POTENTIAL FOR ENERGY CONSERVATION IN NWSDB WATER SUPPLY SCHEMES

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Degree of Master of Engineering

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Declaration

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Senior Lecturer,
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Abstract

This research was aimed to study the potentials for conservation of energy in main schemes of NWSDB in Southern Province. The results are usable on benchmarking energy usage on water supply schemes those operating under NWSDB. From the history of operation of NWSDB over 40 years, energy audits for the resent past were studied for water supply schemes. Specific energy consumption is used to benchmark the energy consumption of each category of operations which leads to identify the potentials for energy conservation. An energy audit was carried out in Southern Province, region-vise Matara, Galle and Hambantota to evaluate the energy conservation potentials.

In electrical energy form, kinetic energy around 25 % of the total consumed is used for pumping raw water. Other 75% is used for major components including water treatments, treated water pumping and distribution networks. Apart from the energy usage on water treatment and pumping, component from total energy as high as 12% was identified as loss on non-revenue water, an area to work on reduction of energy usage.

The main area identified as need for improvements was pumping and transmission equipment and their unit operations where around 14% energy could be targeted for energy saving.

It is worth to improve water sources for free from algae, impurities, pollution and contamination through community awareness, national policy planning and programmed long term vision to meet huge energy conservation in future and to harvesting healthy generation out in danger with numerous diseases.

Direct distribution of water to consuming terminals with continuous pumping is better option to focus to save energy in vigorous amounts instead of distribution through elevated towers yet not ready to be implemented with prevailing electricity pattern in the country.

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List of Abbreviations

Abbreviation	Description
ADB	Asian Development Bank
AWWA	American Water Works Association
BPH	Booster Pump Hour
CARL	Current Annual Real Losses
CEB	Ceylon Electricity Board
DAF	Dissolved Air Floatation
DMS	Demand Side Management
ELL	Economic Level of Leakage
EPRI	Electrical Power Research Institute
GHG	Green House Gasses
GOSL	Government of Sri Lanka
ILI	Infrastructure Leakage Index
IWA	International Water Association
KPI	Key Performance Indicator
LECO	Lanka Electricity Company
LKR	Sri Lanka Rupee
NRW	Non-Revenue Water
NWSDB	National Water Supply and Drainage Board
PI	Performance Indicator
SCADA	Supervisory Control and Data Acquisition
SEC	Specific Energy Consumption
UARL	Unavoidable Annual Real Losses
VFD	Variable Frequency Drive
WHO	World Health Organization
WOP	Water Operators Partnership
WSS	Water Supply Scheme
WTP	Water Treatment Plan

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1. INTRODUCTION

1.1 Background

By 2035, energy consumption will increase by 50% which will increase the energy sector's water consumption by 85%. Today 15% of global water withdrawals are for energy production. Hydropower supplies about 20% of the world's electricity, a share that has remained stable since the 1990s. Energy requirements for surface water pumping are generally 30% lower than for groundwater pumping. It can be expected that groundwater will become increasingly energy intensive as water tables fall in several regions (WWAP, 2012).

Energy and water are intricately connected. Every living human sense the future with water scarcity. Consumption of water could undoubtedly be considered as the most important human requirement. Humans habitually tend not only to use water, but also consume it in various ways. Water is a basic requirement for all types of functions in every stages of every living creature. Besides the basic requirement it is required for preparation of raw food and their stages of processing, preparation of consumable items, cleaning requirements, fulfilment of transportation needs and various fueling requirements. No longer water is a primitive requirement to human.

Water management is a factor being developed by the human continuously. Water sector has a co-relation with energy sector to explore or extract the quantity wise requirement directly or indirectly and for transmission too. The initial power source and water nexus interlinked basically as the interdependencies comparatively. The whole world is bound to survive only when water is protected. The extraction or the generation of energy has marginal effect when the basic concept of kinetic energy is converted to electricity. Global warming due to human activities will come in to effect in return. However, water processes much higher validity of its own at the interest of generating power or power –water combined activities.

Human consume water for drinking, bathing, washing/cleaning, cooling off, heating, cooking, growing food, swimming, painting and creating art, boating and skiing on, getting rid of wastes, making electricity, transportation of goods, putting out fires, making products like paper and steel and many more in categories as production, washing, sanitation and in other various forms.

Water availability in sufficient quantities is becoming severe threat to living creatures with population growth, and climate changes which are co-related with development through human desire. Water demand has a direct relationship with energy consumption. Energy is used within the water cycle in every stage. The indicator, intensity of energy consumption (kWh/m^3) is an important measure at each of the water production stage. Energy conservation directly effects the water conservation. It therefore opens human eyes to look for possibilities with modern technology to make drinking water availability with low intensity of energy consumption.

Development of energy is vital when the water factor is concerned in dealing with energy. Strategically much concern is necessary to be paid in inserting the water factor in energy development since the water is a paramount requirement to consider while protection water with its sources is equally important.

Globally availability of natural water is very rare to be used in safe drinking purposes. Water treatment processes are removing contaminants in raw water to make it suitable for human needs. Conventional drinking water treatment process includes solids separation used in water treatment plants as a physical process such as lamella plate settling and filtration, as well as chemical treatment used in water sector such as disinfection and clog coagulation. Chlorination process is used in many water treatment plants for disinfection.

Water pumping stations and treatment facilities are significant energy consumers representing approximately between 2 to 3 percent of the world's energy consumption. Water Supply Schemes (WSSs) are among the largest energy consumers for many electricity providers around the world (EPRI, 1994). Energy consumption in most water systems worldwide could be reduced by at least 25 percent through cost-effective efficiency actions. Energy costs draw precious budgetary resources from other important municipal functions such as education, public transportation, and health care. In the developing world, energy consumed to supply water may easily consume half of a municipality’s total budget. In municipal water systems in developed countries, energy is typically the second largest cost after labour. Unfortunately, relatively little attention has been given to reduce energy use and to improve energy efficiency in municipal water systems (James et al, 2002).

Energy must be carefully handled for future investments as future generation will be ahead with more effective tools to face energy efficiency related activities. Global population already feel the environmental impact on come in return to burning of fossil fuels and drawing out the energy. Air becoming polluted when generating power for supplying drinking water. Emissions from power plants contribute to high levels of pollutants in the urban environment and also in lakes and forests. In addition, millions of tons of carbon dioxide are emitted every year, contributing to global climate change, adversely affecting the quality of life of the people. Global climate change is likely to reduce water tables and affect water supplies in many areas, making water even more costly and energy intensive to obtain in the future (James et al, 2002).

Benchmarking originated as business management practice designed to systematically evaluate product, services and work process of organisations for the purpose of improvement. The evaluation often centres on comparison to similar organisations that operate well or exhibit best practices. The basic steps involved in benchmarking are to properly identify the issue or define the operational metrics, assemble internal data to define current operations, collect external data for comparison, analyse the differences, implement changes and monitor the impact. The project was born out of the need to define useful matrices for comparing energy use among utilities.

For water sector, energy and cost reduction and improvement of energy performance are targeted for benchmarking with key tools of energy consumption in drinking water supply schemes at scheme level and process level. This is achieved through identifying possible energy savings opportunities initially to fix existing energy consumption processes through a technical energy survey. This will figure out unitvice energy demands in each process, then will determine the most appropriate operation or units, and determine factors on specific energy usage per quantity of water. The specific energy is assessed and measured in kWh/m^3 targeting efficiency improvements of the operation.

National Water Supply and Drainage Board (NWSDB) holds the sole authority as the local organisation for providing safe drinking water and sanitation facilities for local population as the most important social and economic objectives and the responsibility of the Government of Sri Lanka (GOSL). Currently NWSDB provides with pipe borne water supply through water supply schemes in operation throughout with surface water in Sri Lanka and dug wells, hand wells and rainwater harvesting.

1.2 Aim and Objectives

The Aim:

The aim of this research project is to study for potential energy consumption in each unit process of drinking water treatment plants to improve energy performance and to minimise energy costs in water supply

The objectives:

1. To investigate the potentials to minimise energy consumption on water treatment and supply by conducting energy audits in selected water supply schemes in Southern Province
2. To benchmark the energy consumption of water treatment and supply processes

1.3 Scope of Study

1. Conducting energy audits with five selected drinking water schemes in Southern Province to find out the energy consumption of treatment processes and to identify the best practices and potentials for energy conservation
2. Benchmarking the energy consumption of water treatment processes based on the data of the above energy audit

2. LITERATURE REVIEW

2.1 Energy Factor

When physically analysed, energy is the property that must be transferred to an object in order to perform work on or to heat the object, and can be converted in form, but not created or destroyed. The SI unit to measure energy is the Joule, which is “energy transferred to an object by the mechanical work of moving it a distance of 1 metre against a force of 1 newton”.

Common energy forms include the kinetic energy of an object, the potential energy stored by an object's position, the elastic energy stored by stretching solid objects, the chemical energy released when a fuel burns, the radiant energy carried by light, and the thermal energy due to an object's temperature. Kinetic energy of an object is the energy which it possesses due to its motion and quantified by the work needed to accelerate a body of a given mass from rest to its stated velocity. Potential energy is the energy of a body or a system due to the position of the body or the arrangement of the particles of the system and it is the energy difference between the energy of an object in a given position and its energy at a reference position. Many familiar types of energy are a varying mix of both potential and kinetic energy. Energy may be transformed between these forms, with varying conversion efficiencies. Equipment that transforms energy between these forms are called energy transducers. Mechanical energy is transformed to mechanical energy by lever, thermal energy by breaks, electric energy by dynamo, electromagnetic radiation by synchrotron, chemical energy by matches and nuclear energy by particle accelerator.

Electrical energy is the energy newly derived from electric potential energy or kinetic energy. When loosely used to describe energy absorbed or delivered by an electrical circuit "electrical energy" talks about energy which has been converted from electric potential energy. This energy is supplied by the combination of electric current and electric potential that is delivered by the circuit. At the point that this electric potential energy has been converted to another type of energy, it ceases to be electric potential energy. Thus, all electrical energy is potential energy before it is delivered to the end-use. Once converted from potential energy, electrical energy can always be called another type of energy.

