastewater storage exposed surface in m2, >= 0
8	Collect wastewater from upstream clusters? 0 or 1
9	Cluster scale wastewater storage overflow to sewer? 0 or 1
10	Cluster scale wastewater storage overflow to stormwater? 0 or 1
11	Aquifer storage and recovery storage capacity in m3, >= 0
12	Maximum aquifer storage and recovery recharge rate in m3/day, >= 0
13	Maximum aquifer storage and recovery rate in m3/day, >= 0
14	Supply public open space irrigation from imported water? 0 or 1
15	Supply public open space irrigation from a cluster stormwater store? Specify cluster number or 0
16	Supply public open space irrigation from a cluster wastewater store? Specify cluster number or 0
17	Supply public open space irrigation from the catchment stormwater store? 0 or 1
18	Supply public open space irrigation from the catchment wastewater store? 0 or 1
19	Drain stormwater runoff into the cluster stormwater store? 0 or 1

0 = no; 1 = yes

Table 4. 4: Catchment Data Input

1	Catchment size in hectares, >= 0
2	0
3	Catchment scale stormwater storage capacity in m3, >= 0
4	Catchment scale stormwater storage exposed surface area in m2, >= 0
5	Catchment scale stormwater storage first flush in m3, >= 0
6	Catchment scale wastewater storage capacity in m3, >= 0
7	Catchment scale wastewater storage exposed surface area in m3, >= 0
8	Catchment scale wastewater storage overflow to stormwater not sewer? 0 or 1

0 = no; 1 = yes

4.7.6 Parameter and Initial Value

The parameter and initial value input contains details on the measured parameters; calibrated parameters; and initial storage level values for each cluster in the catchment being simulated. Data input for catchment is shown in Table 4.5. Since there is a limited data available for calibrated parameters, the data gap will be replaced with default value from Aquacycle. For detail parameter and initial value for all strategy and scenarios can be seen in annex 4.

4.8 Model Baseline with Aqua cycle

The model baseline will represent the existing urban water management in the study area where there is no intervention (strategy) applied. Baseline situation only consider water source from GWCL. Urban settlement receives input water; pass the system and output in the forms of waste water discharge, stormwater and evapotranspiration. All the parameter

that contributes to the interaction of that system will be assessed and determined according to their associated modelling spatial area (unit block, cluster and catchments).

Table 4. 5: Parameter and Initial Value Data Input

Measured parameters	
1	No. of blocks in cluster, >= 0
2	Avrg household occupancy, >= 0
3	Area of unit block in m2, >= 0
4	Area of unit block garden in m2, >= 0
5	Area of unit block roof in m2, >= 0
6	Area of unit block pavement in m2, >= 0
7	Per cent of unit block garden irrigated as a %
8	Total area of cluster in hectares, >= 0
9	Road area in hectares, >= 0
10	Area in public open space in hectares, >= 0
11	Percent of public open space irrigated as a %
12	Water supply leakage rate as a %
13	Cluster stormwater output flows into cluster No? Specific cluster number or 0
14	Cluster wastewater output flows into cluster No? Specific cluster number or 0
Calibrated Parameters	
1	Per cent area of pervious store 1 as a %
2	Capacity of pervious store 1 in mm
3	Capacity of pervious store 2 in mm
4	Roof area max initial loss in mm
5	Effective roof area as a %
6	Paved area max initial loss in mm
7	Effective paved area as a %
8	Road area max initial loss in mm
9	Effective road area as a %
10	Base flow index as a ratio
11	Base flow recession constant as a ratio
12	Infiltration index as a ratio
13	Infiltration store recession constant as a ratio
14	Percent of surface runoff as inflow as a %
15	Garden trigger-to-irrigate as a ratio
16	Public open space trigger-to-irrigate as a ratio
Initial Storage Level	
1	Unit block tank storage level in m3
2	Unit block treated wastewater storage level in m3
3	Cluster scale stormwater storage level in m3
4	Cluster scale treated wastewater storage level in m3
5	Cluster scale aquifer storage level in m3

4.9 Future Scenarios

Based on model baseline, selected scenario of water management will be simulated in the urban water balance using Aquacycle. These will show ‘what if?’ scenarios on the amount of imported water, discharged waste water and storm water in the study area. Future

scenarios will consider climate change prediction based on IPCC study report and population growth will be predicted within 25 years period from the baseline situation following present population growth rate.

The projected population is calculated based on the equation below:

$$P = Pi\ (1 + r)^{n}$$

Where P: projected population, Pi: initial population, r: population growth rate, and n: number of years.

4.10 Proposed Strategies

After evaluating the existing system in study area, strategies will be formulated. Alternative strategies of water management scheme on study area will consist of rain water use and waste water reuse as alternatives water sources. Rainwater harvesting is practiced during the rainy season to store water to be used during the dry season. Rainwater is relatively clean but the quality is determined by factors such as the type of roofing material used, amount of filtering achieved, the condition of storage tanks and long period of dryness. Recycle of wastewater involves the reuse of wastewater for household activities such as toilet flushing and gardening watering. The combination of these two alternatives will also be assessed; to obtain the most reliable and suitable alternate solution.

It is important to note that there is rule in Aquacycle to determine the priorities if there is more than one source as strategy of water management selected to supply a particular demand. Based on the Aquacycle user guide (Mitchell, 2005), the rules are as follows:

1. Use the lowest quality water sources available, which meets the requirements of the demand first
2. Supply indoor water demands before outdoor demands
3. Use the water sources within the unit block before cluster sources
4. Use cluster scale water sources before catchment scale water sources
5. Use all local sources of water before importing water (reticulated water)
6. If a particular potential source of water has not been selected by the user, then the next highest priority source is used instead

4.11 Nutrient Flows Analysis

The calculation of nutrients flow is based on the secondary data of the selected nutrients. They are Nitrogen, Phosphorus and Potassium which are considered as the main nutrient content in fertilizer. Those nutrients can be applied in farming land or for agriculture purposes. For each strategy chosen, the nutrient flows will be quantified.

In order to have a holistic assessment of material flows within the system (four clusters), the nutrients flow is being traced and mapped as shown in fig 4.9. This nutrient mapping is

further used as a basis for designing a schematic model system as will describe in next chapter.

By calculating the flux of nutrients, the specific flow of each nutrient will be defined. A flow is defined as a mass flow rate (mass per time) and a flux is defined as a flow per cross section (mass per time and cross section). In mass flow analysis, a person or the surface area of the system is commonly used as cross sections. The advantage of using fluxes is that they can be easily compared among different processes and systems, since fluxes are specific values.

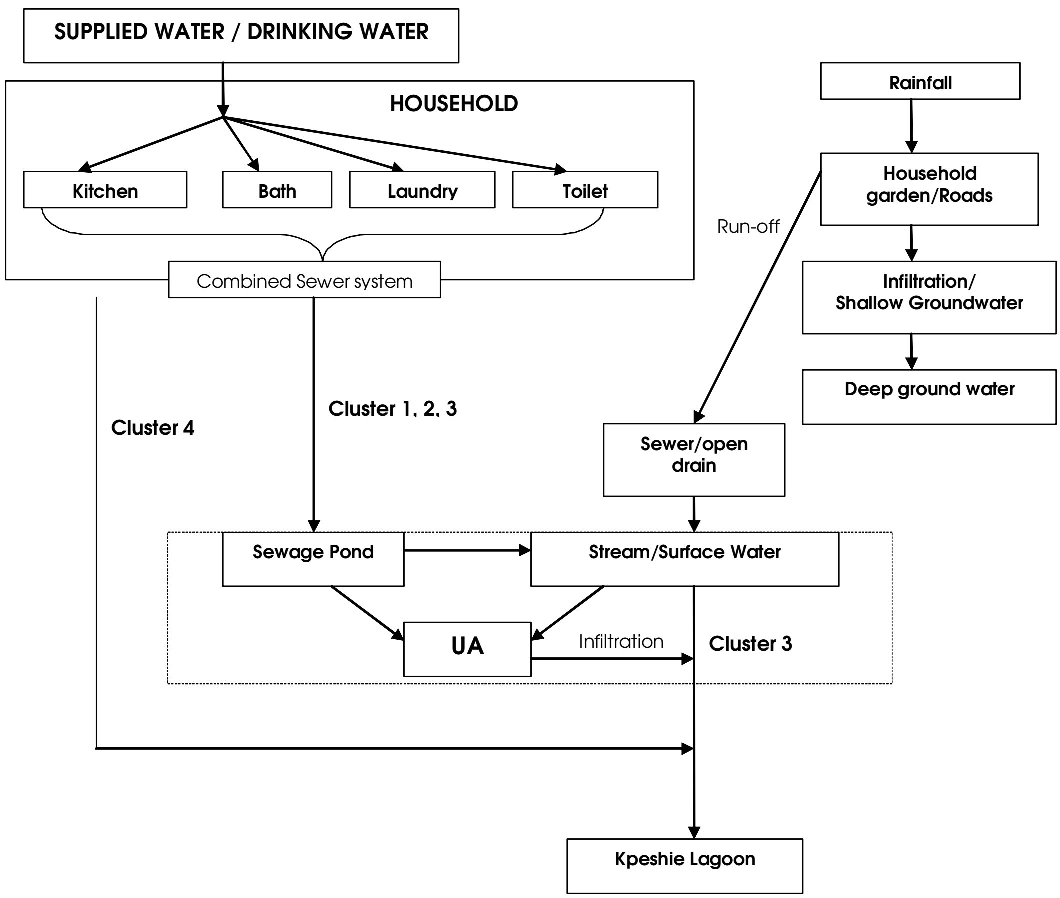


Figure 4. 9: Nutrient Mapping

The mass flow calculation is based on the equation below:

Fluxes = flows / person = mass / (time. person)

= volume of wastewater discharge / (person. day) x concentration

Total fluxes = flows / persons x population
= volume of wastewater discharge / (person. day) x concentration x population

In this study, the output of Aquacycle in term of amount of water discharged and estimated population growth are used as the inputs for nutrient flow analysis.

5 STRATEGIES and SCENARIOS

5.1 General

The following section contains model consideration of which input data values of each strategy has been chosen for present situation and future scenarios. In order to visualize the existing situation of the study area, the following information is needed:

1. Identification of water inflow and outflow
2. Water flow direction
3. Water consumption activity

Furthermore, that information is outlined in the sketch model below:

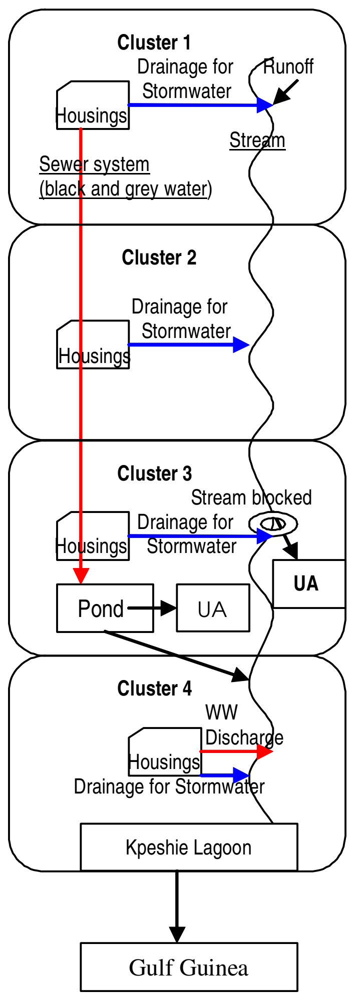


Figure 5. 1: Sketch of Existing Situation of Study Area

Proposed strategies are applied in each cluster, either for present and future scenario. For model input data value, both practical calculation and on the ground situation are taking into account. However, since there is a lack of data available, Aquacycle default value is

used for the calibrated parameters input. Details consideration for three strategies is described in the following section.

5.2 Proposed Strategies

There are 3 strategies that are chosen to be applied for current situation and future scenario of population growth and climate change. They are onsite household rain water tank-where rain water is the alternative water source, onsite waste water treatment and cluster waste water treatment, where wastewater reuse is contributed as water source alternative. For wastewater treatment recycled, it is assumed that it has been treated and meets the specific needs for toilet flushing and agriculture application.

5.2.1 Unit block Rainwater Tank

Average water consumption for each person is 55L. Considering the average occupancy per household is 5, the total water consumption per day is 167 L (table 4.1). In Kpeshie, most of household has their own rain tank (size 1m3). Thus, 1m3 tank size is preferred to be used for unit block rain water strategy.

According to rain water manual by Texas Water Development Board, a first-flush diversion for rainwater tank is minimum 10 gallon for every 1,000 square feet of collection surface (roof). Since the average roof size in the study area is 125 m^2 and 100 m2, the first flush for rainwater tank is 50 L and 40 L respectively.

Figure 5. 2: Household Water Tank in Kpeshie

5.2.2 Onsite Wastewater Storage

Considering combined sewer system already exists, the wastewater from bathroom, kitchen, and laundry will be treated and used within unit block scale. Based on water usage profile, average wastewater discharge per household is 167 L. However, the option for wastewater reuse is intended only for toilet flushing which only needs 35.45 L water

(household with occupancy 5). Thus, the proposed size for this wastewater storage is 50 L and it should be a closed system to prevent stormwater enters the tank and to avoid odour problems.

A greywater diversion device is assumed to be applied in each unit block and diverts the greywater to a subsurface irrigation area or toilet by means of a hand activated valve or switch. Since only small amount of wastewater will be used within unit block scale, the overflow will be diverted back to existing sewer system.

5.2.3 Cluster Wastewater Storage

Within cluster scale, the unit block wastewater will be draining to cluster wastewater storage. And this wastewater will be used only for toilet flushing. The storage capacity for each cluster is calculated based on the needs of water for flushing purposed for the whole inhabitants in each cluster.

5.3 Baseline Situation

Baseline situation reflects the present situation where no intervention has been applied. Water source for household consumption is only obtained from GWCL either through pipe distribution system or water tanker. Based on generated population data from Ghana Statistical Service number of inhabitants in each cluster is calculated, while the area of study area is calculated from GIS map by arc map. With the modification from Ghana population census 2000, GIS map and Google earth image, number of houses, road area and public space are identified. The characteristic for each cluster on present situation is shown in table 5.1 below.

Table 5. 1: Cluster Characteristic at Present Situation

Cluster Characteristic	Total Area (m2)	Population	Housing Area (m2)	Number of Houses	Roof Area (m2)	Road Area (m2)	Public Area (m2)
1. Settlement	1396429	5542	277000	1108	138500	40880	1078549
2. Settlement	1301858	2230	111500	446	55750	22858	1167500
3. Settlement + agriculture	1061871	796	39750	159	19875	17818	1004303
4. Settlement	686789	429	17200	86	8600	4770	664819
Total Area	4446947						

As shown in fig 5.1 wastewater from cluster 1, 2 and 3 drain to sewage pond in cluster 3. Together with small blockade stream in cluster 3, water is used for irrigate urban agriculture in cluster 3. In baseline situation this pond and blockade stream is considered as wastewater storage and stormwater storage. The size is 3000 m^2 (1 ha x 3 m depth) and 5 m^3 respectively.

5.4 Future Scenarios

5.4.1 Climate change

In general, data input for climate change scenario is the same with data input for present situation, except for the climate data. Following the IPCC data for climate prediction for

African basin as shown is table. 5.2, Volta basin data is used as the reference for climate change prediction in the study area. This basin is the closest one to the study area and also in Ghana, thus it is more likely have the same climate pattern. Related to data input, table 5.2 shows the change is only on potential evaporation. The lowest and highest evapotranporation changes are 4% and 5% respectively. Since there is no change in precipitation, for the research purpose, future scenario model will consider 10 % change for both extreme dry and wet.

Table 5. 2: Estimation of ranges of changes in precipitation, potential evaporation and runoff in African river basin (IPCC, 2007)

Basin	Change in Precipitation (%)	Change in Potential Evaporation (%)	Change in Runoff (%)
Nile	10	10	0
Niger	10	10	10
Volta	**0**	**4 to -5**	**0 to - 15**
Zaire	10	10 to 18	10 to 15

5.4.2 Population Growth

The baseline data for population is based on census 2000. There are three setting years considered within population growth scenario. They are for 2009, 2016, 2021, where population is predicted increase by 50 %, 100% and 150% respectively, based on present growth rate of 4.4 %.

The data inputs for this scenario are generally the same with present situation, except for cluster wastewater storage size (which is calculated based on number of inhabitants in the future), and the parameter value which consider the change of population, number of household, area of open space and roads. The average occupancy for this scenario follows the present situation and the size of the road will expand by 20% for every 50% population increase.