Mechanical energy is identified as the sum of kinetic energy and potential energy. It is the energy linked with the position and motion of an object. The principle of conservation of energy as in mechanical form states that in an isolated system that is only subject to conservative forces the mechanical energy is constant. If an object is moved in the opposite direction of a conservative net force, the potential energy will increase and if the speed of the object is differed, the kinetic energy of the same is differed as well. However, when real system is concerned, Non-Conservative forces, like brake (frictional) forces, is present, but when figures are of smaller values, it can be being constant can be treated as valued approximation. In collisions, the mechanical energy is conserved, some mechanical energy is converted into heat. James Prescott Joule discovered the equivalence between lost mechanical energy and an increase in temperature. In modern devices, like motor or in steam engine, similar mechanism today for conversion of mechanical energy into their different forms of energy.

The unit used for everyday electricity, particularly for utility bills, is the kilowatt-hour (kWh); one kWh is equivalent to 3.6×106 J (3600 kJ or 3.6 MJ). Electricity usage is often given in units of kilowatt-hours in a time. This is actually a measurement of average power consumption, i.e., the average rate at which energy is transferred. One kWh/yr is about 0.11 watts.

2.2 Energy on Water

Connection between water and Energy just is complicate to analyse. Electricity is produced using water with potential it acquired. Water and energy are used by human in many ways. Cultivation is the basic and main process that the human start usage water and different types of energy. Cleaning is another primitive process the human gets the use of it. Transportation, food preparation also among the major activities energy and water is equally used.

About 55% to 78% of human body is water, compared to body size. Also body needs one to seven litres of water in a day to avoid the human from dehydration. However, it may depend on other governing factors of atmospheric conditions, weather, humidity, temperature, etc. and also human activities. Direct water consumption and water from fruits or food are major sources are the main water intake of a human being to be comfort. Though different figures are spoken as water intake. Medical background favours a lesser water consumption as better performance to be undergone as a human in spite the activities are holding the major component for a human being to be dependent in the field of for example, athlete who dissipates much energy in the activities,

Transportation and treatment processes require energy in different rates as illustrated in Figure 2.1.

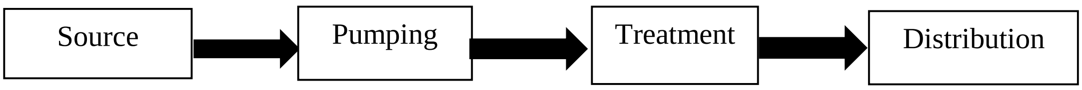


Figure 2.1: Energy usage levels in water treatment

Once raw water is available to be treated is initially collected or pumped depending upon the elevation to water treatment plant from primary source. Sometimes, though it is rare, gravity feeding may be possible where no raw water pumping energy required. In cases where water treatment plant is located far from primary source or at a higher elevated location, much higher rates of energy may be necessary or in some occasions boosting or multi stage elevations are required. Lifting raw water to a higher elevation for treatment sometimes has benefits in return where distribution process is not necessary and gravity distribution could be used for particular zones.

2.3 Treatment Process

2.3.1 Water quality

One of the unique characteristics of water is its capacity to dissolve a variety of substances. As water moves through its cycle, called the hydrological cycle, comprising of rainfall, runoff, infiltration, impounding, use and evaporation, it comes into contact with many different substances that may be found in non-purified water to some extent or that may be suspended in the water. Very small suspended particles and colloidal substances collectively determine water quality level and its suitability factor to be consumed for domestic purposes.

The types of contaminants or substances of concern that may occur in water sources vary over a wide spectrum and include inorganic salts, micro-organisms, clay particles and organic material. Those with similar characteristics that can be treated by the same type of treatment process are normally grouped together for design purposes and for general discussion. It is normally not possible to consider each individual substance of concern with the view to treatment. There are exceptions, however, for example the removal of a toxic substance from water is often specific for the particular substance.

The principal objective of water treatment is to produce water that is fit for domestic use reliably and consistently from a raw water source at a cost that is reasonable to the consumers. A water treatment plant employs many individual treatment processes (sometimes called unit processes and unit operations) that are linked in a process train to produce water of the desired quality.

The substances of concern in water can be categorised in different ways, e.g. as dissolved or suspended, as inorganic or organic, as macro or micro substances, as natural or synthetic substances, suspensions of micro-organisms etc.

2.3.2 Dissolved substances

Most substances are to a greater or lesser extent dissolved by water. Substances that are dissolved in water are such as ammonia (NH_3), carbon dioxide (CO_2), calcium sulphate ($CaSO_4$), oxygen (O_2), sodium chloride (NaCl), acids and carbohydrates. Dissolved substances are generally more difficult to remove from water than suspended substances, since they must either be converted into the solid form by means of precipitation, or to the gas form by means of oxidation so that the gas can escape or be stripped from water. A further possibility to remove dissolved substances is by using advanced processes such as reverse osmosis or activated carbon adsorption.

The conventional drinking water treatment process for surface water sources is shown in Figure 2.2 (Kalaimathie, 2012).

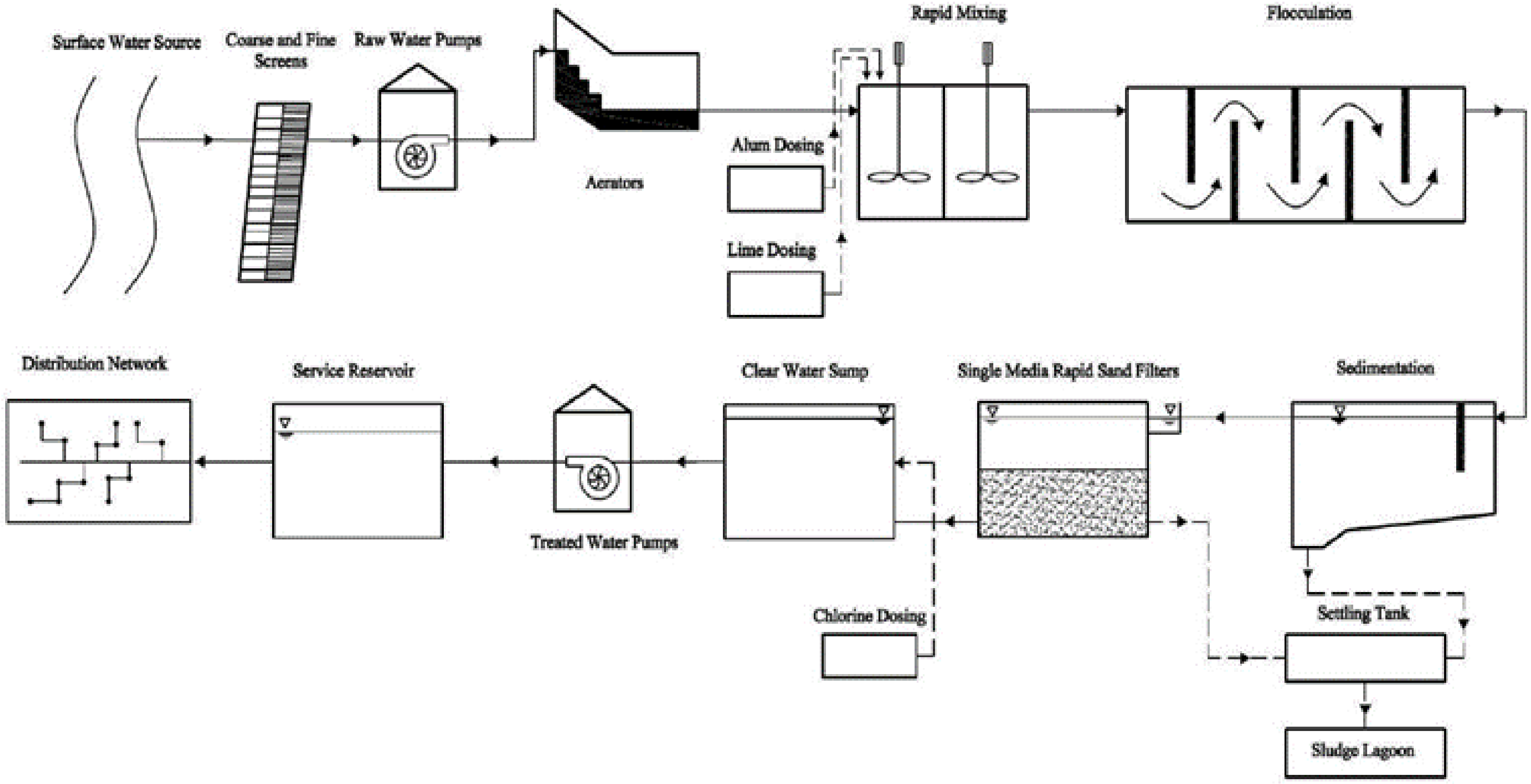


Figure 2.2: Conventional drinking water treatment processes for surface water sources
Source: Kalaimathie, 2012).

Raw water is contaminated with dissolved particles and nun-dissolvable large particles as well. Screening is the primary process at the initial stage to strain such as rubbish, leaves, sticks which may cause the damages to the equipment and system. There are two types of screens; Tow strains, course screen and fine screens could be employed depending on the requirement. Screens are employed directly across the water lead to block the impurities. Manual or mechanical arrangement may be employed in removing the rubbish collected periodically.

Since the water in raw stage are lesser contacted with air it may contain odour, iron or toxins, the water is run through air. This aeration process removes odour, taste, toxins and any irons which are in soluble form. In general cascade or tank aeration with or without air bubbling is implemented in water treatment industry.

In coagulation, colloidal suspensions are destabilized at the addition of coagulant and then coagulation takes place. In flocculation, polymers are added in to water that is subjected to the treatment and particles are destabilized and form into bigger aggregates being easy to become larger aggregates to remove from water. The formation of flocs which is known as flocculation has no involvement with neutralization of the particles charge. In the general sequence of water treatment, coagulation and flocculation is done as an intermediate process to assist filtration for water as clarification requirement and prior to sedimentation process. and Iron is widely used in water treatment sector as a coagulant. Aluminium salts are also used as a coagulant because of zirconium and titanium salts also found as other metals as highly effective. Particles settle at lower rates or not at all in a colloidal suspension due to the particles acquire electrical charges of the surface that repel each other. A coagulant (in general, one of metallic salt) having the opposite charge is allowed to be mixed to overcome the charge to be repulsive the suspension. The colloidal are negatively charged particles and coagulant is added for example, alum as a to set ions as positively charged. When the repulsive charge has been neutralized, van der Waals forces act and the agglomeration takes place. Other processes like oxidation are also take part in completion of the treatment processes of wastewater or raw water in line with filtration and sedimentation. Coagulant aids as polymers that bridge the colloids together are also often used to the of the process. Polymers are also use to add to the treatment process colloids gathering method as a clog thereby the efficiency of the process gets increase.

Clarification is the first treatment barrier against particles and protozoan passage during conventional water treatment (Edzwald and Kelley, 1998). This process is accomplished through sedimentation, which allows large floc-particle masses to settle prior to filtration (Olson et al, 2002). Nowadays it is common to use dissolved air flotation or sludge blanket clarifier to accomplish clarification (Binnie et al, 2002). Sedimentation is basically a hydraulic process and plane sedimentation tanks and plate/tube settler sedimentation tanks are the commonly used options. Dissolved air floatation consumes energy for creating air bubbles and sludge blanket clarifiers utilize energy for providing slow mixing.

Physical removal of turbidity and microorganisms from water is ultimately accomplished by filtration. Filters within a conventional water treatment process are considered as the last barrier to the release of particles and protozoan cysts into the distribution system (Cornwell et al, 2003). During filtration, water passes through a pore structure made up of a variety of bed materials that can be composed of the following: (i) a bed of sand (sand filtration) or (ii) a layer of diatomaceous earth (diatomaceous earth filtration), or (iii) a combination of coarse anthracite coal overlying finer sand (dual- and tri-media filtration) (Troyan and Hansen, 1989). The removal of particles in suspension occurs by straining through the pores in the filter bed, by adsorption of the particles to the filter grains, by sedimentation of particles while in the media pores, by coagulation while traveling through the pores, and by biological mechanisms such as slow sand filtration (Troyan and Hansen, 1989). The latter is accomplished by the filtering action of the schmutzdecke. The schmutzdecke is the top layer (a few centimetres in depth) of sand and particulate materials (fine soil particles, plant debris, algae, free-living or non-pathogenic protozoa) that have been removed from the water as it percolates downward through the sand filter bed (Fox, 2006). Filter backwashing of rapid sand filters is an energy consuming process.

Disinfection is the process by which an organism’s viability/infectivity is destroyed with a specific percentage of the population dying over some time frame defined as a rate. Water disinfection is accomplished with chemical or physical disinfectants and the most common of these is chlorine (added to water as a gas or solid) and the specific disinfection referred to as chlorination (Betancourt and Rose, 2004). Alternative disinfectants including ozone and ultra violet (UV) irradiation are also widely used now (Peeters et al, 1989). Motive water pumps are the main energy consuming equipment of gas chlorinators.

2.4 Availability of Electricity in Sri Lanka

Power requirement in Sri Lanka is fulfilled by mainly from hydro power. In addition to that and when sacristy of water in catchments are experienced, other thermal sources as coal power plants or diesel generators are run. Wind power in Sri Lanka in in initial stage and so as to photovoltaics. However nuclear or geothermal power are not in the power scope in Sri Lanka yet.

There are two on-grid electricity providers in Sri Lanka; Ceylon Electricity Board (CEB) and Lanka Electricity Company (LECO). The CEB is the main electricity company in Sri Lanka and it controls all major functions of electricity generation, transmission, distribution and retailing in Sri Lanka. The CEB use both hydropower and thermal power as main energy sources. The LECO is engaged mainly in distribution and retailing in certain areas of the country (CEB, 2013).

CEB provides electricity to all five audited WSSs.

Hydroelectricity is the oldest and historically the principal source of electricity generation in Sri Lanka, holding a share of 48% of the total available grid capacity in December 2013 and 58% of power generated in 2013. Hydroelectric power generation has been constantly under development since the introduction of the national grid itself, but its market share is declining because suitable new sites are scarce. Currently, ten large hydroelectric power stations are in operation, with the single largest hydroelectric source being the Victoria Dam. Although a large portion of the country's hydroelectric resource are tapped, the government continues to issue small hydro development permits to the private sector, for projects up to a total installed capacity of 10 MW per project. The peak demand is approximately 2050 MW (CEB, 2013).

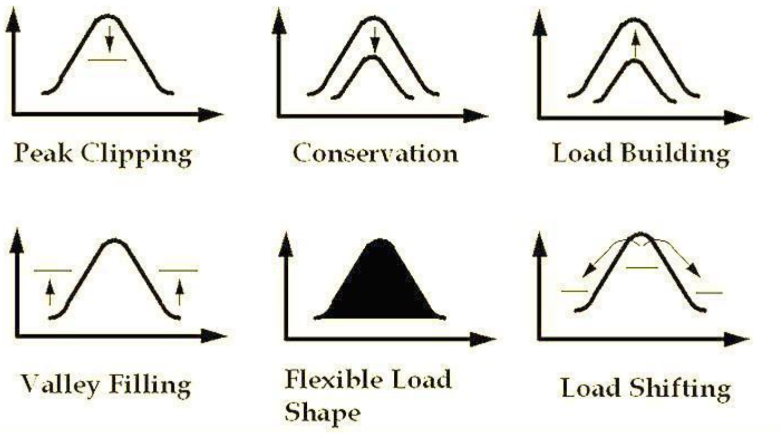


Figure 2.3: Load shape objectives of demand side management
Source: CEB, 2013

The CEB promotes demand side management (DSM) among its consumers. DSM encompasses "systematic utility and government activities designed to change the amount and/or timing of the customer's use of electricity" for the collective benefit of the society, the utility and its customers. As such, it is an umbrella term that includes several different load shape objectives, including load management and energy efficiency. DSM options generally primarily address one of the following specific load shape objectives; peak clipping, conservation, load building, valley filling, flexible load shapes and load shifting. (CEB, 2013). These options are graphically illustrated in Figure 2.3. This study investigates on the conservation, peak clipping and load shifting opportunities available at the audited WSSs.

2.5 Energy Consumption behaviour in Water Supply Schemes

2.5.1 Overall cost of energy consumption in water supply schemes

Energy cost is a major component for NWSDB as shown in Figure 2.4. The relevant cost data are attached in Table A.2 of Appendix A. The overall cost of energy consumption in NWSDB in 2012 was 23.7% and it is the second largest cost component of the total annual cost. The largest cost component is the personnel cost which is very difficult to reduce without engaging transformational changes in the utility organization. Therefore, the largest controllable cost component in NWSDB is the cost of energy.

The breakdown of cumulative expenses of 2012 in the water supply regions of which the selected WSSs are located is attached in Table A.3 of Appendix A and shown in Figure 2.5. Percentage cost of energy consumption of Malimbada, Hapugala and Tangalle schemes in 2012 are 36.6%, 19.3% and 25% of the total cost of the relevant water supply schemes. Therefore, any attempt to reduce the operation cost in NWSDB as an organization or as regions, should concentrate more on conservation of energy consumption.

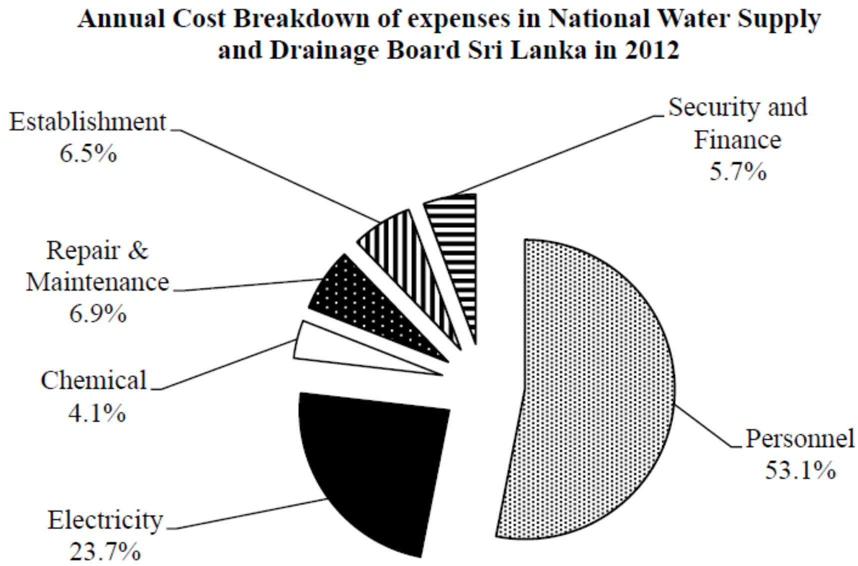


Figure 2.4: Breakdown of expenses in National Water Supply and Drainage Board in 2012
Source: Kalaimathie, 2012

2.5.2 Energy consumption in operations

Inefficient pumping system causes the technical and commercial losses resulting in higher cost of delivery of water and as well as poor realization of water charges contributing to bad financial performances of water utilities. Approximately 2 to 3% percent of the total electricity generated by the electric power industry is consumed by water industries for pumping and treatment activities for urban residents and industries globally (EPRI, 1994). Energy consumption in the operation and maintenance phase of the urban water network is directly related to both the quantity and the desired quality of the supplied water and in other words, to maintain the level of service to the consumers. Energy efficiency improvements at water and wastewater treatment facilities can have high rates of return, and can significantly reduce costs at a water facility since energy costs typically constitute 25 to 30% of the operations and maintenance costs at water facilities (Kalaimathie, 2012). Energy consumption for water conveyance to lift water from river and groundwater sources is 26% and 30% is consumed for the treatment and then 43% is consumed for pumping it to service reservoirs (Bunn and Reynolds, 2009).

The energy intensity of treatment required for different types of water source is found to vary widely between the extremes of relatively fresh surface waters, which use energy mainly in pumping, and seawater which requires desalination. Generally, the water industries use either surface or ground water as its water source for drinking water production processes. In a typical water facility treating groundwater only, 1% of electricity is used for chlorination and the balance 99% is used for pumping activities. The onsite energy use of the groundwater supply system is approximately 27% greater than the surface water supply system due to more extensive pumping requirements. On the other hand, the groundwater system uses approximately 31% less indirect energy than the surface water system, mainly because of fewer chemicals used for treatment (Mo et al., 2011).