Table 5. 3: Cluster Characteristics for 50% of Population Increase

Cluster Characteristic	Total Area (m2)	Population	Housing Area (m2)	Number of Houses	Roof Area (m2)	Road Area (m2)	Public Area (m2)
1. Settlement	1396429	8313	415500	1662	207750	49056	931873
2. Settlement	1301858	3345	167250	669	83625	27430	1107178
3. Settlement + agriculture	1061871	1194	59500	238	29750	21382	980989
4. Settlement	686789	643.5	25600	128	12800	5724	655465
Total Area	4446947						

Table 5. 4: Cluster characteristics for 100% of population increase

Cluster Characteristic	Total Area (m2)	Population	Housing Area (m2)	Number of Houses	Roof Area (m2)	Road Area (m2)	Public Area (m2)
1. Settlement	1396429	11084	554000	2216	277000	57232	785197
2. Settlement	1301858	4460	223000	892	111500	32002	1046856
3. Settlement + agriculture	1061871	1592	79500	318	39750	24946	957425
4. Settlement	686789	858	42750	171	17100	6679	637360
Total Area	4446947						

Table 5. 5: Cluster characteristics for 150% of population increase

Cluster Characteristic	Total Area (m2)	Population	Housing Area (m2)	Number of Houses	Roof Area (m2)	Road Area (m2)	Public Area (m2)
1. Settlement	1396429	13855	692750	2771	346375	65408	638271
2. Settlement	1301858	5575	278750	1115	139375	36574	986534
3. Settlement + agriculture	1061871	1990	99500	398	49750	28510	933861
4. Settlement	686789	1072.5	53500	214	21400	7633	625656
Total Area	4446947						

5.5 Nutrient Analysis

Figure 5.3 shows a schematic model system of nutrient flows. The modelled system was conceptualized as a flow chart containing boxes and arrows. Boxes represent the unit where nutrients are produced, consumed or stored. Arrows represent the nutrients flows between two boxes. Nutrient flows are expressed in g/day.

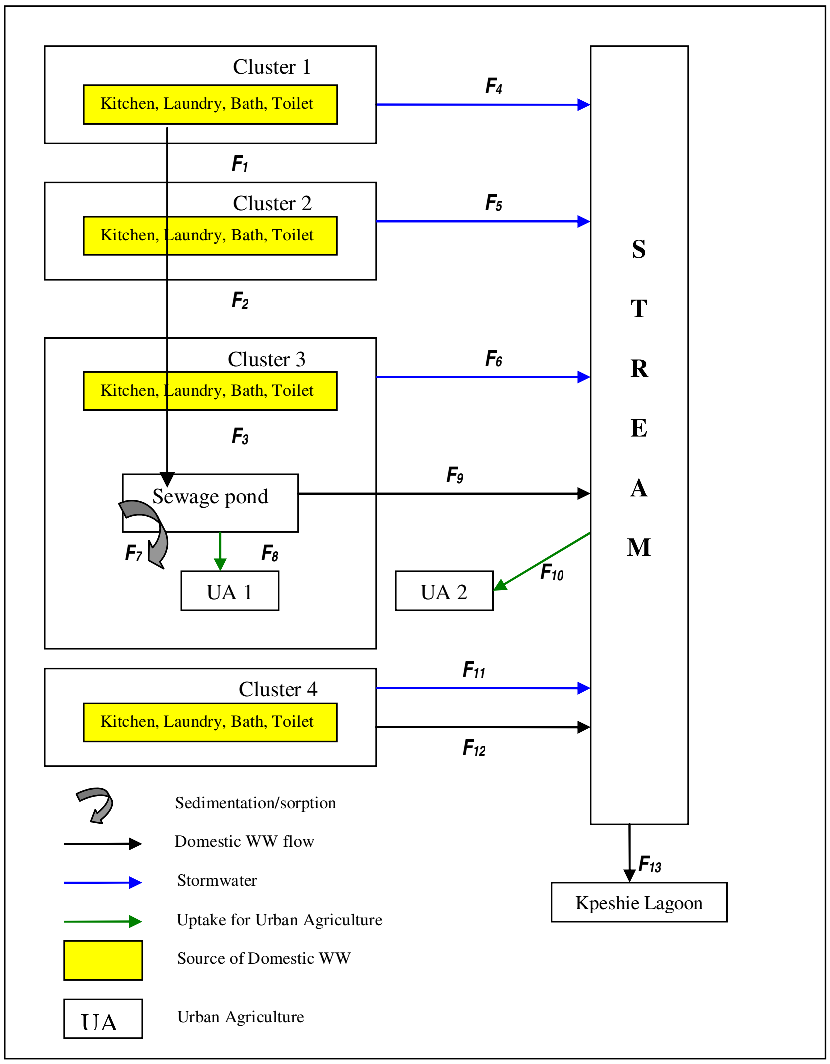


Figure 5. 3: Flow chart of Conceptual Model

Within the study area, the main source of nutrients in the surface water is household activity. However there are other sources that entered the water system and contribute to this load such as solid waste washed out to the stream that is not considered in this study. Most of the pathway of nutrients, either lost to atmosphere, washed to ground water, or any other bio-chemical process that might take place is also not taking into account. Nevertheless, the sedimentation/sorption of N, P and K that take place in sewage pond is assumed as much as 25%, 10% and 10% of nutrients input loading respectively.

The average load and concentration of each nutrient used in this research is based on literature review as shown in table 5.6. The calculation of nutrient flows is applied for both present situation and future scenario.

Table 5. 6: Nutrient loads through wastewater and stormwater system

Nutrient	Domestic Waste water				Stormwater [5]		
	Kitchen [1]	Bath [2]	Laundry [3]	Toilet [4]	Open Space	Roof Runoff	Road Runoff
N	0.36 g/p.d	5 - 10 mg/l	0.28 g/p.d	2.5 kg/p.y	0.01635 kh/h/y	0.94053 kh/h/y	0.11445 kh/h/y
P	0.06 g/p.d	0.2 - 0.6 mg/l	0.2 g/p.d	0.4 kg/p.y	0.0002 kh/h/y	0.0351 kh/h/y	0.0405 kh/h/y
K	59 mg/l	1.5 - 5.2 mg/l	5 g/p.d	1.4 kg/p.y	0.56 mg/l	7 mg/l	2 mg/l

[1] Hargelius et all (1995) as cited by Eva Ericksson et all (2002)
[2] Nolde (1996) as cited by Eva Ericksson et all (2002)
[3] Hargelius, Holmstrand and Karlsson (1995) as cited by Eva Ericksson et all (2002)
[4] Langergraber and Muellegger (2005)
[5] Gray and Becker (2002) and Gobel et all (2007)

6 RESULTS

6.1 Population growth and Water Demand

Following the current population growth rate of 4.4 % in Accra and average water consumption per capita per day is 55 L, fig 6.1 and fig 6.2 shows the estimation of population and water consumption in study area.

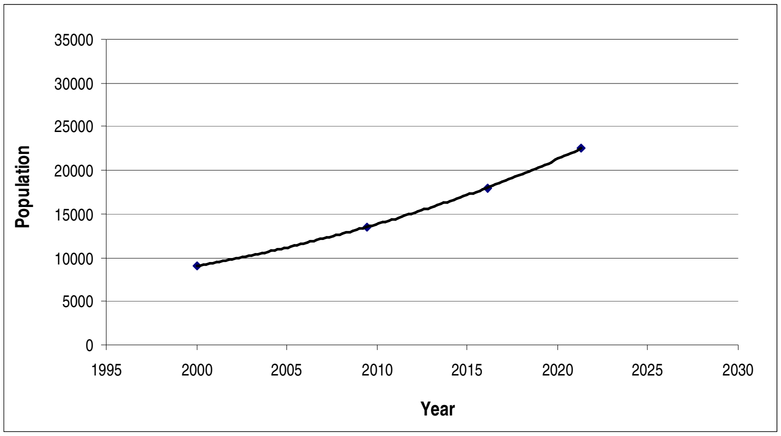


Figure 6. 1: Population Projection of Study Area

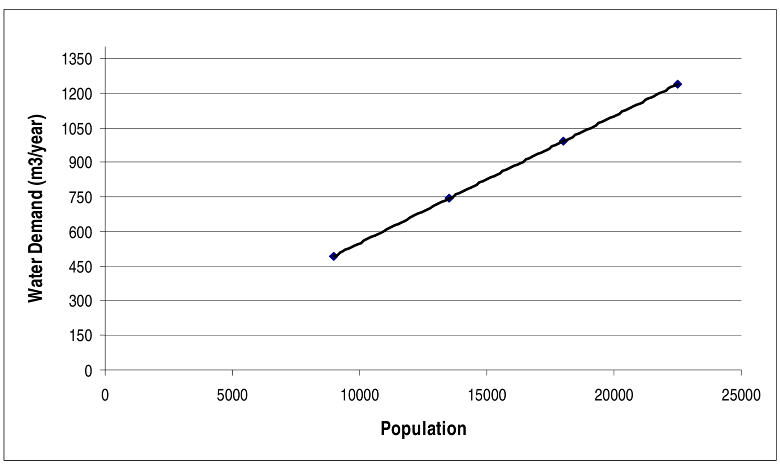


Figure 6. 2: Water Consumption Projection on Study Area

6.2 Water Balance

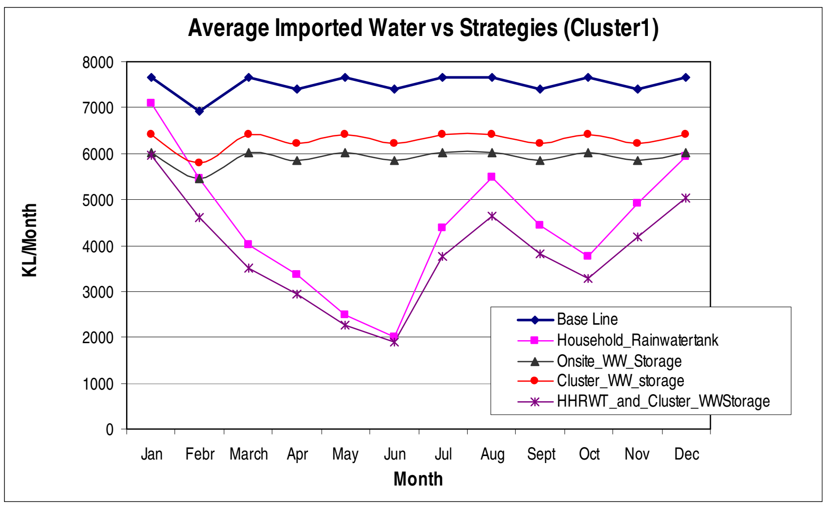
6.2.1 Present Situation

The water balance performance of each strategy, Household Rainwater Tank (HHRWT), Onsite Wastewater Treatment (Onsite WWT), Cluster Wastewater Treatment (Cluster WWT) and the combination of HHRWT and Cluster WWT is presented in table 6.1.

Table 6. 1: Water Balance Performance for Present Situation

Strategy	Average Annual Water Balance - Areal Depth (m3/year)		
	Imported Water	Stormwater Runoff	Wastewater Discharge
Baseline	144,132	1,870,728	327,661
HH_RWT	81,001	1,705,270	324,963
Onsite_WWT	112,212	1,859,728	285,114
Cluster_WWT	120,401	1,862,873	280,562
Combination HHRWT_and_Cluster_WWT	69,666	1,702,572	293,456

The detail allocation of annual imported water is further described in terms of monthly average of imported water that needs to be distributed to each cluster under each strategy as shown in fig 6.3. The fluctuation of monthly imported water is seen on HHRWT and combination of HHRWT and Cluster WWT strategies. As in other two strategies onsite WWT and cluster WWT they are considerably stable.



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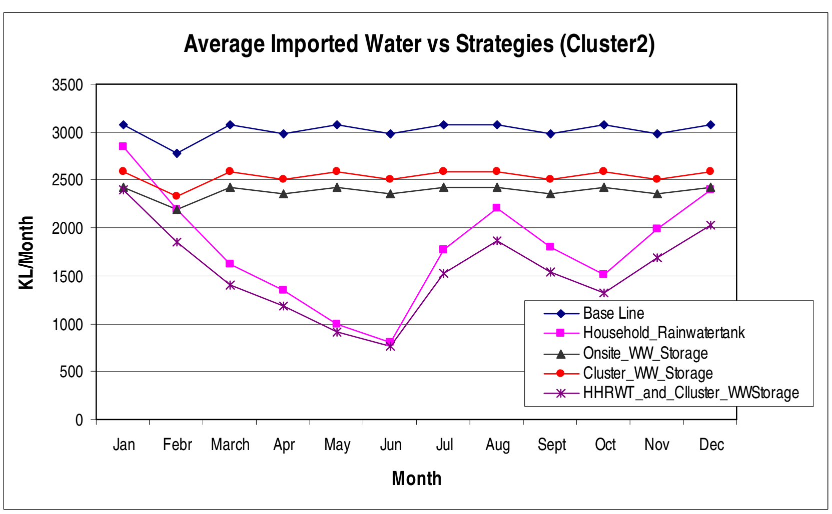

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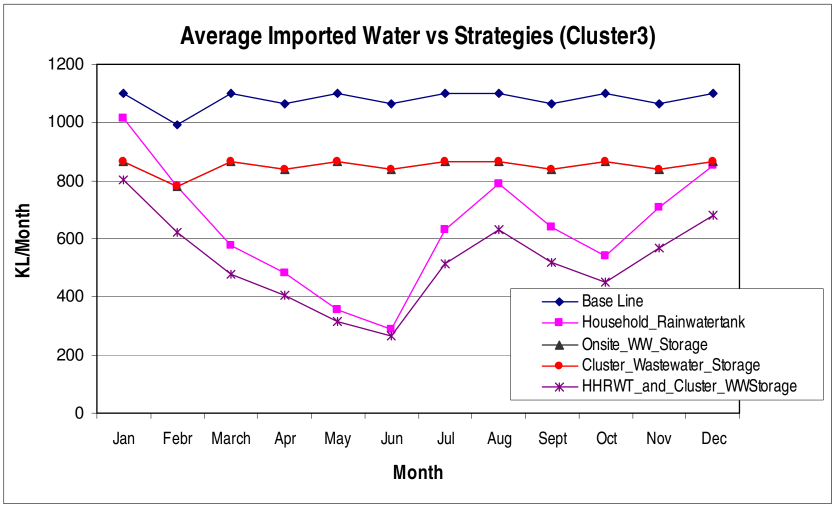

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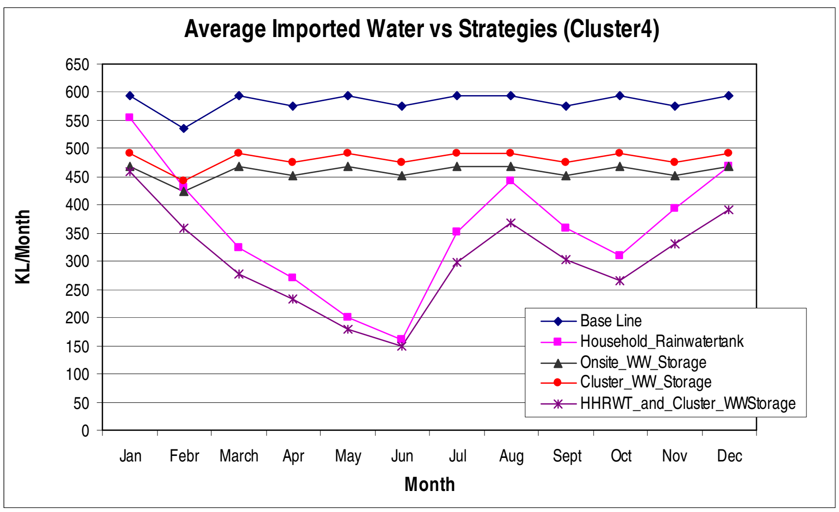


(d)

Figure 6. 3: Monthly Average Imported Water of Each Strategy for Present Situation

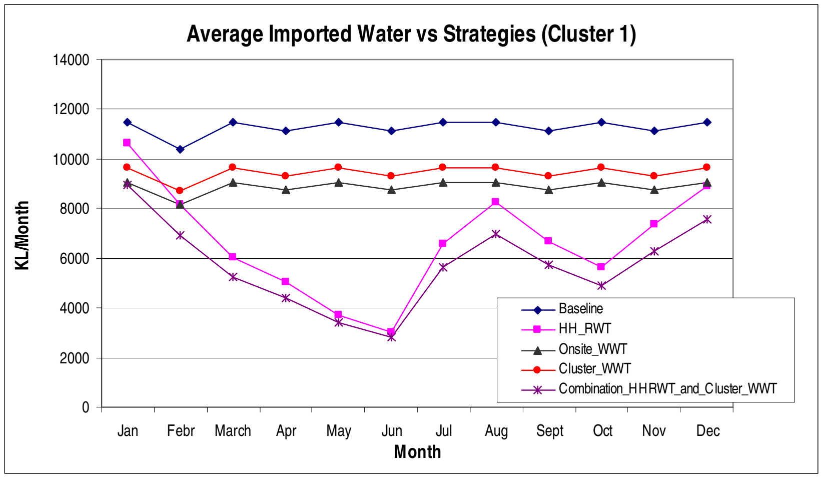
6.2.2 Future Scenarios and Strategies

6.2.2.1 Population Growth

The scenario of population growth is divided into 50%, 100 % and 150 % increasing of population based on number of population from census 2000. This increased population will likely to occur on 2009, 2016 and 2021 respectively.