The average energy consumption in Wisconsin surface water system was 1500 kWh per million gallons of water (0.33 Wh/m^3). Out of this, 73% of energy was consumed for pumping water and 19% of energy was consumed for filter backwashing. Application of advanced water treatment systems lead to increase the electricity consumption in water industries. After introduction of ozonation the estimated energy consumption increased by 0.12 kWh/m3 and for micro filtration it was increased by 0.16 kWh/m3 (Elliiott et al, 2003). In addition, energy consumption pattern varies with the treatment capacity of the WSSs. The percentage contribution of the electricity consumption in different components of Harris water treatment plant in Toronto city is illustrated in Figure 2.6 (Racoviceanu et al, (2007). It shows that a significant percentage (73%) of energy was consumed for raw water and treated water pumping and filtration consumed the largest portion (22%) of the energy consumed for water treatment process.

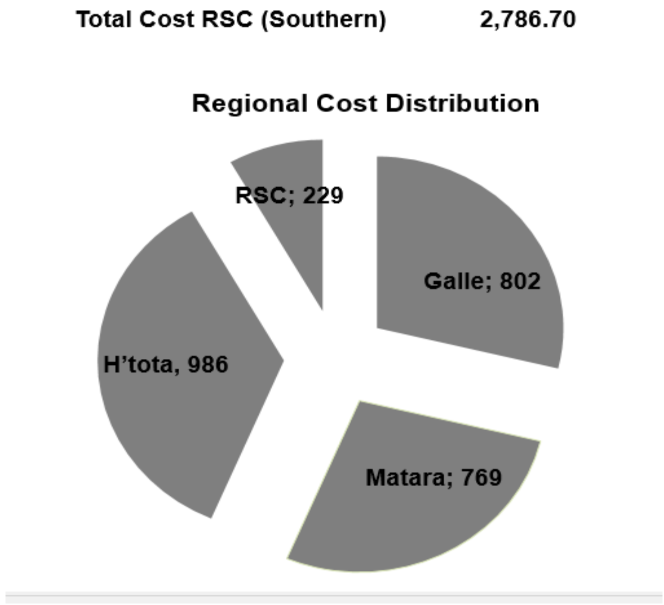


Figure 2.5: Cost break down of Regions in Southern Province in year 2013,
Source: NWSDB, 2013

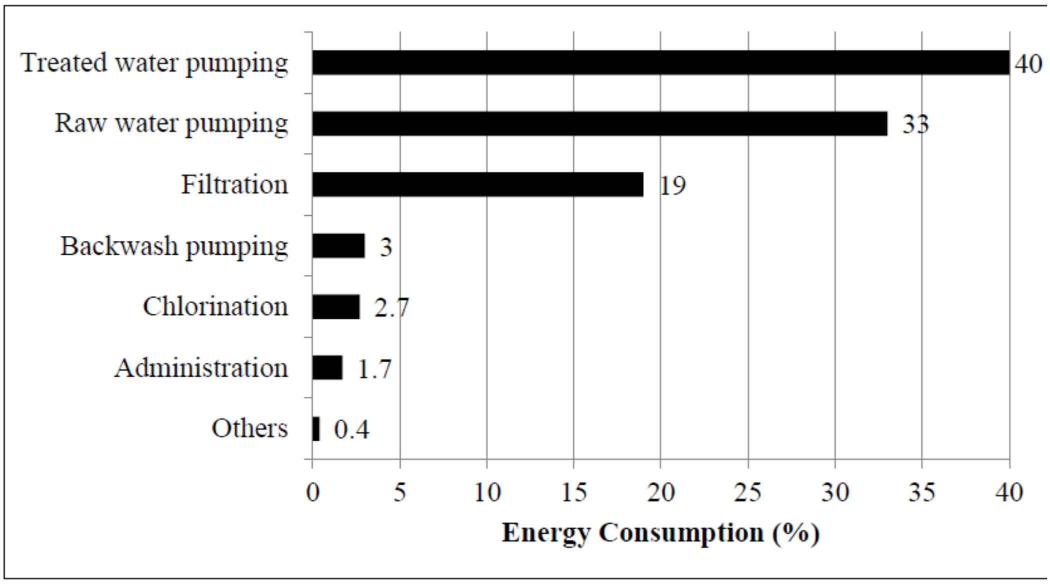


Figure 2.6: Energy use in Harris water treatment facility in City of Toronto
Source: Rcoviceanu et al. 2007

The specific energy consumption for a smaller plant is higher than the specific energy consumption for a larger plant (Elliott et al, 2003). The energy consumption per unit production for different plant capacities are presented in Table 2.1.

Table 2.1: Energy Consumption Pattern for Different Capacity Water Treatment Plants

Number of consumers	**Energy consumption /(kWh/m^3)**	**Energy consumption /(kWh/m^3)**
	Mean Value	**Range**
< 1000	0.42	0.30 - 0.62
1000 - 4000	0.40	0.30 - 0.52
> 4000	0.34	0.26 - 0.45

Source: Elliott et al, 2003

The water, energy and greenhouse gas emissions are interlinked and estimated 8% of greenhouse gas emissions in cities are accounted for water related energy consumption. Rising concerns over scarce energy resources and global climate change has forced the water industry to reduce its energy consumption. Life cycle inventories focusing on energy use and greenhouse gas (GHG) emissions were developed for many WSSs. Toronto municipal WSS burdens, 60% of energy attributed to on-site pumping, accounted for 94% of total energy use and 90% of GHG emissions. The normalized energy use of the system was found to be in between 2.3 and 2.5 MJ/m3 (Racoviceanu et al., 2007). The energy consumption and related GHG emission in different process in a water treatment plant is stipulated Table 2.2.

Table 2.2: Total Energy Use and GHG Emissions in Water Sector

Process	**Total energy use (TJ/year)**	**GHG emissions (t CO_2eq/year)**	**Specific energy use (MJ/m^3.year)**	**Specific GHG emissions (t CO_2eq/m^3.year)**
Chemical Manufacturing	71	4622	0.14	8.87
Chemical Transportation	16	1018	0.03	1.95
Operation of water treatment plant	1271	61156	2.44	117.31

Total	1359	66796	2.62	128.13

Source: Racoviceanu et al, 2007

United States water systems and waste water systems consume 75 billion kWh/yr nationally and it is about 3% of annual USA electricity consumption. However as per a case study done in San Diego, the energy consumption for water treatment is quite small. The range of variation of specific energy consumption of each component of the water supply schemes in California are presented in Table 2.3 (Cohen et al, 2004).

Table 2.3: Range of Specific Energy Consumption for California Water Supply Schemes

Water supply component	**Range of Specific Energy Consumption/ (kWh/MG)**	
	Low	**High**
Raw water pumping	0	14,000
Water treatment	100	16,000
Treated water pumping	700	1,200

Source: Cohen et al, 2004

Energy in water supply and conveyance was near zero cause of gravity-fed systems in Northern California. On the other hand, Central and Southern California has higher energy consumption especially in South because it is needed to transport water more than 3,000 feet up over mountains, which is the highest lift of any water system in the world (Cohen et al, 2004). A comparison of specific energy consumption for above components for Northern and Southern California is presented in Table 2.4.

Table 2.4: Specific Energy Consumption in Typical Urban Water Systems in California

Water-Use Cycle Segments	**Energy Use/ (kWh/MG)**	
	Northern	**Southern**
Raw water pumping	150	8,900
Water treatment	100	100

Treated water pumping	1200	1,200
Total	3950	12,700

Source: Cohen et al, 2004

For California urban water systems; raw water pumping in Northern California consumes energy of 150 kWh/MG while 8,900 kWh/MG was consumed for Southern. This is more than 50 times of Northern California's and also 5 times the national average. The difference is due to the location of water resources, the distance and level of raw water transportation. The amount of energy used to deliver drinking water to residential customers in Southern California is equivalent to approximately one-third of the total average household electric use in the region (Cohen et al, 2004).

2.6 Benchmarking

2.6.1 Benchmarking history and definitions

Xerox Corporation introduced benchmarking in 1980s (Stapenhurst, 2009) as its productivity and market enhancement tool. Over the past few decades benchmarking has evolved into a very robust and popular technique to improve quality, productivity and management improvement. Benchmarking was first used in water utilities by Water Service Regulatory Authority of UK (OFWAT)) in 1989. Benchmarking has been extensively used in many production and service sector to improve performance and extensively used in water and wastewater utilities worldwide. In Southeast Asia benchmarking was first initiated in 2004 by Southeast Asia Water Utilities Network (SEAWUN).

Benchmarking has resulted in more than 100 publications not only in Europe, but also worldwide and it demonstrates the interest of such a tool within the research community (Jeppsson, et al, 2006). In the last few years benchmarking has no longer made headlines, but that is quite possibly because it has now become an established part of business life (Stapenhurst, 2009). Benchmarking has been used in many industry and service sector due to its flexibility of use and as a tool to share and learn from the best in industry. It also helps to increase the scope of every participating organisation. For learners it means new knowledge and for instructors it means new business opportunity.

Benchmarking is a tool of performance evaluation through comparison within and/or outside the organisation. For some industry it just involves comparison of performance metrics, whereas for some industry the process of achieving performance is more important. Benchmarking can be applied to any area where we want to compare performance and/or learn from others (Stapenhurst, 2009). Roger Milliken, CEO Milliken states that benchmarking definitely is not stealing, but it involves adapting to good ideas, practices and technology with due permission from other benchmarking partners.

Water utilities started adapting benchmarking from early 1990"s and since then it has been extensively used worldwide with varying degrees of success. Two major consortium of benchmarking of water utilities has taken place, the European benchmarking initiative and the American initiative. But in most cases the performance indicators and method of assessment are similar for both. Benchmarking of water utilities has evolved, matured as industry standard. Water utilities need to improve performance and performance improvement is no more considered to be more sales or high profit. Especially in water and wastewater utilities it is also about ecology and equity.

Benchmarking is defined as the continuous process of measuring products, services and practices against the toughest competitors or those companies recognised as industry leaders (Camp, 1989). Benchmarking is also defined as a process of gathering standards for improvement and insights, which may lead the organization to better performance (Venetucci, 1992). Benchmarking is also described as an external focus on internal activities in order to obtain continuous improvement (McNair and Leibfried, 1992).

Benchmarking was defined by the American Water Works Association as a systematic process of searching for best practices, innovative ideas, and highly effective operating procedures that lead to superior performance.

2.6.2 Types of benchmarking

There are different approaches to benchmarking depending on the objective and the availability of data. The common feature of all these approaches is that certain parameters relevant for the observed processes are quantified, and then compared with the best practice. The data are usually compiled by surveying, and are then statistically processed and compared.

Benchmarking can be differentiated as internal, external and functional (Karlof and Ostblom, 1993). When comparisons are made within the organisation (between different branch offices), it is termed as internal benchmarking. Internal benchmarking helps to find the better performing units and factors that influence the performance. External Benchmarking is done with competitors or similar units outside the domain of the organisation. Functional benchmarking is when the process and the function is benchmarked in different industry (it might not be doing the same function) and it is a process to find the best wherever possible.

Metric benchmarking is a quantitative comparative assessment of company performance and process benchmarking is a mechanism of identifying specific work procedures to be improved (Parena and Smeets, 2001). In Metric Benchmarking Performance Indicators (PI) are set to assess the comparison between different utilities; reference points like cost per unit, people per unit production are used.

Process benchmarking on other hand relates to specific business processes with better performing organisation or industry standards. Process benchmarking not only observes the cost comparisons, financial ratios or statistical analysis but also allows organisations to understand the operational perspective like level of automation, training needs, management operations etc. Process Benchmarking is the task of improving the way processes performed every day (Bogan and Michael, 1994).

2.6.3 Benchmarking process

Generally benchmarking exercises are done as standalone projects within a time frame but the integration of lessons learned is a continuous process. Running the water utility in the changing scenario of legal requirements, environmental guidelines, customer satisfaction, technology in use, and management principles need constant performance improvement to provide better service and return on investments. Steps undertaken for benchmarking involve stakeholder objective setting (planning), training of key individuals, data collection, data analysis, report drafting, setting improvement strategy and individual actions followed by monitoring and planning for next stage.

Planning the benchmarking exercise is the critical step and its design influences the success of the initiative; planning process can be externally or internally driven and it is important to consider the benefits and area of interest of individual utility. An paramount sector of planning sequence is to frame the guidelines of the exercise. The guidelines need to identify the responsible people for the work and their specific roles. It also mentions the steering committee which is responsible to provide the required infrastructural support to the exercise.

Once the planning process is set, the second important steps are capacity building and development of tools for the benchmarking exercise. At this stage it is critical to determine the tools that will be used this will depend on the objectives set earlier and the type of data available. The orientations and trainings are not only introduction of key staff and participants but also setting of questionnaires, software orientation, and communication protocols.

The third step of a benchmarking exercise is data compilation and validation. This step can be differentiated into 3 steps determining comparable data, data acquisition and data validation. Comparable data is very critical as it leads to the risk of comparing apples with oranges. It is necessary to have clear questionnaires with precise definitions in data element system along with records of data origin.

In a benchmarking study, the information and data collected is to be valued and compared. To be able to measure the quality of the data and to understand the value of the information given, a performance indicator (PI) system is used.

KPI which is identified as key performance indicator is a nonsense as a measurement of performance. When an industrial organisation is considered, KPI in general, evaluate the success of it or an activity of it. Success is defined Sometimes in terms of making progress towards targeted aims, but sometimes success is simply meet as perfect achievements as 100% or 0 rejects etc. Selection of KPI is intensively 'what is important' to the organisation. It depends on measure of the performance of the department. KPIs for finance and KPIs assigned for sales are different from each other. First it is important to identify what is important, because it is a requirement to develop a sound understanding to identify the real importance of the selection of the performance indicator. It is basically associated with techniques to assess the current state of the industrial goals, and their major activities.

Data analysis and reporting is the first outcome of the benchmarking exercise, and it involves various forms of analysis depending on the objectives and the data availability. Clustering of utilities based on likely comparators is done to match benchmarking indicators, normalisation of Figures is also done wherein certain factor is cost-effective than other, like power is cheap in one country and costly is another. Different reports are generated which serve the purpose of different people; managers tend to have synopsis report which help them to take actions based on facts.

Performance improvement stage is the most challenging stage and requires efforts from every participant, it needs open introspection of performance gaps and sharing knowledge for improvement actions. Improvement actions can range from optimisation to new technology or change in management style.

Benchmarking is defined as a continuous process and without a review of the improvement actions the process becomes stand alone. Review of benchmarking exercise is needed to identify if the performance gaps and possible performance improvement strategy are rightly identified and to assess if the benchmarking has helped to address the identified performance gaps.

There are many government and non-government organisations involved in benchmarking of water utilities in world in different zones and details of these organisations are summarised in Table 2.5.

Table 2.5: Organizations Engaged in Benchmarking of Water Supply Utilities

Organization	**Country/Region**
Water Services Regulation Authority (OFWAT)	United Kingdom
6-Cities Group	Scandinavia
International Benchmarking Network (IBNET)	Worldwide
Southeast Asia Network of Water Utilities (SEAWUN)	Southeast Asia
National Water and Wastewater Benchmarking Initiative (NEBC)	Canada
European Benchmarking Cooperation (EBC)	Europe
World Bank (WB)	South Asia
Asian Development Bank (ADB)	South Asia
Water Operators Partnership (WOP)	Africa

2.7 Energy Benchmarking

The benchmarking of water and wastewater treatment plant at site level or process level, is a key tool to improve performance and to reduce costs in particularly to reduce energy costs. The first step in identifying opportunities for energy savings is to establish current energy consumption patterns through a comprehensive energy audit. An audit will establish the energy demands of each part of the water treatment process, determine the most energy intensive equipment and processes, and provide information on energy use per throughput of water. This baseline assessment will also provide information to evaluate the benefits of any equipment or process changes to improve efficiency of the operation. The usual energy performance indicator is the electrical energy consumed in kilowatt hours divided by flow (kWh/ flow). This indicator is used as a benchmark for water companies to measure their performance. The internationally recognized average energy consumption for water supplied under normal conditions are equal to 0.4 – 0.5 kWh/m3 with a total system pumping head of 100 meters (Jantzen, 2002). Specific energy consumption for drinking water supply in different cities of Australia and New Zealand is presented in Table 2.6.

Table 2.6: Specific Energy Consumption for Drinking Water Supply in Different Cities of Australia and New Zealand

City	Sydney	Melbourne	Brisbane	Gold Coast	Adelaide	Auckland
Population Served (millions)	4.300	3.621	1.006	0.449	1.095	1.232
Specific energy consumption (kWh/m^3)	1.0238	0.0928	0.2072	0.9806	1.9116	0.2061

Source: modified from Kenway et al, 2008

Sydney required very much water for the steadily increasing population. The specific energy consumption of water supply in Sydney in 2006/2007 has increased by 300% since 2000. The highest energy consumer, Adelaide needs to maintain extra water storage during drought conditions. Gold Coast energy demand has been gradually increasing while the water supplied has varied in response to reduced rainfall and subsequent low storage levels (Kenway, et al, 2008).

Energy consumption of a significant proportion of water treatment plants in Sri Lanka has been studied and the overall energy benchmarks have been produced as per different categories of water sources. These values are presented in Table 2.7. (Kalaimathie, 2012).

Table 2.7: Overall Specific Energy Consumption in Water Supply Schemes in Sri Lanka

Water Source	Specific Energy Consumption (kWh/m^3)		
	Average	Minimum	Maximum
Surface	0.44	0.07	0.76
Ground	0.51	0.37	0.82

Source: Kalaimathie, 2012

Table 2.8: Specific Energy Consumption of Major Components of Drinking Water Supply in Bangkok, Thailand

Water supply component	**Range of Specific Energy Consumption/ (kWh/m^3)**	
	MWA, 2011	**Anusart, 2012**
Raw water pumping	0.006	0.0097
Water treatment	0.1378	0.0469
Treated water pumping	0.075	0.1772
Total	0.152	0.2338

Source: Anusart, 2012

Rothausen and Conway reviewed the energy consumption of different components of water supply schemes from the studies of energy use and GHG emissions in the water sector. They summarized their findings into a table which present the region, audit method, water sector processes, Energy consumption and measured unit. Table 2.9 was adapted to present only the energy use (Rothausen and Conway, 2011).

Table 2.9: Specific Energy Consumption of Water Supply Processes in Different Regions in USA

Author	**Region**	**Water-Sector Processes**	**Energy Consumption**	**Unit**
Cohen et al.,	San Diego	Supply and treatment	80-4,200	kWh/acre foot
Klein et al.,	California	Raw water pumping	0-14,000	kWh/MG
		Water treatment	100-16,000	kWh/MG
		Water distribution	700-1,200	kWh/MG
Goldstein and Smith	California	Surface-water treatment	0.371-0.392	kWh/m^3

Source: modified from Rothausen and Conway, 2011

The results of various energy benchmark studies regarding water industry in different cities in the world are presented in Table 2.10. Very high amount of energy consumption is observed for sea water desalination compared to conventional water treatment.

Table 2.10: Specific Energy Consumption in Water Treatment and Supply in Different Cities of the World

City	Treatment option	Benchmark (kWh/m^3)	References
Oslo	Conventional	0.40	Venkatesh and Brattebo,(2011)
California	Imported water	5.00	Strokes and Horvarth,(2009)
	Desalination of ocean water with conventional pre treatment	11.67	
	Desalination of ocean water with membrane pre treatment	11.39	
	Desalination of brackish ground water	7.50	
	Recycled water	4.72	
Wisconsin	Conventional	0.33	Elliott et al.,(2003)
Toronto	Conventional	0.59 – 0.64	Racoviceanu et al., (2007)

Source: Kalaimathie, 2012

The specific energy consumption of conventional water treatment varies significantly for different countries and Table 2.11 presents the data for several countries around the world (Plappally and Lienhard, 2012).