Performance of 50% increased population scenario on four strategies is shown in fig 6.4. The same way of calculation is also applied for 100 % and 150% increasing population, and the graphs are presented in annex 5 and 6. The amount of water needed to be supplied

to the study area within present situation and the future growth population scenario within four strategies is summarized in fig. 6.5.



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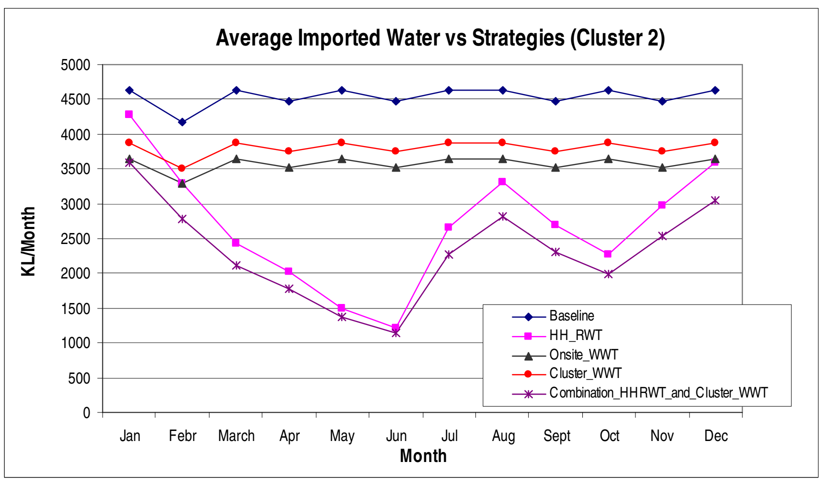

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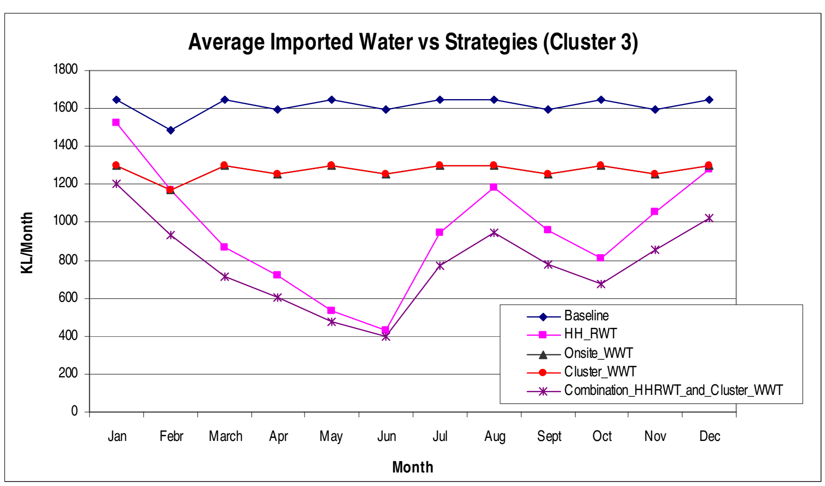

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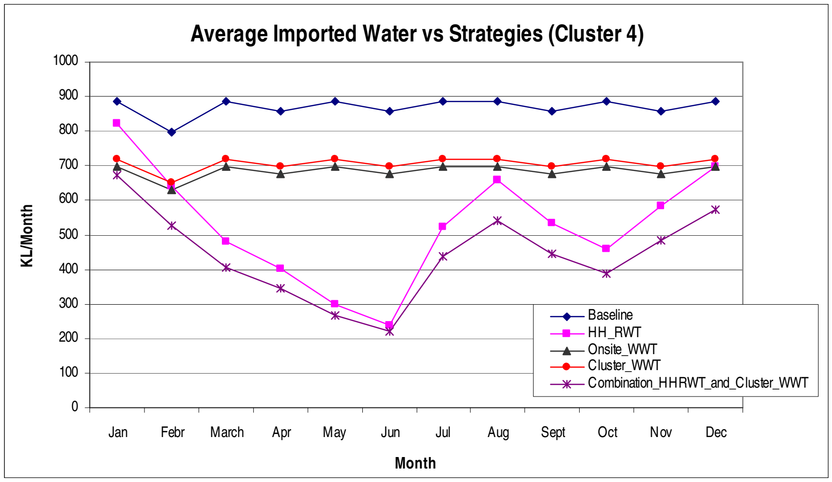

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Figure 6. 4: Monthly Average Imported Water of Each Strategy for 50 % Population Growth Scenario

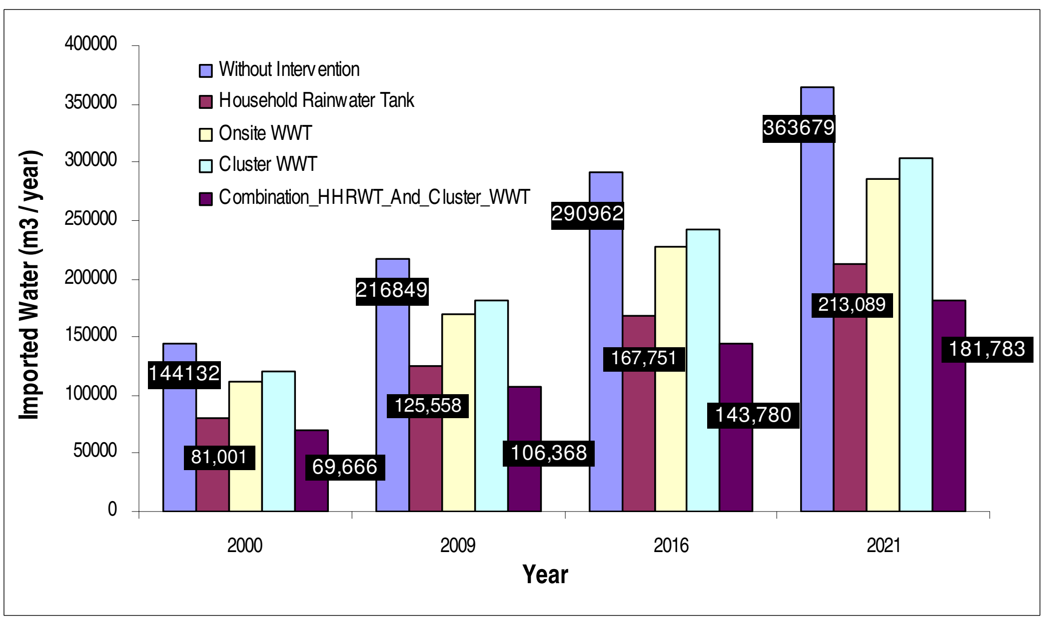


Figure 6. 5: Comparison of Imported Water for Present Situation and Population Growth Scenario

6.2.2.2 Climate Change

Following climate change prediction from IPCC, the water balance performance of both highest and lowest evaporation changes is shown in table 6.2 and table 6.3 respectively. The "what if "scenario of 10% increasing of precipitation is also simulated and the water balance performance is shown in table 6.4.

Table 6. 2: Water Balance Performance for Highest Increasing Evapotranspiraton Scenario

Strategy	Average Annual Water Balance - Areal Depth (m3/year)		
	Imported Water	Stormwater Runoff	Wastewater Discharge
Without Intervention	144,132	1,848,779	322,528
HH_RWT	81,001	1,684,717	322,528
Onsite_WWT	112,212	1,840,237	279,294
Cluster_WWT	120,401	1,843,622	276,138
Combination HHRWT_and_Cluster_WWT	69,666	1,680,623	289,959

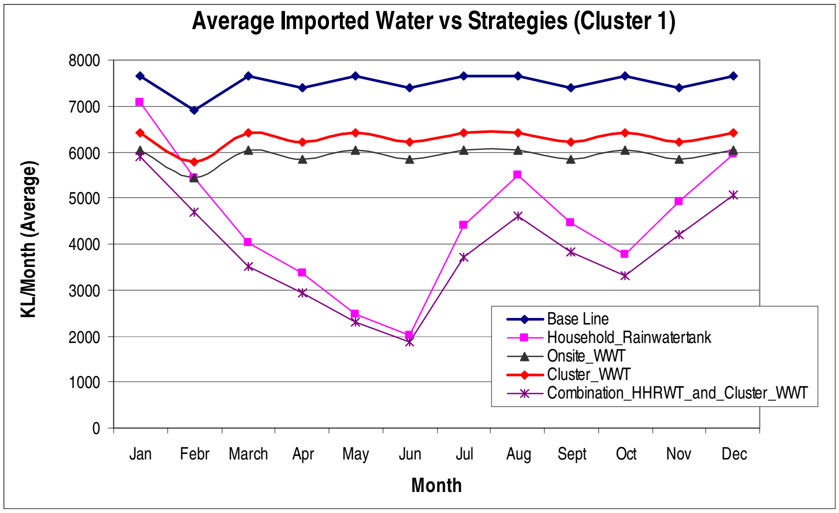
Table 6. 3: Water Balance Performance for Lowest Decreasing Evapotranspiration Scenario

Strategy	Average Annual Water Balance - Areal Depth (m3/year)		
	Imported Water	Stormwater Runoff	Wastewater Discharge
Without Intervention	144,132	1,900,246	333,834
HH_RWT	81,001	1,734,101	331,845
Onsite_WWT	112,212	1,890,308	290,600
Cluster_WWT	120,401	1,893,006	284,746
Combination HHRWT_and_Cluster_WWT	69,666	1,731,308	299,963

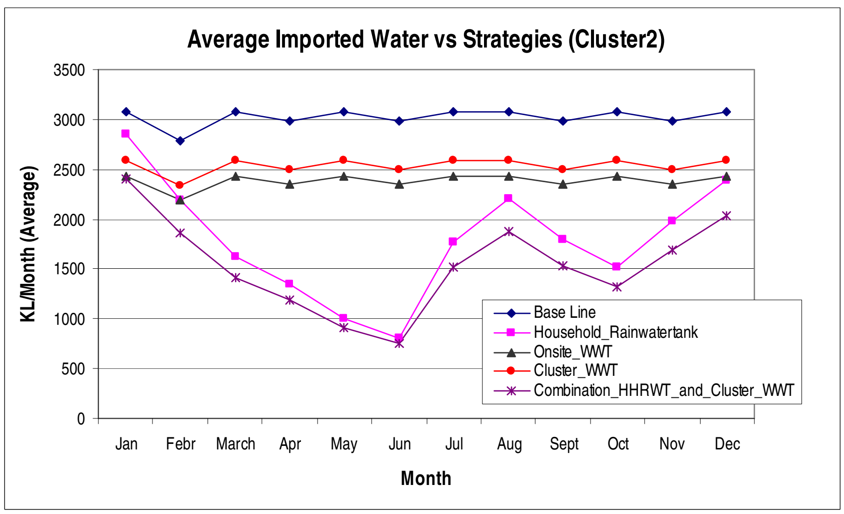
Table 6. 4: Water Balance Performance for 10% Increasing of Precipitation Scenario

Strategy	Average Annual Water Balance - Areal Depth (m3/year)		
	Imported Water	Stormwater Runoff	Wastewater Discharge
Without Intervention	144,132	2,176,789	362,436
HH_RWT	81,001	2,010,645	361,134
Onsite_WWT	112,212	2,168,153	317,900
Cluster_WWT	120,401	2,171,298	313,348
Combination HHRWT_and_Cluster_WWT	68,270	2,007,852	329,627

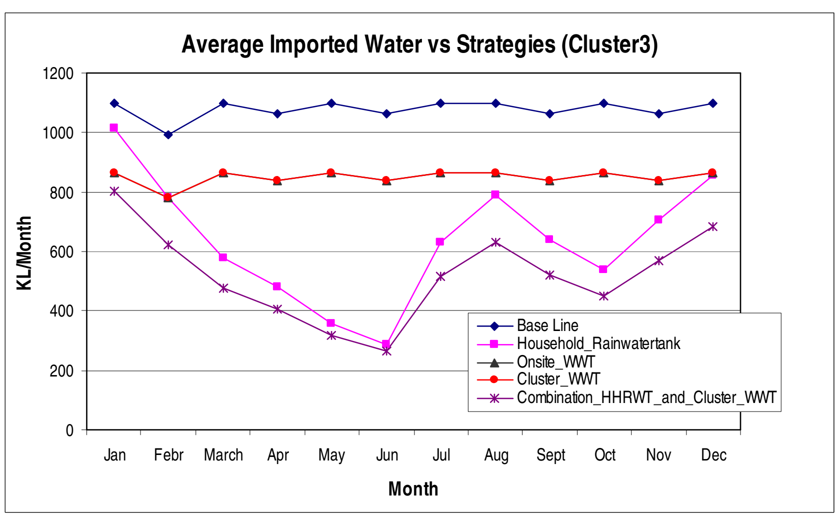
The average imported water of four strategies under the highest increasing of evaporation condition can be seen in fig 6.6. The same calculation for lowest decreasing of evapotranspiration and 10 % increasing of precipitation were also carried out and the results are presented in annex 7 and 8.


Average Imported Water vs Strategies (Cluster 1)
8000
7000
6000
5000
4000
3000
2000
1000
0
KL/Month (Average)
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Base Line
Household_Rainwatertank
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

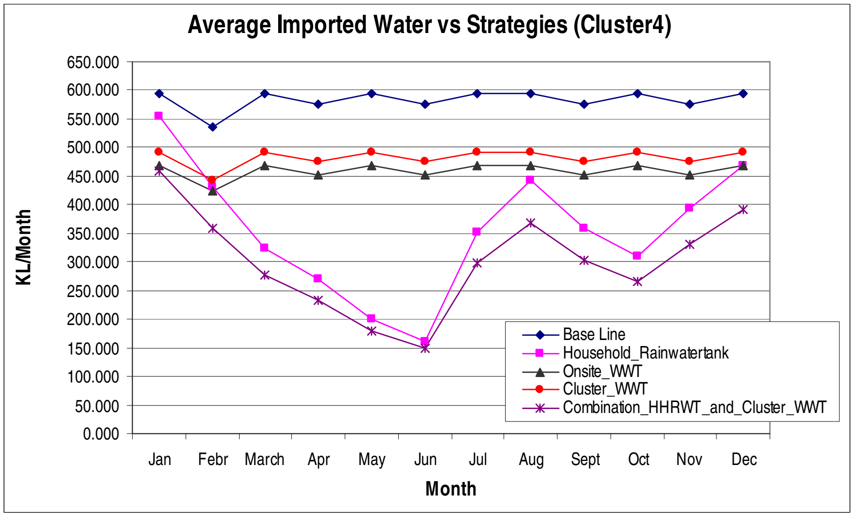
(a)


Average Imported Water vs Strategies (Cluster2)
3500
3000
2500
2000
1500
1000
500
0
KL/Month (Average)
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Base Line
Household_Rainwatertank
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

(b)


Average Imported Water vs Strategies (Cluster3)
1200
1000
800
600
400
200
0
KL/Month
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Base Line
Household_Rainwatertank
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

(c)



(d)

Figure 6. 6: Monthly Average Imported Water of Each Strategy for Climate Change Scenario

The comparison of amount of imported water need to be supplied to the study area in order to meet the water usage for present situation and climate change prediction scenario is shown in figure 6.7. This figure will help us to deal with the uncertainties of climate change in the future and measurement that should be done following the limited availability of water supply.

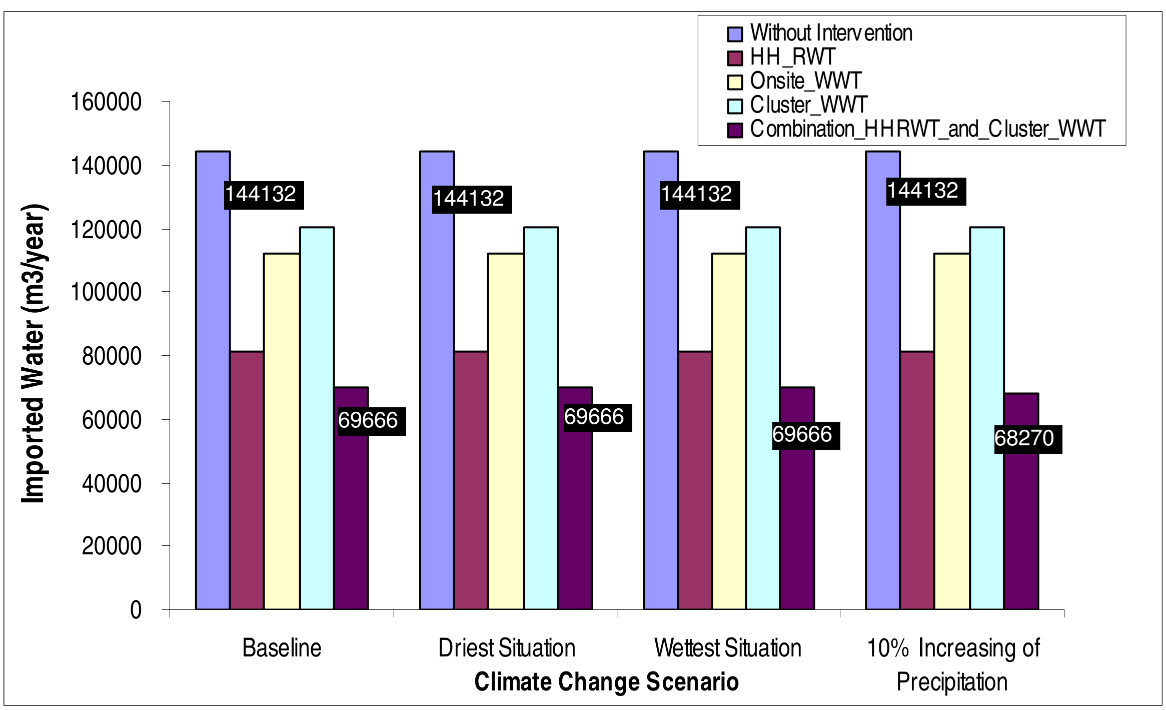


Figure 6. 7: Comparison of Imported Water for Present Situation and Climate Change Scenario

6.3 Nutrient Load

Based on the nutrient mapping and flux calculation, the total nutrients (N, P, and K) load from both domestic waste water and stormwater for present and future population growth scenario is shown in table 6.5.

Based on fig 5.2, the simplified nutrients flows mainly consist of domestic wastewater and stormwater. The end point of nutrients flow is in Kpeshie lagoon, which is the discharged point of those two sources. In this schematic flow, the final nutrients load to this lagoon is presented as flux 10.

Table 6.5: Nutrients Loads

Nitrogen (g/day)					
Flux	**Description**	**Present Situation**	**50 % Increasing of Population**	**100 % Increasing of Population**	**150 % Increasing of Population**
F1	Domestic-sewer system	42420	63630	84840	106051
F2	Domestic-sewer system	59489	89234	118979	148723
F3	Domestic-sewer system	65582	98373	131164	163955
F4	Stormwater-Drainage	3252	4878	6504	8133
F5	Stormwater-Drainage	1309	1964	2618	3273
F6	Stormwater-Drainage	467	699	933	1168
F7	Sedimentationa/Sorption	16396	24593	32791	40989
F8	Urban Agrculture Uptake	136	136	136	136
F9	Stormwater-Drainage	49051	73644	98237	122831
F10	Urban Agrculture Uptake	1096	1096	1096	1096
F11	Stormwater-Drainage	252	376	502	628
F12	Domestic-sewer system	3284	4926	6567	8209
F13	Stream/Surface water	57615	86486	115362	144242

Phosphorus (g/day)					
Flux	**Description**	**Present Situation**	**50 % Increasing of Population**	**100 % Increasing of Population**	**150 % Increasing of Population**
F1	Domestic-sewer system	7563	11345	15126	18908
F2	Domestic-sewer system	10606	15910	21213	26516
F3	Domestic-sewer system	11693	17539	23385	29232
F4	Stormwater-Drainage	230	345	460	575
F5	Stormwater-Drainage	93	139	185	232
F6	Stormwater-Drainage	33	49	66	83
F7	Sedimentationa/Sorption	1169	4385	5846	7308
F8	Urban Agrculture Uptake	11	11	11	11
F9	Stormwater-Drainage	10512	13143	17528	21913
F10	Urban Agrculture Uptake	164	164	164	164
F11	Stormwater-Drainage	18	27	36	44
F12	Domestic-sewer system	585	878	1171	1464
F13	Stream/Surface water	11471	14582	19446	24310

Potasium (g/day)					
Flux	Description	Present Situation	50 % Increasing of Population	100 % Increasing of Population	150 % Increasing of Population
F1	Domestic-sewer system	53692	80537	107383	134229
F2	Domestic-sewer system	75296	112944	150592	188240
F3	Domestic-sewer system	83008	124512	166016	207519
F4	Stormwater-Drainage	26	26	26	26
F5	Stormwater-Drainage	26	26	26	26
F6	Stormwater-Drainage	26	26	26	26
F7	Sedimentationa/Sorption	8301	31128	41504	51880
F8	Urban Agrculture Uptake	25	25	25	25
F9	Stormwater-Drainage	74682	93359	124487	155615
F10	Urban Agrculture Uptake	603	603	603	603
F11	Stormwater-Drainage	26	26	26	26
F12	Domestic-sewer system	4156	6234	8312	10391
F13	Stream/Surface water	78943	99698	132904	166110

The comparison of nutrients load at final discharge point in Kpeshie lagoon for present and future population growth scenario is presented in fig 6.8.

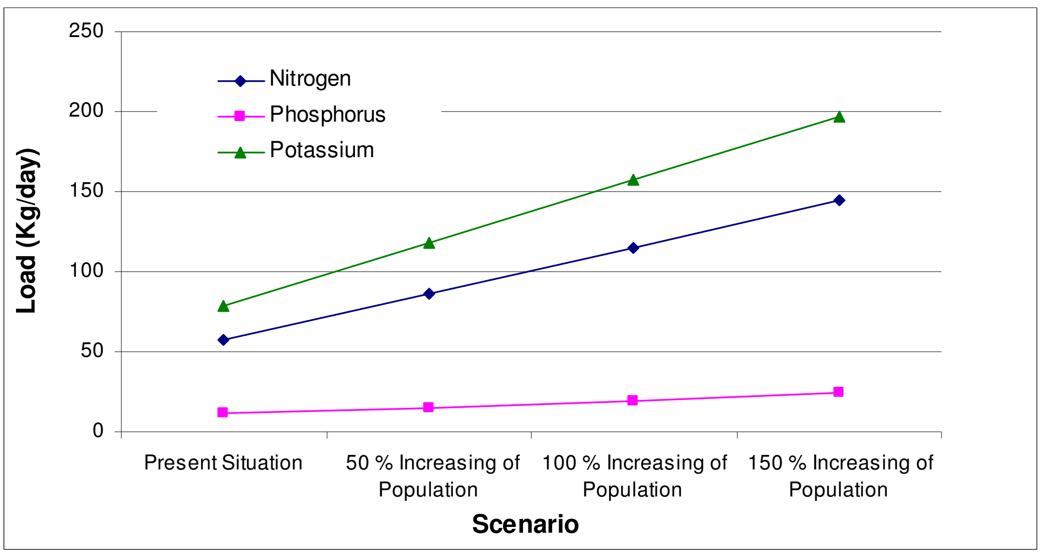


Figure 6. 8: Nutrients Load Discharge at Kpeshie Lagoon

Following nutrients uptake rates for selected crops (table 6.6), demand for existing urban agriculture (0.2 ha cultivated by vegetables and 2 ha cultivated by cereal/maize) in the study area is shown in fig 6.9. This figure also showed a comparison between nutrients supplied by each strategies and its current demand. The calculation of nutrients load under WWT strategy follows recommendation from wastewater reclamation system practices; where N and P contents should be reduced by approximately 70 % before being recycled (*Oceta*, 2000).

Table 6. 6: Nutrients Uptake

Crops	Nutrients Uptake rates for crops Kg/ha-year (EPA, 1981)[1]		
	Nitrogen	Phosphorus	Potassium
Corn	175 - 200	20 - 30	110
Vegetables	250	10 - 20	30 - 55

[1]*as cited by Polprasert and Veenstra, 2000*

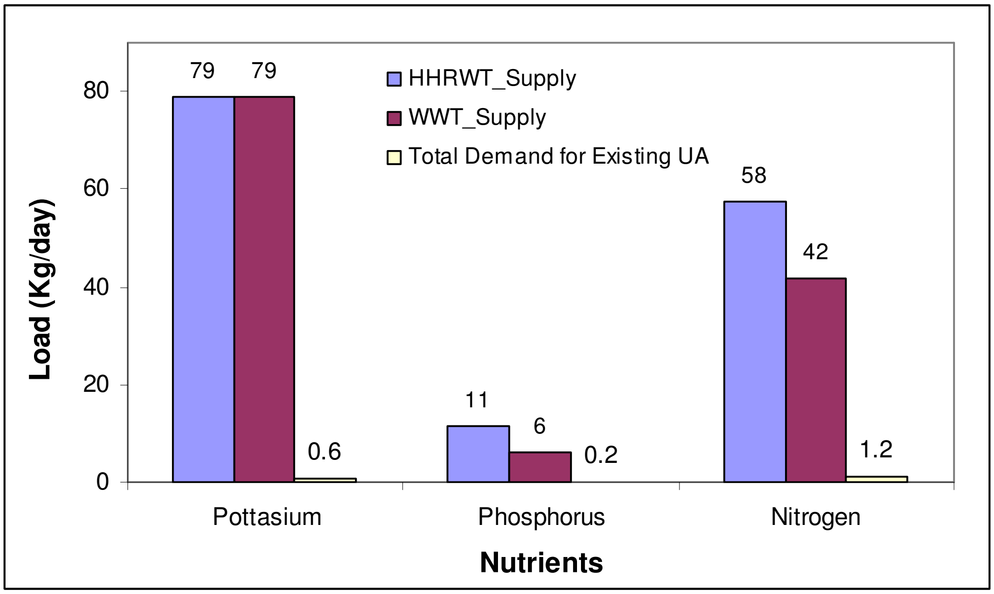


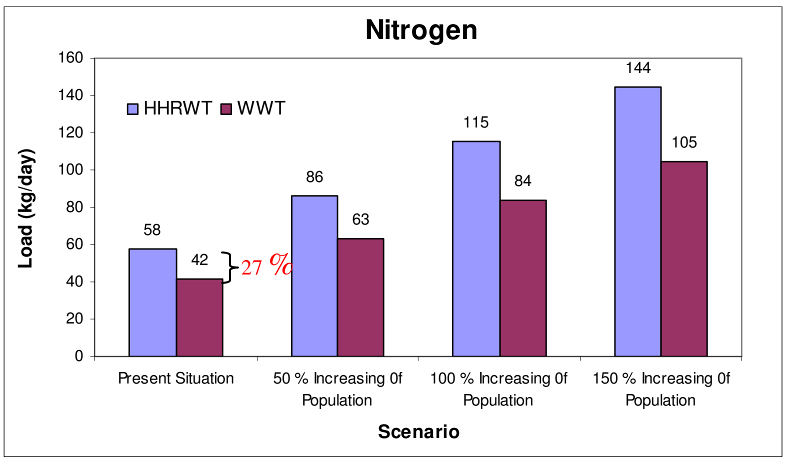
Figure 6. 9: Supply and Demand of Nutrients in Present Situation

Table 6. 7: Nutrients Loads under Different Strategies and Scenarios

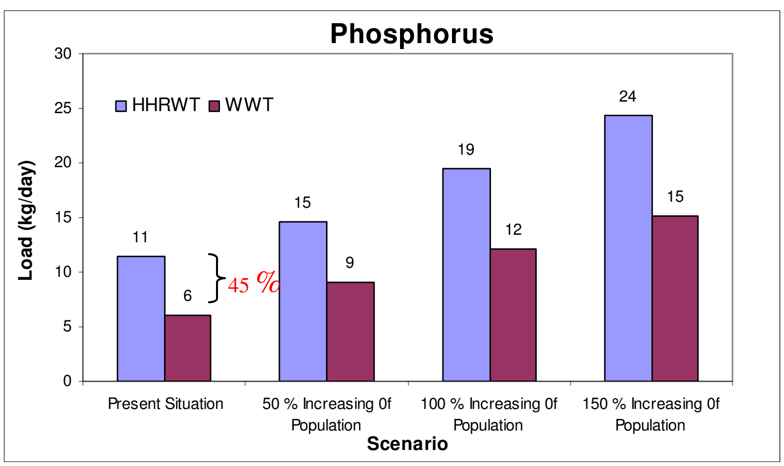
Nitrogen (g/day)									
Flux	Description	Present Situation		50 % Increasing 0f Population		100 % Increasing 0f Population		150 % Increasing 0f Population	
		HHRWT	WWT	HHRWT	WWT	HHRWT	WWT	HHRWT	WWT
F1	Domestic-sewer system	42420	29694	63630	44541	84840	59388	106051	74235
F2	Domestic-sewer system	59489	41643	89234	62464	118979	83285	148723	104106
F3	Domestic-sewer system	65582	45908	98373	68861	131164	91815	163955	114769
F4	Stormwater-Drainage	3252	3252	4878	4878	6504	6504	8133	8133
F5	Stormwater-Drainage	1309	1309	1964	1964	2618	2618	3273	3273
F6	Stormwater-Drainage	467	467	699	699	933	933	1168	1168
F7	Sedimentationa/Sorption	16396	11477	24593	17215	32791	22954	40989	28692
F8	Urban Agrculture Uptake	136	136	136	136	136	136	136	136
F9	Stormwater-Drainage	49051	34295	73644	51510	98237	68725	122831	85941
F10	Urban Agrculture Uptake	1096	1096	1096	1096	1096	1096	1096	1096
F11	Stormwater-Drainage	252	252	376	376	502	502	628	628
F12	Domestic-sewer system	3284	2299	4926	3448	6567	4597	8209	5746
F13	Stream/Surface water	57615	41874	86486	62874	115362	83880	144242	104889

Phosporus (g/day)									
Flux	Description	Present Situation		50 % Increasing 0f Population		100 % Increasing 0f Population		150 % Increasing 0f Population	
		HHRWT	WWT	HHRWT	WWT	HHRWT	WWT	HHRWT	WWT
F1	Domestic-sewer system	7563	5294	11345	7941	15126	10588	18908	13235
F2	Domestic-sewer system	10606	7424	15910	11137	21213	14849	26516	18561
F3	Domestic-sewer system	11693	8185	17539	12277	23385	16370	29232	20462
F4	Stormwater-Drainage	230	230	345	345	460	460	575	575
F5	Stormwater-Drainage	93	93	139	139	185	185	232	232
F6	Stormwater-Drainage	33	33	49	49	66	66	83	83
F7	Sedimentationa/Sorption	1169	818	4385	1228	5846	1637	7308	2046
F8	Urban Agrculture Uptake	11	11	11	11	11	11	11	11
F9	Stormwater-Drainage	10512	7355	13143	11039	17528	14722	21913	18405
F10	Urban Agrculture Uptake	164	164	164	164	164	164	164	164
F11	Stormwater-Drainage	18	18	27	27	36	36	44	44
F12	Domestic-sewer system	585	410	878	615	1171	820	1464	1025
F13	Stream/Surface water	11471	8139	14582	12213	19446	16288	24310	20364