Table 2.11: Specific Energy Consumption of Conventional Water Treatment Process

Country	Specific Energy Consumption ranges (kWh/ m^3)	Reference
Australia	0.01 – 0.2	Cammerman,2009
Taiwan	0.16 – 0.25	Chang, 2002
USA	0.184 – 0.47	World Energy Foundation, 2010
Canada	0.38 – 1.44	Mass,2010
Spain	0.11 – 1.5	Munoz et al.,2010
New Zealand	0.15 – 0.44	Kneppers et al.,2009

Source: Plappally and Lienhard, 2012

The specific energy consumption for water treatment unit processes was reviewed by Plappally and Lienhard (2012) for USA and values are presented in Table 2.12.

Table 2.12: Specific Energy Consumption of Water Treatment Unit Processes

Unit Process	Specific Energy Consumption ranges (kWh/ m^3)	Reference
Raw water pumping	0.02 - 0.05	Goldstein and Smith, 2002
Chemical Feeding	0.0005 - 0.001	World Environment Foundation, 2009
Rapid mixing	0.008 - 0.022	World Environment Foundation, 2009
Flocculation	0.001 – 0.004	Cammerman,2009
Sedimentation	0.0005 - 0.001	World Environment Foundation, 2009
Filtration	0.005 – 0.014	World Environment Foundation, 2009
Chlorination	0.0024 – 0.0025	Arpke and Hutzler, 2006
Treated water pumping	0.0024 – 0.0025	World Environment Foundation, 2009

Source: Plappally and Lienhard, 2012

2.8 Energy Auditing

2.8.1 Introduction

Water utilities are intensive energy users and continually seek ways to improve their productivity through the effective and judicious use of energy. An effective manner of reducing energy consumption is to conduct an energy audit. An energy audit involves a critical examination of an energy consuming facility. It determines the performance of a facility in terms of energy use and relates its energy consumption to production and compares it with the performance of similar organizations. An energy audit is an imperative first step for any organization interested in implementing an energy management program within their facilities. It assists with identifying areas where potential savings can be made (EPRI, 1994).

The results of an energy audit can improve the energy efficiency of a facility. Increasing the energy efficiency will enhance the facility's operations and products in numerous ways:

- It can reduce energy costs. Depending on the process, energy costs amount to 15% to 40% of the production cost.
- It can help the company improve the quality of its product.
- It can lead to corollary benefits such as reduced maintenance costs and improved worker safety. Many energy efficient technologies are more reliable than their inefficient counterparts.
- It can help reduce pollution. With reduced pollution, payment of any existing environmental fees and fines can be minimized (Alliance to Save Energy, 2002).

2.8.2 Types considered for energy audit

The types considered for energy audit are basically dependant of on resources available to observe, physical parameters to be observed, working environment and final outcome from preliminary audits. Thereafter detailed audits are conducted.

An audit has basically two parts, namely recording and analysing. Since the audit is aimed on energy, energy usage is considered over a particular period of time. (purchased energy) in a facility over a fixed period of time. Initial attention is in general could be started from utility bills, general rates etc. over a reliable period depending on practical pattern or complexity in two-three days. Simply the energy usage is focused to the events directly the energy consumption is visible and accountable to be recorded in a cost centre, a small sector for monitoring.

A detailed audit consists of recording both purchased and generated energy use data for every cost centre in the water district over a fixed period of time and also calculating the energy balances and efficiencies. This audit may require back-up portable measuring instruments referred to as “energy audit equipment”. It may take 1 to 2 weeks to complete a detailed audit depending on the size and type of the facility. The procedure for energy audit is stipulated in Energy Audit Guidebook for Water Utilities in the Philippines (James et al, 2002).

2.8.3 Process components for energy audit

The four (4) process stage components for energy auditing:

- Procedure for planning
- data collection on energy consumption
- analysis gathered data
- initial recommendations

The above stages are discussed below:

a. Planning

b. Different implementing stages are possible for water sector energy audit management programmes are brought to for analysing. As the initial stage prior to the implementation several phases are considered:

   Step 1: Commitment from management

   Step 2: Assignment of an audit team

   Step 3: Formation of objective and goal

   Step 4: Measuring equipment as audit tools

Step 1: Commitment from management

Commitment is required to be granted from relevant management levels for a successful energy management. This has to be a successful programme prior to attend the energy audit and that is a must in order the programme not to be failed to reach the goals targeted.

In general, when the programme is presented to the authorised management with the facts and figures for the financial savings and benefits to the factory or the organisation, permission could be achieved for the implementation. It could contain historical data of a similar programme attended by some related parties and the successful results that they have achieved. Among those figures, utility bills would prove the initial flow for the requirement. Since the energy audit program is targeting the reduction of energy consumption and cost component as well, the real benefit could be highlighted. Support from the relevant management authority levels are really focused only when the contribution from them are felt worth.

Step 2: Assignment of an audit team

Once the support from management is attained, audit team is created to visit and attend relevant activities for the establishment of energy audit programme. Those components include:

- Collecting data for energy consumption
- Gathering real stage of activity performance
- Measuring equipment efficiencies
- Forming standards for activities
- Assessing opportunities for energy conservation
- Presenting an energy audit report

Step 3: Formation of objective and goal

Every energy audit is targeted with an objective and a goal and that is presented by a real statement. The formation of the statement for the objective and the goal will announce the road to define related standards. The management sector is willing to look for proceedings that audit team being attended to see how effective their findings are. They may consist of opportunities for conservation of investment and energy, future goals on saving time and duration of implementation, method for capitalisation of programme etc.

Step 4: Measuring equipment as audit tools

Equipment are required to measure parameters governing the audit survey. When it is basic parameters, standard devises could be used, and when they are secondary or other measurements. Then technically known devises could be implemented. These measurements are very important in. Measuring devises normally use to determine efficiencies are mentioned as follows:

Flowmeter: Device to measure a quantity of fluid over a specific period and also cumulative quantity of flow of the liquid could be measured with flowmeter. Also flow rates and flow velocities could be derived over the reading.

Voltmeter: Electrical potential difference of an electrically driven device is measured by the voltmeter. The audit team need not to be worried about the data printed in the name plate data sometimes in an occasion that they were gone with time or due to the way the device has been conducted to get the performance by deferent employees over a period of time. Sometimes more sophisticated device like multi-meter could be used to measure all Voltage, Current and Resistance.

Wattmeter: Technically the rate of energy is used is measured with this device and it is some mode of product of voltage and current.

Power Factor Meter: Technically this measure gives the figure or the factor of real efficiency compared to total power or energy used.

Thermometers: It measures the temperature and different measures and devises are required to get different measurements of high low levels and also on humidity factor related measures.

Meter Ruler/ Tape: Length is a vital measurement for every application of energy measurement. In water sector energy audit activities, pipe lengths or in compartment dimensions with device arrangements for different aspects of user could be measured and recorded.

Collecting energy consumption data

When all plans are covered data gathered are established in a proper management establish system. Initial meetings and gatherings are held to convey knowledge to the management and the personals those involved in the audit. These gathering result healthy success towards the successful end of the programme. Sometimes attending every activity with top management simply does not give total success. In a factory for example, technical staff, equipment operators are more effective in data collection aspects. Data may be in different categories, technical data like dimensions of the factory premises for ventilation, comfort etc. dimension of the equipment like blowers surge vessels etc. Sometimes all expenses recorded in bills vouchers are among the needs for energy audit. What type of data are aiming to gather is given in table 2.13 as a summery. Proper approach with reduced expenses over an activity to be implemented in future could be focused with these gathering, implementation and utilisation of the data. Bench marks are fixed by the outcome of the energy audit which will be more and more for the future implementation and required goal achievements.

Table 2.13: Energy Audit Data Required in Water Utilities

General	**Pumps**	**Electric Motors**
Utility bills	Rated head	Motor application
Fuel bills	Discharge and shaft speed (nameplate)	Name plate data
Facility bills	Actual discharge	Rated power
Facility layout	Pump suction pressure	Rated voltage
Production output	Discharge pressure	Current
Operating hours	Pump shaft speed	Full load amps
Inventory of equipment	Pipe sizes	Power factor
	Water level (source)	Load profile
	Flow velocity	

Source: James et al, 2002

c. Analysing energy audit data

Having data is collected, energy managed pattern and equipment efficiencies are calculated. Energy is utilising by different systems in different ways. It may not necessarily be the same audit concocting pattern or the same category of equations are involved to assess the final results or recommendations,

- **Energy Utilisation Calculation**

Calculating to determine energy utilisation explains different dimensions on energy management. Energy is used by machineries but the same machinery gives or dissipates heat still the heat not being among the required component. Someone to recognise with cost comparison whether the water is a media to use as incompressible fluids than developed other oils. Management of system will explore the engineering practice like thermodynamics or application of Bernoulli's equation is more helpful to continue the programme.

- **Efficiency Calculation**

Efficiency is determined over the energy input to a system simply to energy balance among input and losses, and derive a figure for implementation of a system to achieve better results:

$$EnergyEfficiency\ (\%) = \frac{Energy\ input - Energy\ Losses}{Energy\ input} \times 100 \qquad \text{Equation (2.1)}$$

Equipment wise the result achieved from the audit components as the efficiency could be used to compare with industry norms. When any of the results for an example, efficiency, is weak against the industry norms set out by some industrial, supply or factory basis figures, then it would be a sign to go for the improvements that may be for a single or for a category, step wise:

First Step : Calculate the difference between normal value and result obtained from energy audit.

Second Step : Above difference is multiplied with input of total energy. It is called energy saving potential

It could be considered as a goal for energy conservation and this result is for one type or category.

d. Evaluating opportunities and making recommendations

Different approaches are possible to carry out with energy reduction opportunities. In one energy audit, different opportunities could be approached to have better results. When multiple number of opportunities are executed to attend with programme, improvement is possible with better overall efficiency as an integrated or as a whole plant together.

- Capital requirement to implement recommendation?
- Saving of energy and capital to implement recommendation?
- Saving time to implement recommendation?

The whole outcome of the energy audit is a talent dependant for when the team is more experienced and more skilful, then it is very much easier to identify and implement some more effective measures. Desperate decisions are a team dependant, identifying which component to replace or which equipment to remove is time, capital, energy effected activities. Second consideration is necessary to be focused whether to need additional skill training to new implementation of equipment which is costly. When new plant or equipment is placed. all literature on the installation, operation and operational and break-down maintenance related catalogues logs guidelines are required to be arranged and examined.