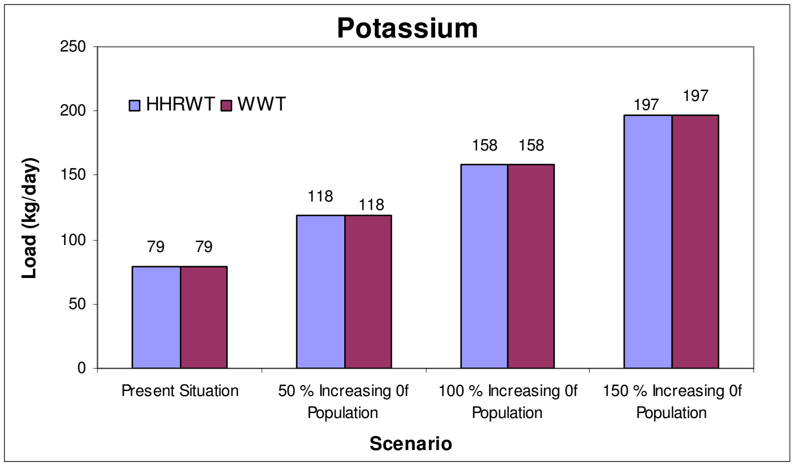
Flux	Description	Potassium (g/day)							
		Present Situation		50 % Increasing 0f Population		100 % Increasing 0f Population		150 % Increasing 0f Population	
		HHRWT	WWT	HHRWT	WWT	HHRWT	WWT	HHRWT	WWT
F1	Domestic-sewer system	53692	37584	80537	56376	107383	75168	134229	93960
F2	Domestic-sewer system	75296	52707	112944	79061	150592	105414	188240	131768
F3	Domestic-sewer system	83008	58105	124512	87158	166016	116211	207519	145264
F4	Stormwater-Drainage	26	26	26	26	26	26	26	26
F5	Stormwater-Drainage	26	26	26	26	26	26	26	26
F6	Stormwater-Drainage	26	26	26	26	26	26	26	26
F7	Sedimentationa/Sorption	8301	5811	31128	8716	41504	11621	51880	14526
F8	Urban Agrculture Uptake	25	25	25	25	25	25	25	25
F9	Stormwater-Drainage	74682	52270	93359	78417	124487	104565	155615	130712
F10	Urban Agrculture Uptake	603	603	603	603	603	603	603	603
F11	Stormwater-Drainage	26	26	26	26	26	26	26	26
F12	Domestic-sewer system	4156	2909	6234	4364	8312	5819	10391	7273
F13	Stream/Surface water	78943	55284	99698	82886	132904	110488	166110	138090



(a)



(b)



(c)

Figure 6. 10: Comparisons of Nutrients Loads under Different Strategies and Scenarios

7 DISCUSSION

It is clear that the proposed strategies will result to a decrease of imported water need to be supplied to the study area. The proposed strategies under present and future scenario of population growth and climate change prediction shows different performance of their water balance. The result from strategies and scenarios modelled by Aquacycle are compared and some remarkable results are discussed in this chapter.

7.1 Water Demand Projection

Provided current average water consumption of 55 L/capita day for domestic use will remain the same, there is an increase of annual water consumption from around 500 m^3 in 2000 up to 1250 m^3 in 2021 (fig 6.2). With the current existing water supply capacity it is obvious that the water shortage in the future will get worse.

7.2 Water Balance

7.2.1 Strategies for Present Situation

The average annual water balance on proposed strategies shows that the combination strategy (HHRWT and cluster wastewater treatment) is likely to have the least imported water. Compared to the current situation where no intervention takes place, the decrease in imported water reach to 75000 m^3 or about 52 % of current imported water needed (table 6.1). This can be explained as the amount of water supply from combination strategy is more than those of only one particular strategy.

Monthly imported water for each strategy in all clusters shows the same pattern of fluctuation. The difference is only average amount of water, as it is defined by the number of population in each cluster.

The imported water for onsite WWT and cluster WWT strategy is to a large extent the same, due to the amount of wastewater to be recycled is relatively constant. This is the advantage of WWT strategy as its availability is reliable. Moreover the usage of WWT in both scale are for same purpose that is for toilet flushing, thus the size is designed based on the average demand for each inhabitant. The fluctuation of monthly average imported water for onsite and cluster WWT is related to number of days within month.

The fluctuation of monthly average imported water using HHRWT is due to number of rainy days within month as shown in fig 7.1. The amount of water to be used from rainwater tank still can be increased, as there is water spilling from rain tank, as shown in the annex 9. However, the size of tank is the main constraint of this strategy. The selected 1m^3 tanks are because most of the families already have this tank and it is sufficiently big for an average five inhabitant per house. In addition, the area for putting bigger tank is also one of the concerns, where not every family has enough space in their yard. Thus the increasing of tank size is considerably impractical.

Since the available water to be recycled from cluster WWT is considerably constant, the fluctuation of imported water under combination strategy is due to the availability of rain water. This can be seen from fig 6.6, where the variation of average imported water under HHRWT and combination strategy has the same pattern.

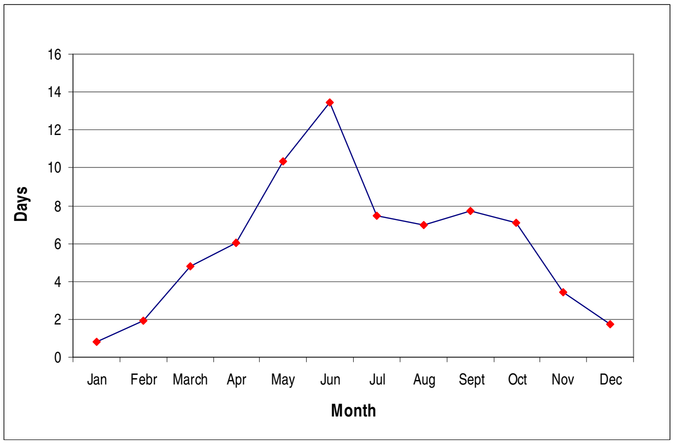


Figure 7. 1: Average Number of Rain days

From table 6.1 it is also shown stormwater runoff and wastewater discharge of proposed strategies is less compare to present situation where no interventions take place. This means, for any strategy chosen, there will be a lower total costs for wastewater handling, since there will be a reduced load of water.

7.2.2 Strategies for Population Growth Scenario

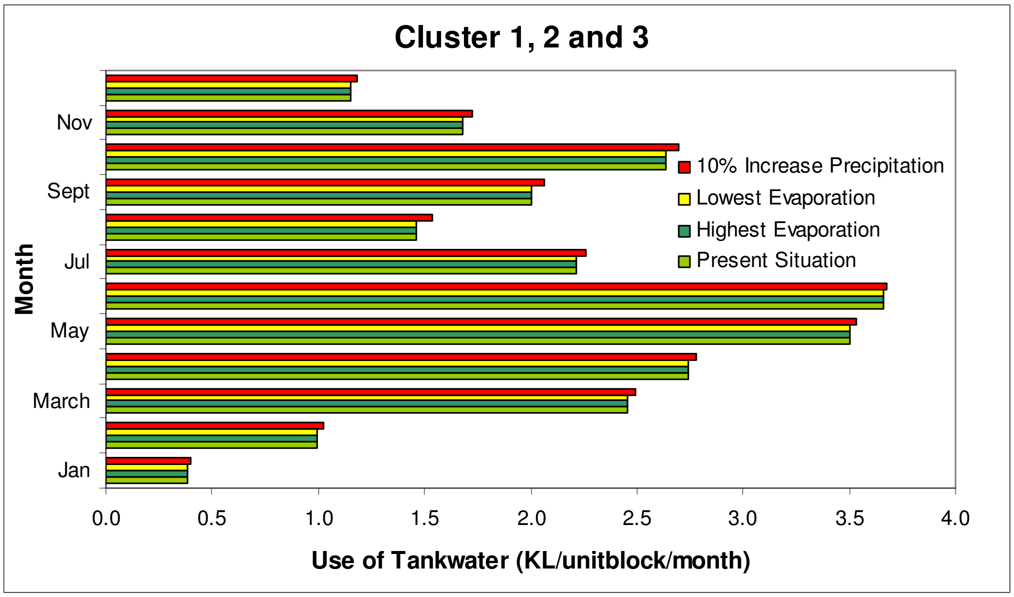
As the population is increasing, the total water consumption will also increase. Similar to the present situation, the performance of proposed strategies shows that the combination of HHRWT and cluster WWT has the least amount of imported water.

Fig 7.2 shows the need of imported water under combination strategy up to 2016 is still less than the baseline situation (2000). It means up to 2016 the existing water supply system will still able to meet the water demand (with an assumption water consumption per capita per day will remain the same) provided the combination strategy will be applied. However, by simply depend only on the current water supply there is a need to increase the existing supply of 100% by 2016 or 220 % by 2021.

7.2.3 Strategies for Climate Change Scenario

Since the prediction of climate change is only on evaporation, the performance of water balance between present climate condition and future climate change scenario shows no difference. Fig 6.7 shows the amount of imported water for present situation, for both highest increasing of evaporation and lowest decreasing of evaporation are all the same. The difference is only on the amount of stormwater and wastewater discharge, which likely to happen due to the natural evaporation.

However, for the simulation 10 % increasing of precipitation, the amount of imported water under combine strategy is less compare to present situation and other climate change scenario. This is due to the increasing use of tank water as the rainwater supply increased. This can be explained from the comparison of use of tank water between present situation and climate change scenarios under combination strategy as shown in figure 7.2. The difference between cluster 4 compare to other clusters is related to the average roof size in cluster 4 is smaller compare to others.



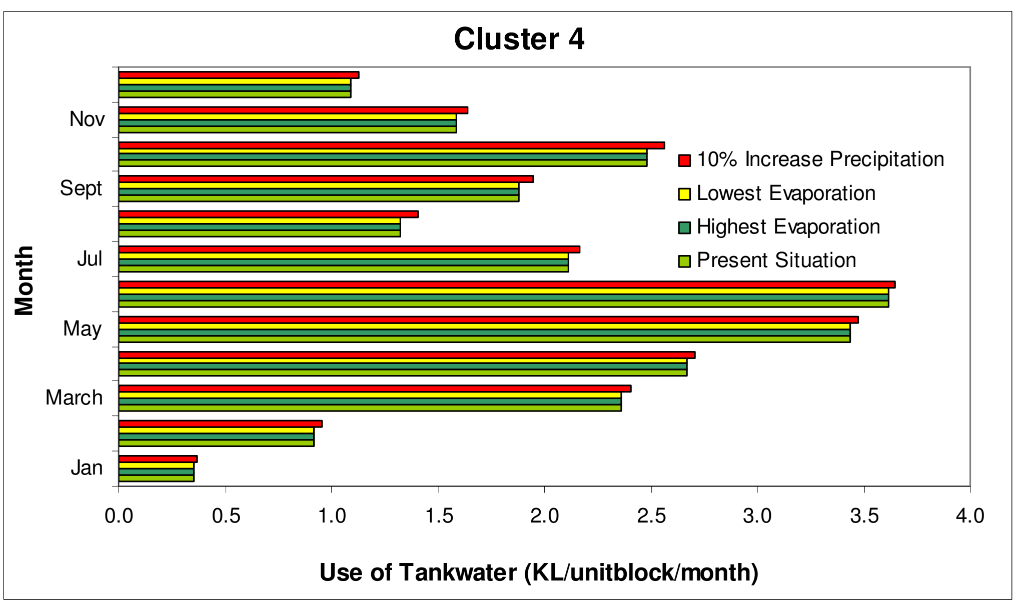


Figure 7. 2: Comparison of Use of Tank water under Combine Strategy

7.3 Nutrient Flows

Since the main nutrient sources is domestic wastewater, it can be predicted that as the population increased the nutrients load is also increasing, as presented in fig 6.8. Except for its usage for irrigation in urban agriculture, there is a potential source of nutrients that can be utilized from wastewater and stormwater discharge. Under baseline situation assuming the nutrients uptake for existing urban agriculture follows table 6.6, there will be enough N, P, K source to be applied in 175 ha, 84 ha and 47 ha agriculture land respectively per year. Hence, for exiting urban agriculture area, there are more supplied nutrients than demand.

Based on nutrients flux calculation under different strategies as presented in fig 6.10, there is a decrease nutrients load (N and P) as WWT is applied. This is due to the wastewater pre-treatment application, before it is recycled. This also means once WWT applied, nutrients loading that enter Kpeshie lagoon will also reduce. However, a decreasing on nutrients contents will still enough to meet demands for existing urban agriculture (fig 6.9).

8 Conclusion and Recommendation

Due to the population growth and climate change prediction above, it is clear that there is an urgent need for water source alternatives to provide adequate urban water supply. By taking into consideration water recycled practices through HHRWT, waste water treatment and the combination of those strategies, less amount of imported water will be needed. However further research is needed as identified in this study.

8.1 Conclusion

Based on the water balance simulation, all proposed strategies (HHRWT, WWT and the combination of them) result to the decrease of imported water needed to be distributed to the study area, as well as amount of wastewater and stormwater discharge. Combination of HHRWT and cluster WWT could be a promising strategy since it contributes significantly to the reducing amount of imported water by 52% on present situation.

HHRWT strategy contributes significantly to the reduced amount of imported water, but has drawback on the tank size and its availability, as it highly depends on number of rainy days. Wastewater treatment strategy has less decrease on the amount important water compare to HHRWT, but it is quite reliable since its availability is considerably almost constant and independent of climate.

Increase in population growth has significant impact to the water consumption demand. On the other hand, climate change prediction on evapotranspiration has insignificant impact to the water balance performance of proposed strategy, but 10% increasing in precipitation will likely result to the change of urban water balance composition.

Nutrient load is increased as the population is increasing. Under present situation, WWT strategy is likely will reduce the nutrients load to Kpeshie Lagoon by 27 % and 45 % for Nitrogen and Phosphorus respectively. However, despite of proposed strategies application, nutrients load still sufficient to meet current demand for existing urban agriculture.

8.2 Recommendation

Due to detail data input needed for water balance simulation, it is recommended to use a specific data for each particular study area to get better prediction on water balance performance.

There is a need for further research for the applicability of proposed strategies, as for each strategy it highly depends on local situation.

There is a need for adopting locally feasible nutrient recycle technique, as there is potential nutrient source within study area.

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ANNEX 1. Data Input Unit Block
Present Situation and Population Growth Scenario

DATA INPUT		Baseline				HH_RWT				ONSITE_WWTP				Cluster_WWTP				Combination			
		cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4
1	Supply garden irrigation with imported water? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Rain tank storage capacity in m3 >= 0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1
3	Rain tank exposed surface in m2 >= 0	0	0	0	0	50	50	50	40	0	0	0	0	0	0	0	0	50	50	50	40
4	Rain tank first flush in Litres >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Domestic hot water from rain tank? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Domestic kitchen cold water from rain tank? 0 or 1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1
7	Domestic bathroom cold water from rain tank? 0 or 1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1
8	Domestic laundry cold water from rain tank? 0 or 1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1
9	Domestic toilet water from rain tank? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Domestic garden irrigation from rain tank? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Kitchen greywater for sub-surface irrigation? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Bathroom greywater for subsurface irrigation? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Laundry greywater for subsurface irrigation? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Wastewater treatment and storage capacity in m3, >= 0	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0	0	0	0	0.05	0.05	0.05	0.05
15	Wastewater treatment and storage exposed surface in m2, >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Treat kitchen wastewater? 0 or 1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
17	Treat bathroom wastewater? 0 or 1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
18	Treat laundry wastewater? 0 or 1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
19	Treat toilet wastewater? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Toilet water from wastewater store? 0 or 1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
21	Garden irrigation from wastewater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Wastewater storage overflow to sewer? 0 or 1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
23	Wastewater storage overflow to storm water? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	Unit block runoff draining to cluster stormwater store? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
25	Supply toilet from a cluster stormwater store? Specify cluster number or 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	Supply garden irrigation from a cluster stormwater store? Specify cluster number or 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Unit block wastewater draining to cluster wastewater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
28	Supply toilet from a cluster wastewater store? Specify cluster number or 0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	0	0	0	0
29	Supply garden irrigation from a cluster wastewater store? Specify cluster number or 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Supply toilet from catchment scale stormwater storage? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Supply garden irrigation from catchment scale stormwater storage? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	Supply toilet from catchment scale wastewater storage? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Supply garden irrigation from catchment scale wastewater storage? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ANNEX 2. Data Input Cluster
Present Situation

DATA INPUT		Baseline				HH_RWT				Onsite_WWTP				Cluster_WWTP				Combination			
		cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4
1	Cluster scale stormwater storage capacity in m3, >= 0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0
2	Cluster scale stormwater storage exposed surface in m2, >= 0	0	0	10	0	0	0	10	0	0	0	10	0	0	0	10	0	0	0	10	0
3	Cluster scale stormwater storage first flush in m3, >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Road runoff to cluster scale stormwater store? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
5	Collect stormwater from upstream slucters? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
6	Cluster scale wastewater storage capacity in m3, >= 0	0	0	30000	0	0	0	30000	0	0	0	30000	0	30	12	30012	2.5	30	12	30012	2.5
7	Cluster scale wastewater storage exposed surface in m2, >= 0	0	0	10000	0	0	0	10000	0	0	0	10000	0	0	0	10000	0	0	0	10000	0
8	Collect wastewater from upstream clusters? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	1	0	1	1	1
9	Cluster scale wastewater storage overflow to sewer? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	1	1	1	1	1	1	1	1
10	Cluster scale wastewater storage overflow to stormwater? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Aquifer storage and recovery storage capacity in m3, >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Maximum aquifer storage and recovery recharge rate in m3/day, >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Maximum aquifer storage and recovery rate in m3/day, >= 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Supply public open space irrigation from imported water? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Supply public open space irrigation from a cluster stormwater store? Specify cluster number or 0	0	0	3	0	0	0	3	0	0	0	3	0	0	0	3	0	0	0	3	0
16	Supply public open space irrigation from a cluster wastewater store? Specify cluster number or 0	0	0	3	0	0	0	3	0	0	0	3	0	0	0	3	0	0	0	3	0
17	Supply public open space irrigation from the catchment stormwater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Supply public open space irrigation from the catchment wastewater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Drain stormwater runoff into the cluster stormwater store? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0

Population Growth Scenario

DATA INPUT		Cluster WWT and Combination											
		50% Increasing Population				100% Increasing Population				150% Increasing Population			
		cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4
1	Cluster scale stormwater storage capacity in m3, >= 0	0	0	5	0	0	0	5	0	0	0	5	0
2	Cluster scale stormwater storage exposed surface in m2, >= 0	0	0	10	0	0	0	10	0	0	0	10	0
3	Cluster scale stormwater storage first flush in m3, >= 0	0	0	0	0	0	0	0	0	0	0	0	0
4	Road runoff to cluster scale stormwater store? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0
5	Collect stormwater from upstream slucters? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0
6	Cluster scale wastewater storage capacity in m3, >= 0	45	18	30016	4	60	24	30022	5	75	30	30027	6
7	Cluster scale wastewater storage exposed surface in m2, >= 0	0	0	10000	0	0	0	10000	0	0	0	10000	0
8	Collect wastewater from upstream clusters? 0 or 1	0	1	1	1	0	0	1	0	0	0	1	0
9	Cluster scale wastewater storage overflow to sewer? 0 or 1	1	1	1	1	0	0	1	0	0	0	1	0
10	Cluster scale wastewater storage overflow to stormwater? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0
11	Aquifer storage and recovery storage capacity in m3, >= 0	0	0	0	0	0	0	0	0	0	0	0	0
12	Maximum aquifer storage and recovery recharge rate in m3/day, >= 0	0	0	0	0	0	0	0	0	0	0	0	0
13	Maximum aquifer storage and recovery rate in m3/day, >= 0	0	0	0	0	0	0	0	0	0	0	0	0
14	Supply public open space irrigation from imported water? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0
15	Supply public open space irrigation from a cluster stormwater store? Specify cluster number or 0	0	0	3	0	0	0	3	0	0	0	3	0
16	Supply public open space irrigation from a cluster wastewater store? Specify cluster number or 0	0	0	3	0	0	0	3	0	0	0	3	0
17	Supply public open space irrigation from the catchment stormwater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0
18	Supply public open space irrigation from the catchment wastewater store? 0 or 1	0	0	0	0	0	0	0	0	0	0	0	0
19	Drain stormwater runoff into the cluster stormwater store? 0 or 1	0	0	1	0	0	0	1	0	0	0	1	0

ANNEX 3. Data Input Catchment

DATA INPUT		Base Line
1	Catchment size in hectares, >= 0	444.69
2	0	0
3	Catchment scale stormwater storage capacity in m3, >= 0	0
4	Catchment scale stormwater storage exposed surface area in m2, >= 0	0
5	Catchment scale stormwater storage first flush in m3, >= 0	0
6	Catchment scale wastewater storage capacity in m3, >= 0	0
7	Catchment scale wastewater storage exposed surface area in m3, >= 0	0
8	Catchment scale wastewater storage overflow to stormwater not sewer? 0 or 1	0

ANNEX 4. Parameter and Initial Value

Present Situation

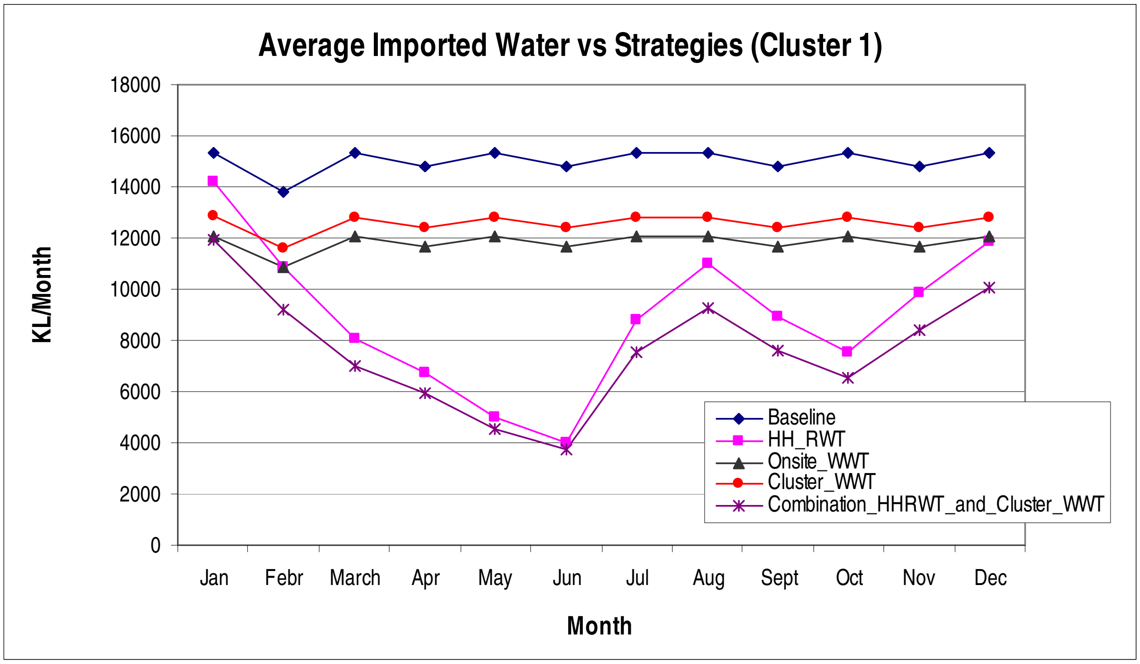
DATA INPUT (Measured parameters)		cluster 1	cluster 2	cluster 3	cluster 4
1	No. of blocks in cluster, >= 0	1108	446	159	85
2	Avrg household occupancy, >= 0	5	5	5	5
3	Area of unit block in m2, >= 0	250	250	250	200
4	Area of unit block garden in m2, >= 0	115	115	115	90
5	Area of unit block roof in m2, >= 0	125	125	125	100
6	Area of unit block pavement in m2, >= 0	10	10	10	10
7	Per cent of unit block garden irrigated as a %	0	0	0	0
8	Total area of cluster in hectares, >= 0	139.64	130.18	106.18	68.67
9	Road area in hectares, >= 0	4.08	2.28	1.78	0.47
10	Area in public open space in hectares, >= 0	107.85	116.75	100.43	66.48
11	Percent of public open space irrigated as a %	0	0	50	0
12	Water supply leakage rate as a %	25	25	25	25
13	Cluster stormwater output flows into cluster No? Specific cluster number or 0	2	3	4	0
14	Cluster wastewater output flows into cluster No? Specific cluster number or 0	2	3	4	0

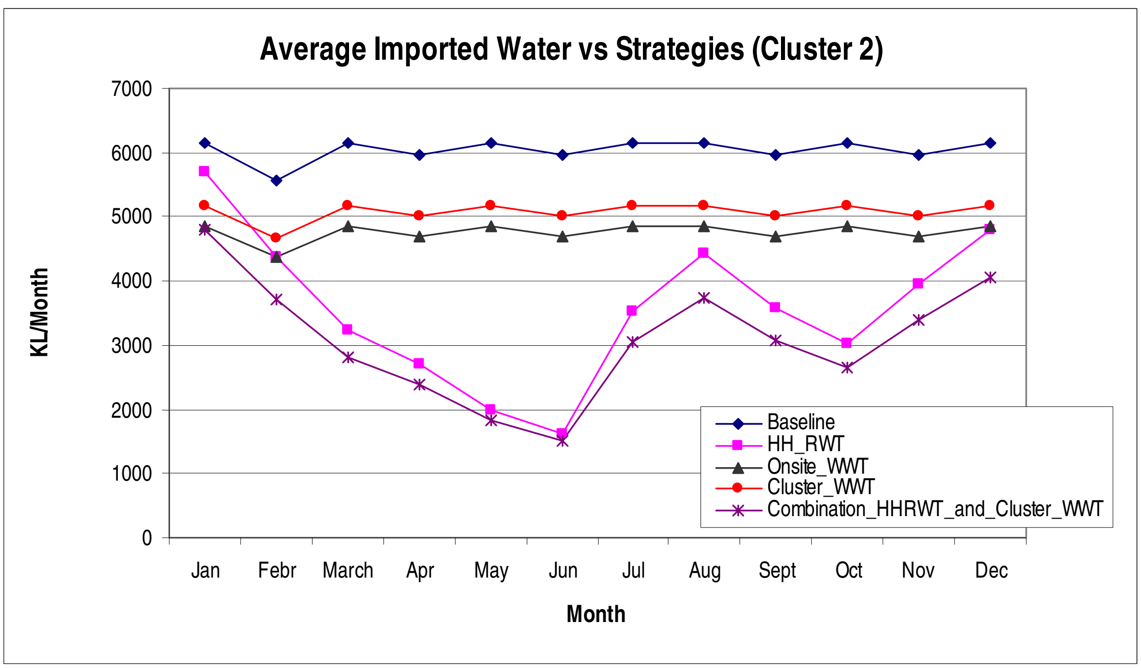
Population Growth Scenario

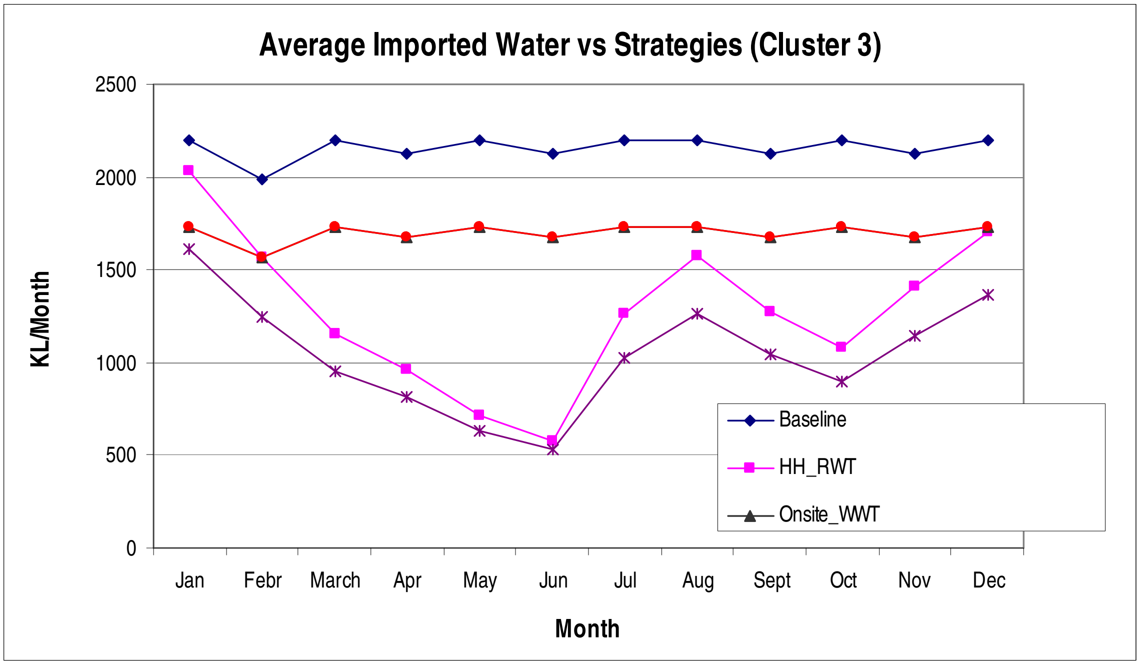
DATA INPUT (Measured Parameters)		50% Increasing Population				100% Increasing Population				150% Increasing Population			
		cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4	cluster 1	cluster 2	cluster 3	cluster 4
1	No. of blocks in cluster, >= 0	1662	669	238	128	2216	892	318	171	2771	1115	398	214
2	Avrg household occupancy, >= 0	5	5	5	5	5	5	5	5	5	5	5	5
3	Area of unit block in m2, >= 0	250	250	250	200	250	250	250	200	250	250	250	200
4	Area of unit block garden in m2, >= 0	115	115	115	90	115	115	115	90	115	115	115	90
5	Area of unit block roof in m2, >= 0	125	125	125	100	125	125	125	100	125	125	125	100
6	Area of unit block pavement in m2, >= 0	10	10	10	10	10	10	10	10	10	10	10	10
7	Per cent of unit block garden irrigated as a %	0	0	0	0	0	0	0	0	0	0	0	0
8	Total area of cluster in hectares, >= 0	139.64	130.18	106.18	68.67	139.64	130.18	106.18	68.67	139.64	130.18	106.18	68.67
9	Road area in hectares, >= 0	4.9	2.7	2.1	0.57	5.7	3.2	2.5	0.66	6.5	3.6	2.8	0.76
10	Area in public open space in hectares, >= 0	93.1	110.7	98	65.5	78.5	104.7	95.7	64.6	63.8	98.6	93.3	63.6
11	Percent of public open space irrigated as a %	0	0	50	0	0	0	50	0	0	0	50	0
12	Water supply leakage rate as a %	25	25	25	25	25	25	25	25	25	25	25	25
13	Cluster stormwater output flows into cluster No? Specific cluster number or 0	2	3	4	0	2	3	4	0	2	3	4	0
14	Cluster wastewater output flows into cluster No? Specific cluster number or 0	2	3	4	0	2	3	4	0	2	3	4	0