- Benefits should be calculated
- Baseline estimate should be prepared
- Energy usage must be compared for new implementation
- Accurate baseline must be set
- Software support will be beneficial
- All must be implemented to one-time programme

e. Report writing

The maim receiver of the audit report is the higher management that the consent is given to the energy audit to be carried out. The content of the audit report must be concisely condensed as a report and there:

- process to be implemented must be described
- recommendations must be clearly emphasised
- summary for possible savings
- facility used for auditing
- provision of graphs and tables
- audited

Management must be well convinced with the facts through how decision are made.

When the auditing team comes up with assumptions, the must be brought to the notice by their report in order to consider in reviewing. Sometimes rates referred to material or equipment as a whole may have changed with time change.

2.9 Energy Consuming Equipment of Water Supply Schemes

In municipal water utilities, the biggest consumers of energy are the pumps and electric motors. Therefore, assessing of energy efficiencies of motors and pumps is required in the identification of energy saving opportunities (EPRI, 1994).

2.10 Energy Consumption Assessment of Pumps

Pumping is the main power consuming motor application in general potential energy of water is converted into kinetic energy. Unique pumping sets are used to the situation. Generally, Centrifugal pumps are implemented for water pumping.

- single-stage centrifugal
- multi-stage centrifugal
- axial
- mixed-flow pumps

Other types of pumps are used on different occasions

- Centrifugal split casing
- Positive displacement pumps
- Diaphragm pumps
- Gear pumps
- Rotary pumps

Pump characteristic dependants:

- capacity
- pump head
- water power
- pump shaft power

- net positive suction head
- pump efficiency
- specific speed

Mainly a pump consists of suction port and delivery port in the pump housing, pump shaft and impeller. When impeller rotates water is centrifugally pushed to delivery port. The pumping head could be defined as the net work done on a unit gravity mass of water by the pump impeller.

The head of a pump is defined by Bernoulli equation:

$$h_p = H_1 - H_2 + h_L \qquad \text{Equation (2.2)}$$

where:

H_1 = Total delivery head

h_p = Pump head

H_2 = Total suction head

h_L = Total head loss

Water power of a pump is the power gained by water by pump. It is in turn, elevation of water column. Water power is measured in SI units:

$$P_{water} = \frac{\gamma Q h_p}{1000} \qquad \text{Equation (2.3)}$$

where:

P_{water} = Water power/ kW

γ = Specific weight of water, 9.81 N/m^3

In the event of water power calculation requirement both pump capacity and the pump head must be known.

The pumping set overall efficiency is derived as:

$$\eta_{total} = \frac{P_{water}}{P_{input}} \qquad \text{Equation (2.4)}$$

Pump efficiency is calculated as a fraction of shaft power. Therefore, its efficiency is shown as:

$$\eta_{pump} = \frac{P_{water}}{P_{shaft}}$$ Equation (2.5)

The motor likewise has its own efficiency rating:

$$\eta_{motor} = \frac{P_{shaft}}{P_{input}}$$ Equation (2.6)

Therefore the efficiency:

$$\eta_{total} = \frac{P_{water}}{P_{input}} = \frac{P_{water}}{P_{shaft}} \times \frac{P_{shaft}}{P_{input}} = \eta_{water} \times \eta_{motor}$$ Equation (2.7)

This equation shows that the overall efficiency for a particular pumping set could be considered as multiplication of the efficiency of the motor and efficiency of the pump. When modern pumping sets are considered they are in efficiencies in higher side and as a figure around 80%. To achieve such a higher efficiency for a pumping set, their individual motor and pump efficiencies must lie around 90% which is a good combination.

In addition, losses could be incurred due to excessive pressure of water that is pumped. If the water delivered in the reservoir has too much kinetic energy, it is all dissipated as heat in the reservoir. If the system was more properly designed, a smaller pump and motor could do the same work instead of using bigger size pump and motor which consume more energy.

As a general statement, pumping sets with 100% is not practical for no perfect motion is ever met. An energy component is separated in the event of sound generation and other component is for generation of heat in both motor section and pump section.

2.11 Assessment of Energy Consumption for Motors

Generally, pumping sets available in the market are about 81 to 92% energy is used by motor as electrical power. Two types of motors are in practice used for pump coupling, one is general-purpose capacitor start and the other type is typical poly-phase design. In national water sector utilities, it is common practice higher capacities are obtained with high voltage panel operations. Medium capacities up to about $500m^3$/hr are operated with low voltage panel operations. Motor variety concept can be obtained from Figure 2.7:

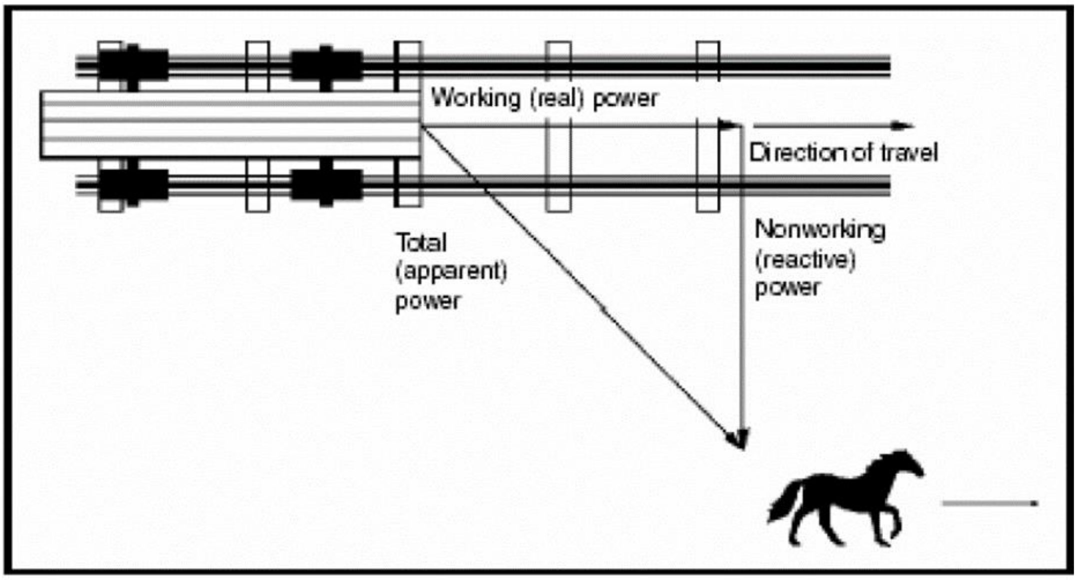


Figure 2.7: Graphic representation of power triangle
Source: Alliance to Save Energy, 2002

As displayed in the figure 2.7, a horse is pulling a rail cart. At any time, the horse is pulling the cart along the railroad, the effort the horse put to pull the cart works to the work. But when the horse is pulling the cart perpendicular to the rail hardly any work could be done. Therefore, as illustrated in the figure, horse is pulling the cart to a direction that a portion of the effort goes for movement of the cart and that force could be named as active power. Perpendicular component to road does nothing to pull the cart along the road and hence that component is called reactive power.

As the power components are said then active power and reactive power are identified. The ratio real power to total power is called the power factor. When from outside the horse is observed, though horse is giving its total effort to pull the cart only a portion of its effort works. This power factor to become 1, horse must pull the cart along the rail road. Then reactive power component become zero. When horse is pulling the cart to perpendicular direction to the road, then the power factor value become one. However, at both occasions, horse is making his full effort to pull the cart, whether the effort is successful or not.

$$Powr\ Factor = \frac{Real\ Power}{Apparent\ Powoer} \quad \text{Equation (2.8)}$$

$$Real\ Power = \sqrt{3}.V.I.\cos\phi \quad \text{Equation (2.9)}$$

$$Apperent\ Power = V.I \quad \text{Equation (2.10)}$$

Where:

V	: Voltage (V)
I	: Current (A)
Cos∅	: Power factor

Several benefits are achievable with improvement of power factor.

- capacity of the plant could be increased
- "penalty" could be eliminated on charges over reduced power factor by Ceylon electricity board
- power losses are reduced and supply voltage is improved
- nationally feeders' effort become less in distribution, transformers and other related equipment.

Power factor improvements possibilities:

- Installation of capacitor banks parallel with motor supply to reduce the reactive power component in the AC circuit
- Eliminating operation of idling or less loaded motors.
- Replacements with efficient motors for inefficient motors as much as possible
- Operating the equipment at its specified operating point
- Make sure that specification for operation is correct

2.12 Energy Conservation Methods

2.12.1 Schedule adjustments for pump operation

Usually for a three phase power supply, the electricity bill consists of two types of charges. One is the charge for the load on the power supply system which is measured in kVA. The other is the charge for electricity consumption measured in kWh (active power). By adjusting the pump operation schedules the load on the system could be reduced and cost savings can be gained. For an example when backwashing filters, backwash pumps and air compressor have to be operated. This will increase the load on the electricity supply and the monthly kVA charge will be increased. If the distribution pumps were turned off before switching on backwash pumps and air compressor the maximum load on the system will not increase. However, this does not have any effect on kWh.

2.12.2 Reduce in pipe frictions in pumping lines

Several factors are affected to pipe internal friction to flow; due to roughness of the pipe with ageing, corrosion, hardness and causing reduction of internal diameter, due to scaling. These cause increases the energy requirement for pumping water. Cleaning or replacing these pipe lines can provide significant energy savings. A cost benefit analysis considering the useful lifetime of pipes should be carried out to understand whether the replacement is cost effective.

The effect of pipe friction on motor power can be described using Figure 2.8. The proposed operating point is OP1 (Q1, H1) on system curve 1. If the friction is reduced the operating point will be shifted to and OP2 (Q2, H2). The efficiencies of pump at these two operations are E1 and E2 (James et al, 2002).

$$The\ change\ of\ pump\ power = (\gamma Q_1\, H_1/E_1) - (\gamma Q_2\, H_2/E_2) \qquad \text{Equation (2.11)}$$

For constant speed pumps we can assume the motor efficiency (Em) to be constant over the operation range.

$$The\ change\ in\ motor\ input\ power = \{(\gamma Q_1\, H_1/E_1) - (\gamma Q_2\, H_2/E_2)\}/E_m \qquad \text{Equation (2.12)}$$

2.12.3 Throttling of pumping lines

Throttling is done to reduce the flow in a fixed speed pumping system when the pump delivers more quantity than required. Pump throttling shifts the operating point of the pump curve to another point where the efficiency shifts from the desired point. This causes additional consumption of energy which is a waste. This energy can be conserved by introducing a VFD to a fixed speed pumping system or by trimming the impellers.