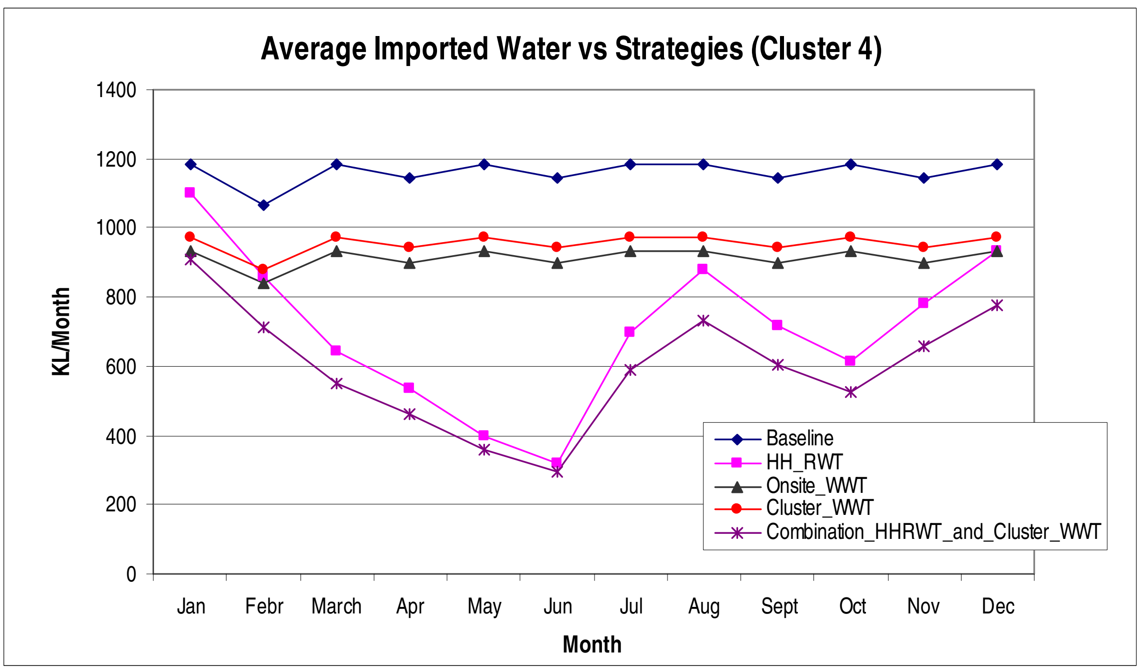
DATA INPUT (Calibrated Parameters)		General			
		cluster 1	cluster 2	cluster 3	cluster 4
1	Per cent area of pervious store 1 as a %	42	42	42	42
2	Capacity of pervious store 1 in mm	30	30	30	30
3	Capacity of pervious store 2 in mm	130	130	130	130
4	Roof area max initial loss in mm	0	0	0	0
5	Effective roof area as a %	100	100	100	100
6	Paved area max initial loss in mm	0	0	0	0
7	Effective paved area as a %	100	100	100	100
8	Road area max initial loss in mm	0	0	0	0
9	Effective road area as a %	100	100	100	100
10	Base flow index as a ratio	0.55	0.55	0.55	0.55
11	Base flow recession constant as a ratio	0.02	0.02	0.02	0.02
12	Infiltration index as a ratio	0.095	0.095	0.095	0.095
13	Infiltration store recession constant as a ratio	0.12	0.12	0.12	0.12
14	Percent of surface runoff as inflow as a %	3	3	3	3
15	Garden trigger-to-irrigate as a ratio	0.5	0.5	0.5	0.5
16	Public open space trigger-to-irrigate as a ratio	0.5	0.5	0.5	0.5

ANNEX 5. Monthly Average Imported Water for 100 % Population Growth Scenario

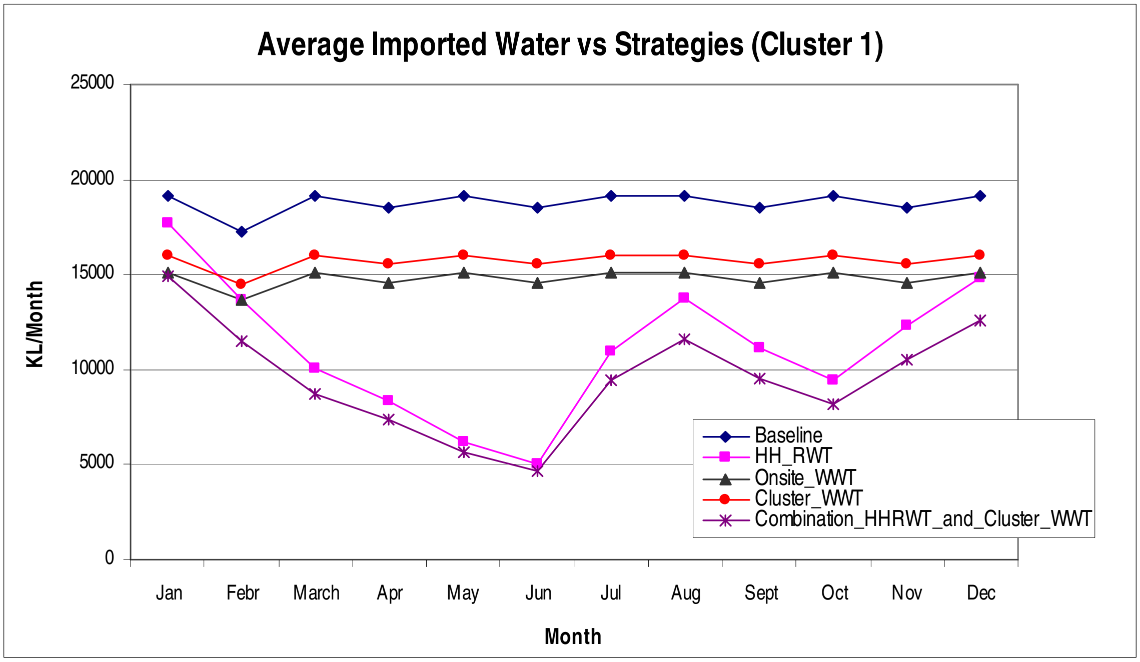


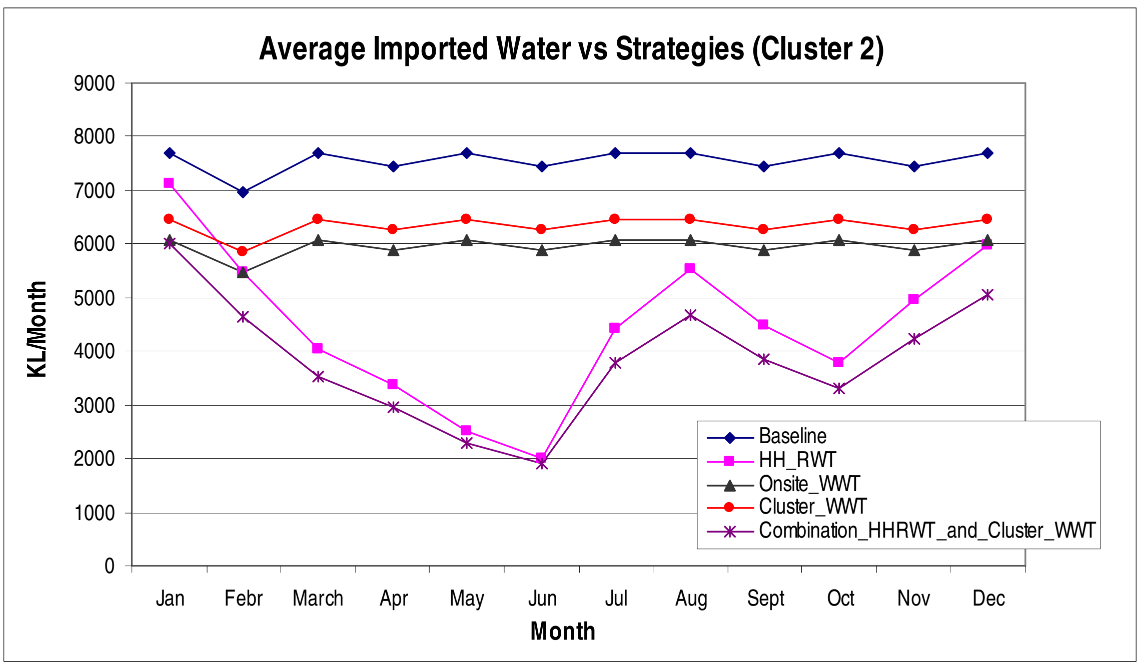


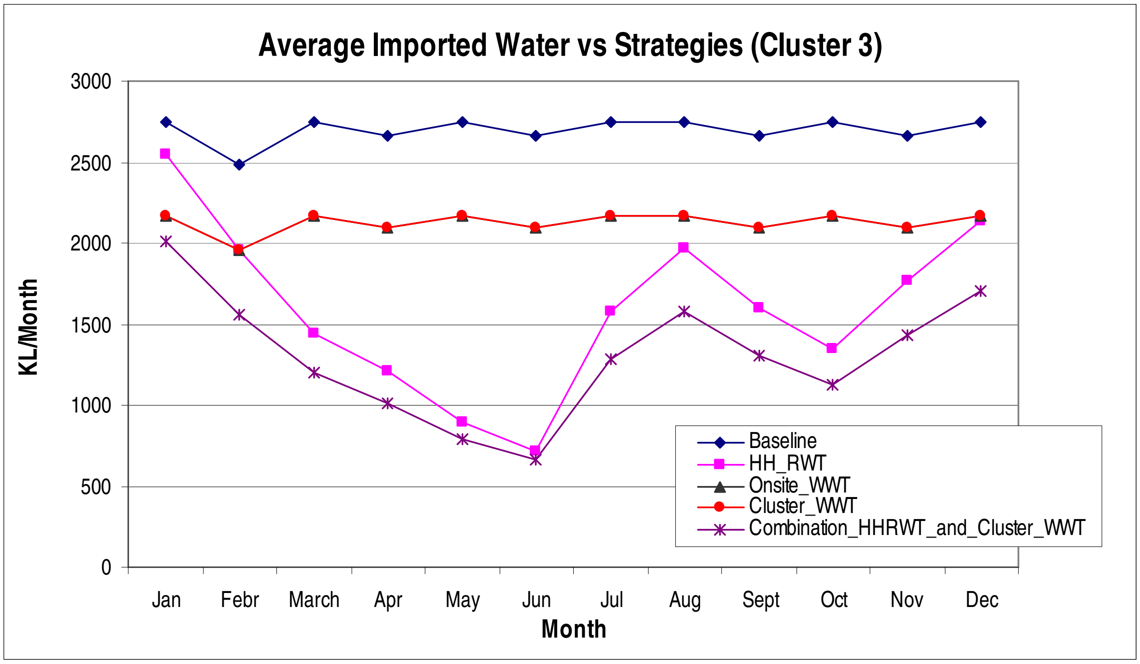

Average Imported Water vs Strategies (Cluster 3)
2500
2000
1500
1000
500
0
KL/Month
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HH_RWT
Onsite_WWT

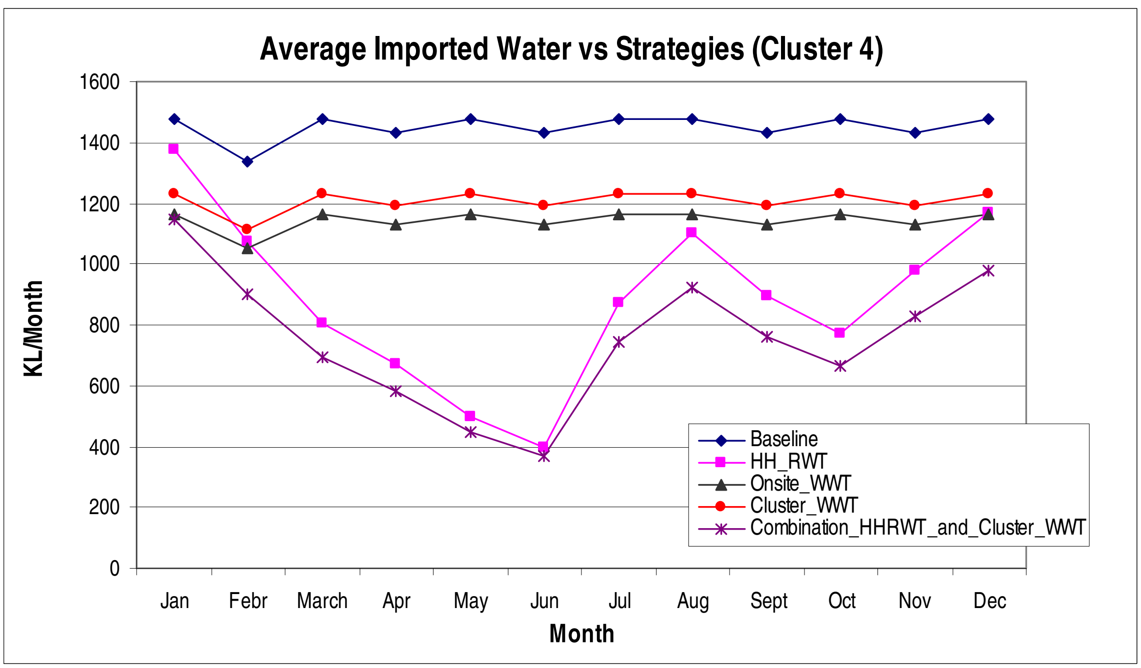

Average Imported Water vs Strategies (Cluster 4)
1400
1200
1000
800
600
400
200
0
KL/Month
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HH_RWT
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

ANNEX 6. Monthly Average Imported Water for 150 % Population Growth Scenario

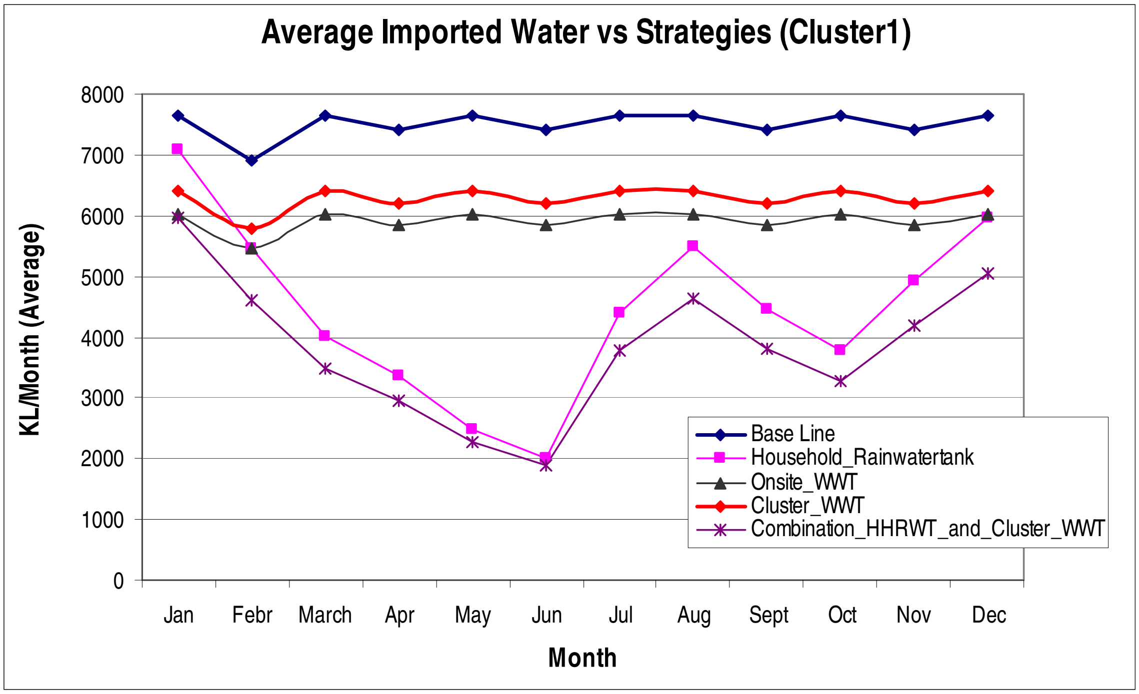


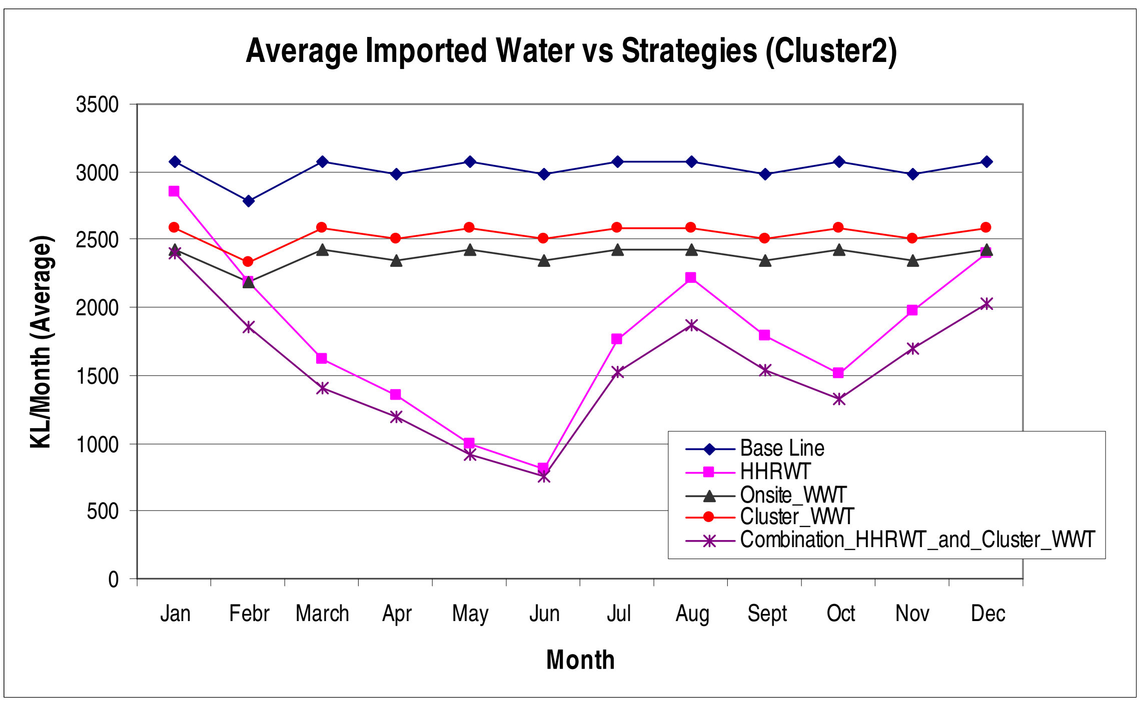


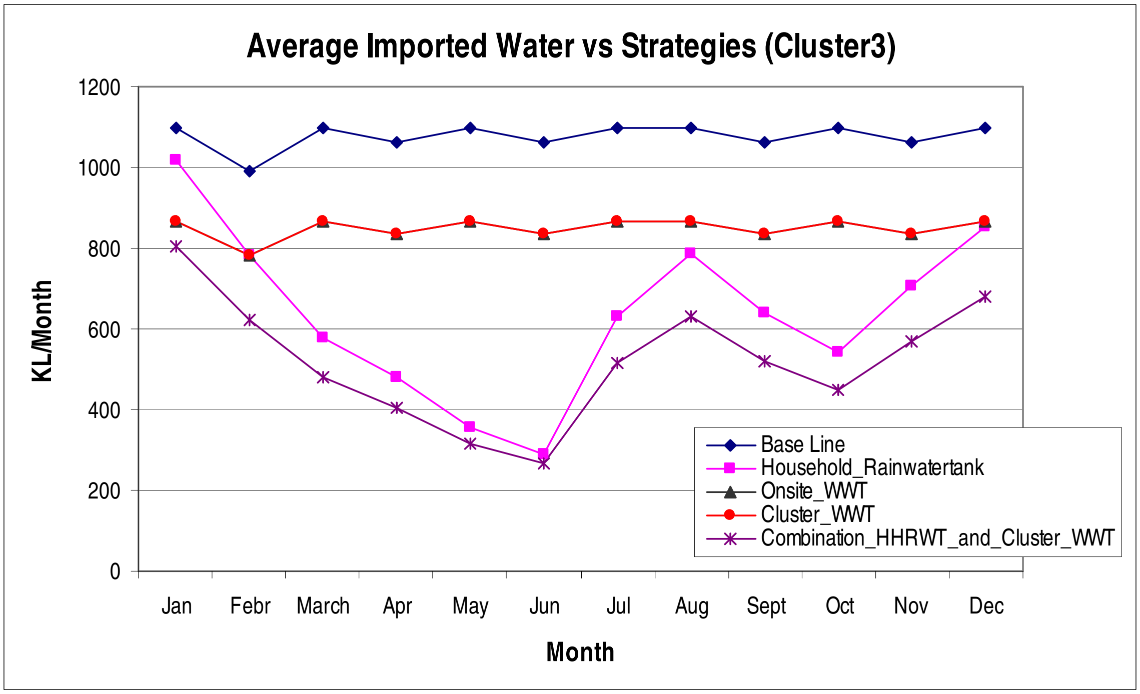

Average Imported Water vs Strategies (Cluster 3)
KL/Month
3000
2500
2000
1500
1000
500
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HH_RWT
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT


Average Imported Water vs Strategies (Cluster 4)
KL/Month
1600
1400
1200
1000
800
600
400
200
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HH_RWT
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

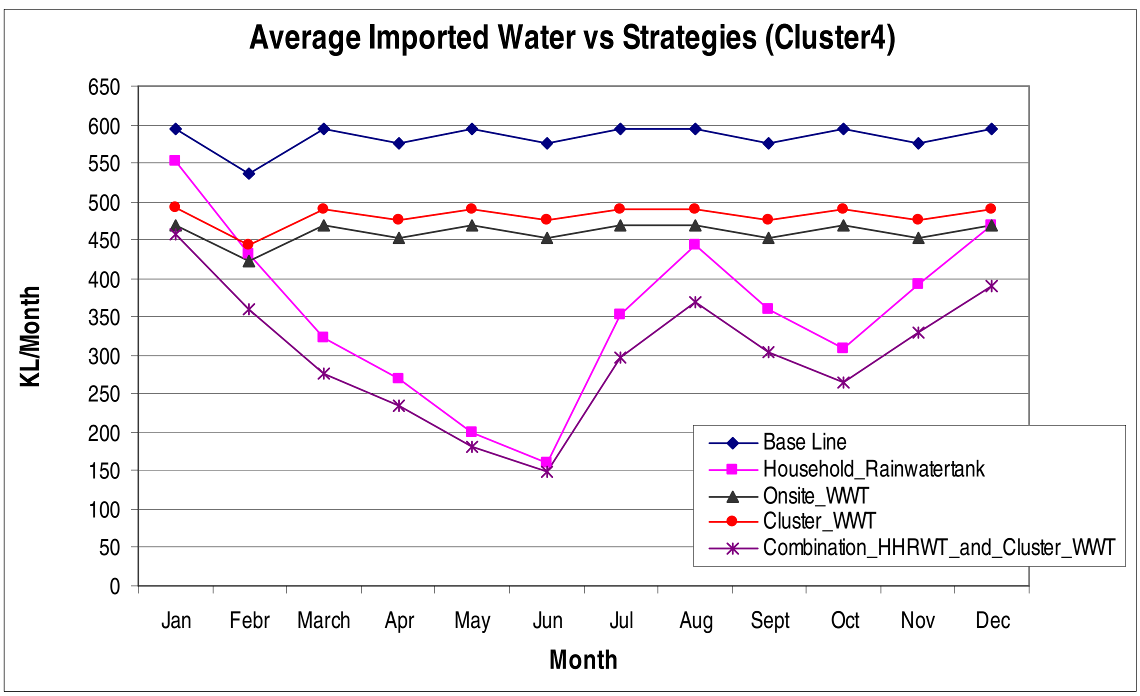
ANNEX 7. Monthly Average Imported Water for Lowest Evaporation Scenario





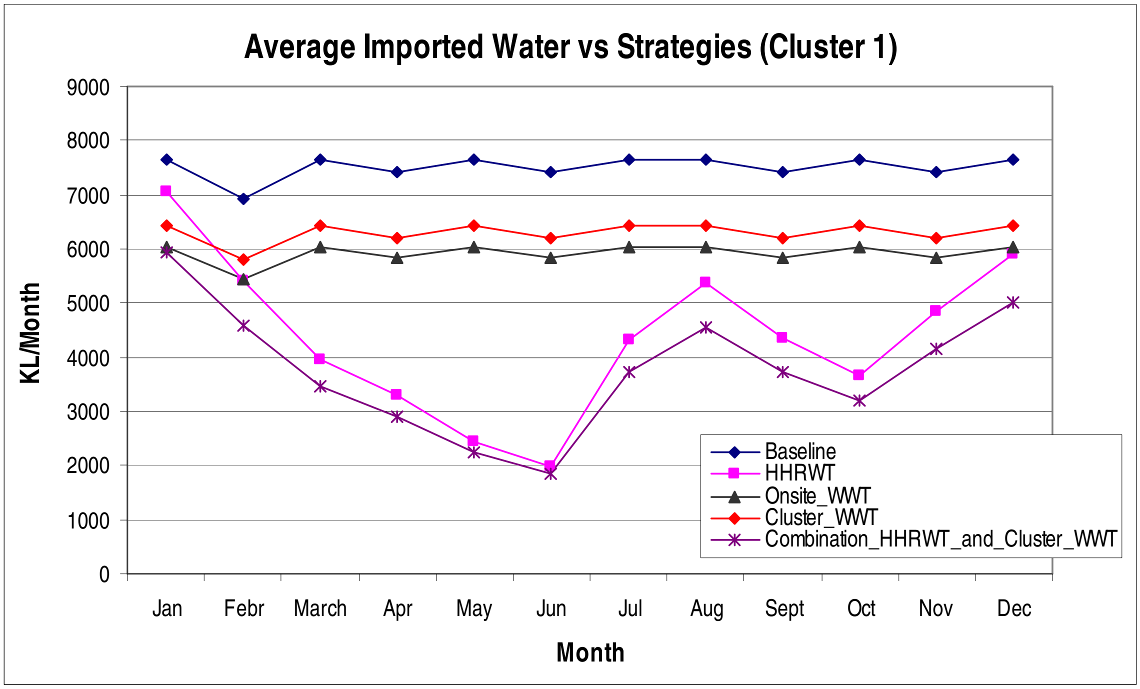


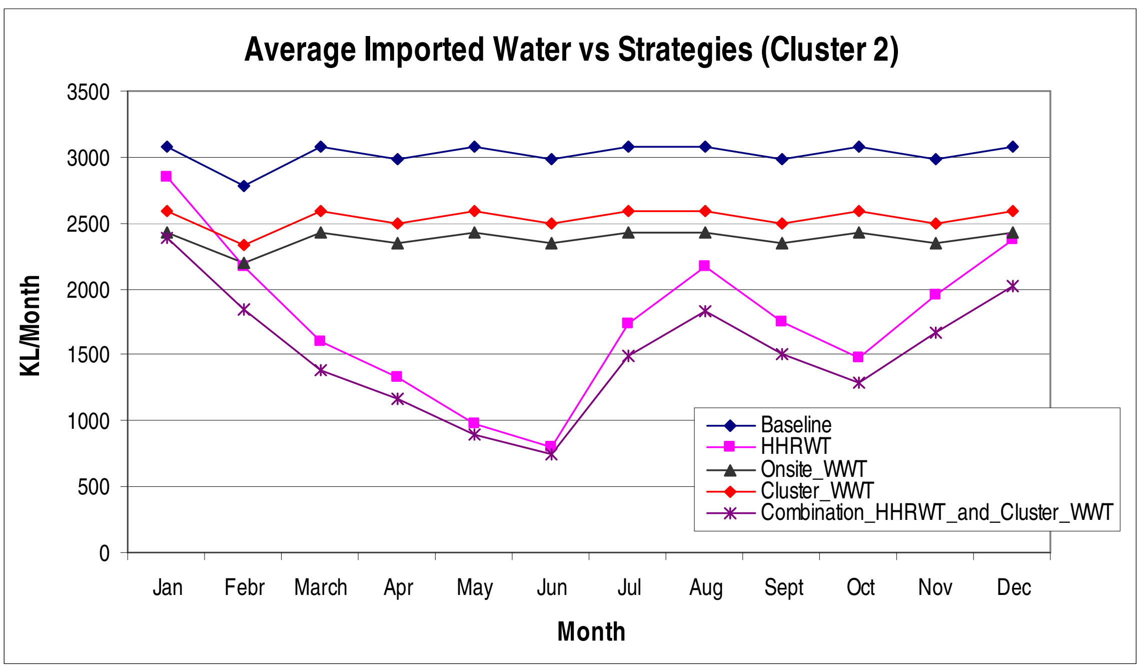
Average Imported Water vs Strategies (Cluster3)
KL/Month
1200
1000
800
600
400
200
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Base Line
Household_Rainwatertank
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

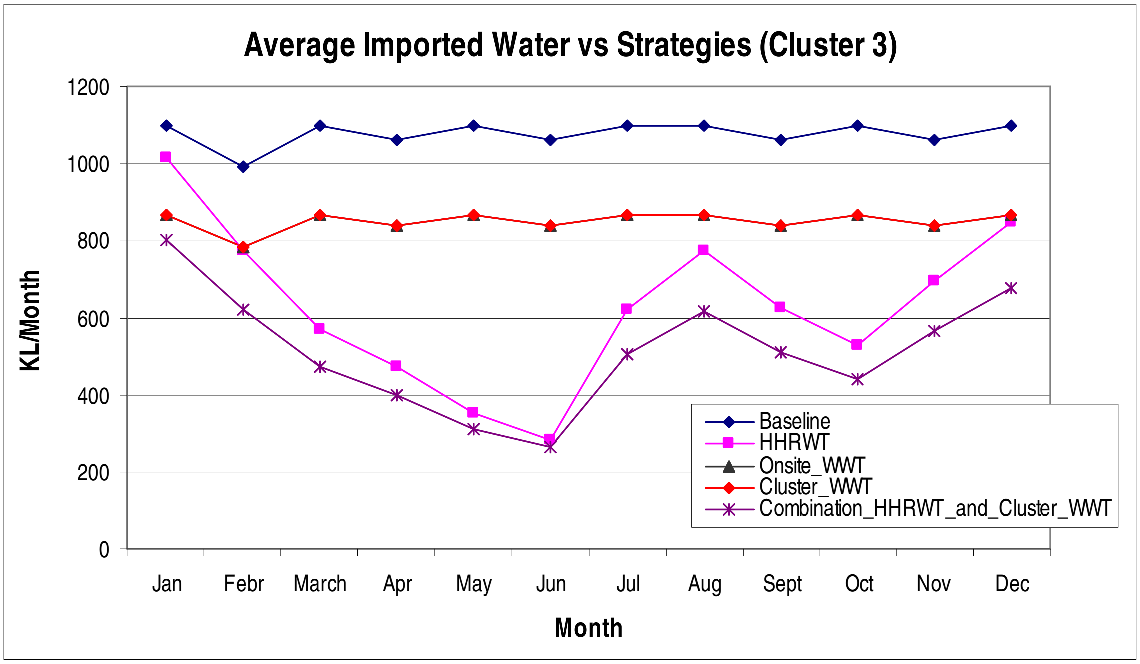


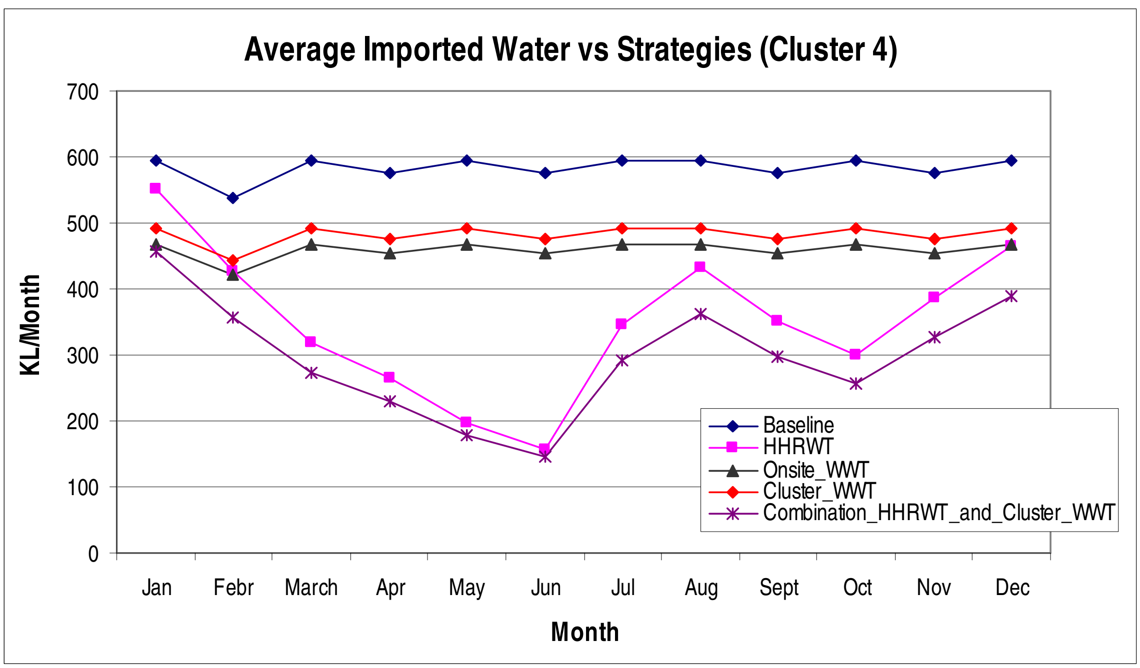
Average Imported Water vs Strategies (Cluster4)
KL/Month
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Base Line
Household_Rainwatertank
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT

ANNEX 8. Monthly Average Imported Water for 10 % Increasing of Precipitation






Average Imported Water vs Strategies (Cluster 3)
KL/Month
1200
1000
800
600
400
200
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HHRWT
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT


Average Imported Water vs Strategies (Cluster 4)
KL/Month
700
600
500
400
300
200
100
0
Jan
Febr
March
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
Baseline
HHRWT
Onsite_WWT
Cluster_WWT
Combination_HHRWT_and_Cluster_WWT