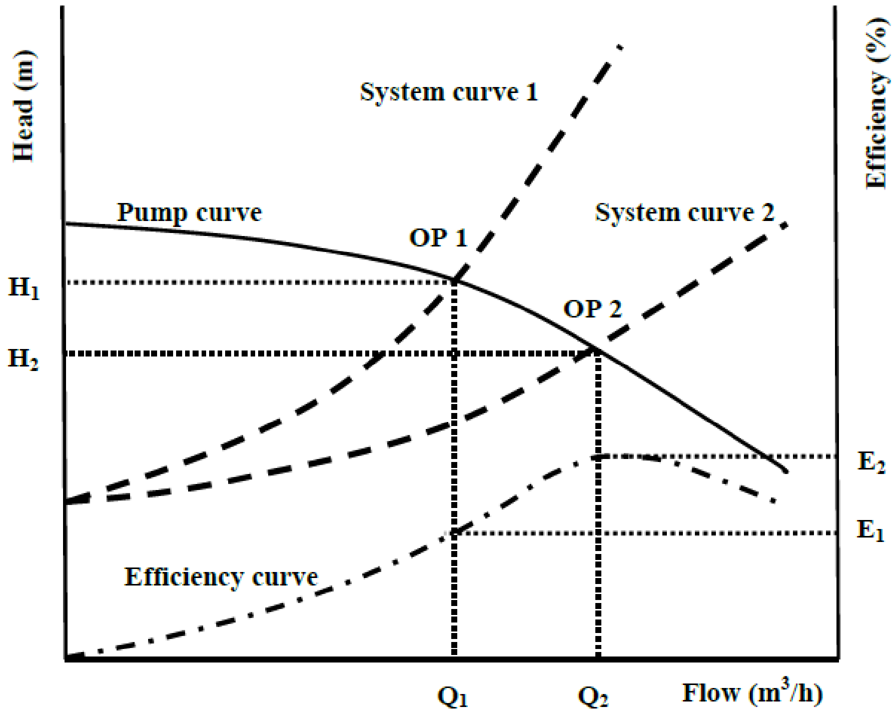


Figure 2.8: Effect of reducing pipe friction
Source: Modified from James et al, 2002

2.12.4 Implementation of capacitor banks

Higher ampere rated equipment are in general uses three phase power supply source which consists of two kinds of power, active and reactive. The reactive power depends on the power factor and the power consumed during the various periods. The active power does the real work. The power factor improvement helps to reduce reactive power component of the electric device. Capacitor bank installation assists the system to reduce the power factor closer towards 1.

2.12.5 Adjusting operation schedules to take advantage of tariff structure

Some countries have different electricity tariffs for peak and off peak times of electricity consumption. If the operation schedules of the WSS could be adjusted accordingly to take the benefit of this tariff structure, significant cost savings can be achieved.

2.12.6 Introduction of Variable Frequency Drives (VFD)

Water demand of a distribution system with direct pumping operation varies according to instantaneous demand pattern and pumps with fixed operating frequency maintains water at the same head and flow rate curve which leads to vary the head depending on the flow rate. This is a waste of energy and equipment and by installing VFD the energy could be saved. VFD helps to adjust the motor speed to the required level with the demand and flow matching with head of the pump, reducing the energy losses.

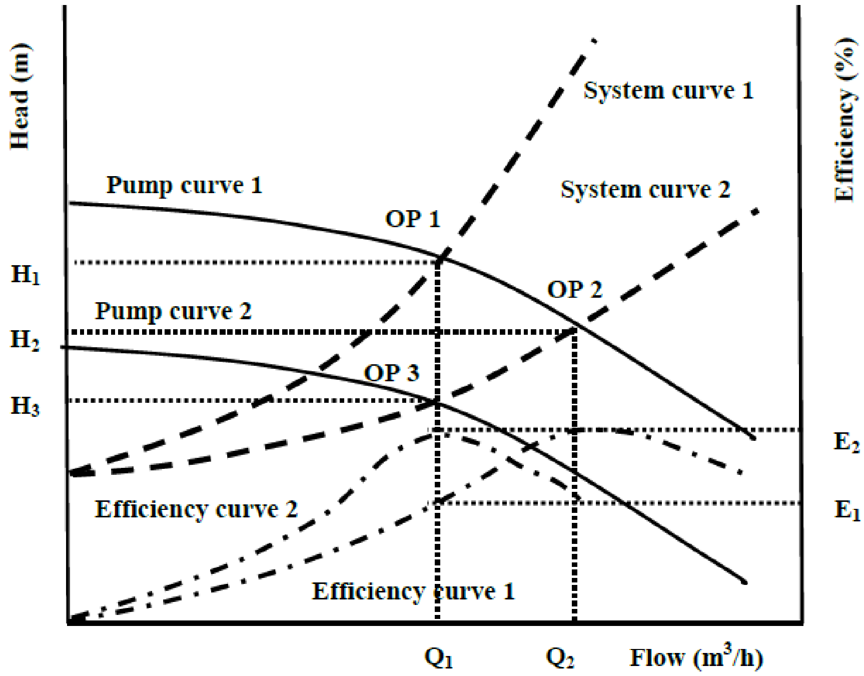


Figure 2.9: The effect of installing a Variable Speed Drive
Source: Modified from James et al, 2002

The effect of reducing pump friction and the function of VSD is shown in Figure 2.9. For an example a pumping system operates at OP1 (Q_1, H_1) at pump efficiency E_1 (system curve 1 and pump curve 1). At this operating point the pump is running at lesser than maximum efficiency also. If the friction of the pumping system can be reduced, the system curve will change as system curve 2 and the operating point will shift to OP2 which will cause the reservoir to overflow due to increased flow. A VSD can shift the pump curve down as shown in pump curve 2. The operation point is OP3 ((Q_1, H_3). At OP3 the flow rate is equal to the required flow rate, head is reduced to H_3 and the pump is running at maximum efficiency. The energy saved could be calculated as follows (James et al, 2002)

$$The\ change\ of\ pump\ power = (\gamma Q_1 H_1/E_1) - (\gamma Q_1 H_3/E_2)$$ Equation (2.13)

For constant speed pumps we can assume the motor efficiency (E_m) to be constant over the operation range.

$$The\ change\ in\ motor\ input\ power = \{(\gamma Q_1 H_1/E_1) - (\gamma Q_2 H_3/E_2)\}/E_m$$ Equation (2.14)

$$Energy\ saved = [\{(\gamma Q_1 H_1/E_1) - (\gamma Q_2 H_3/E_2)\}/E_m]N$$ Equation (2.15)

2.13 Energy Conservation Potential by Reducing Water Losses at Treatment Plant and Distribution

Reduction of water losses at the water treatment plant and the distribution will reduce the energy consumption of a water supply scheme. There are two strategies to reduce the water losses: reducing water losses in treatment plant and reduction of Non-Revenue Water (NRW) in the distribution network. The energy saving from water losses in the treatment plant is due the elevation difference between the WTP and the intake.

The energy saving from NRW is due to the reduction of daily/monthly production. Table 2.14 presents the energy conservation potential of incremental reductions of NRW at Hapugala WSS considering the total specific energy consumption of surface water supply scheme as 0.78 kWh/m^3 and average daily production as 9000m^3/d.

Table 2.14: Energy Conservation Potential of Reducing NRW in Hapugala Water Supply Scheme

NRW Reduction (%)	Quantity saved (m^3/month)	Reduction in production (m^3/month)	Reduction in energy consumption (kWh/month)
1	5169	5169	4032
2	10338	10338	8064
3	15508	15508	12096
4	20677	20677	16128
5	25846	25846	20160
6	31015	31015	24192
7	36185	36185	28224
8	41354	41354	32256
9	46523	36288	46523
10	51692	40320	51692

Source: Modified from Kalaimathie, 2012

2.13.1 Reducing water losses in treatment plant

The water losses in a water treatment plant usually ranges from 2 to 5% of total volume of treated water. The major portion of this water loss is through filter backwash. The energy consumed in pumping this water from the source to WTP is wasted due this water loss.

Reducing the frequency of filter backwashing is one possible option to save energy. However, this has to be done without compromising the flow rate through the filter and required effluent quality.

The other option is the recovery of backwash water. The major concern in backwash water recovery is the removal of Cryptosporidium and Giardia which is concentrated in filter backwash waters. To meet the challenges of the stringent drinking water regulations established to improve controlling of Cryptosporidium and Giardia, additional physical and chemical water treatment processes are required. Pressure-driven membrane processes such as microfiltration and ultrafiltration are playing an important role in drinking water production in the USA and in Europe (Betancourt and Rose, 2004).

Ceramic micro filters have the higher potential for removing Cryptosporidium and Giardia which exists in natural water sources and in filer backwash waters. In addition, ceramic microfiltration can provide high removal for colour, turbidity, iron, manganese and aluminium for 0.1 and 1μm membranes. Ceramic microfiltration facilitates high water recovery leading to minimize the wastewater volume for sludge dewatering process (Kalaimathie, 2012).

As per a pilot plant study carried out in Netherland energy consumption for treating backwash water using dead end micro filtration is 0.15 kWh/m^3 (Willemse and Brekvoort, 1999). The Ducth Foundation for Water Research (STOWA) specifies that the energy consumption for micro filtration ranges from 0.1 to 0.2 kWh/m^3 (STOWA, 2013).

2.13.2 Reduction of Non-Revenue Water (NRW) in the distribution network

Water losses in the treated water transmission and distribution network are indicated using the key performance indicator Non-Revenue Water (NRW). NRW represents the difference between net production and the net water quantity sold.

$$Non\ Revenue\ Water\ (NRW) = \frac{(Net\ water\ production - Net\ water\ quatity\ sold)}{Net\ water\ production} \times 100$$ Equation (2.16)

NRW consists mainly of two components: physical losses (real losses) and commercial losses (apparent losses). The physical losses are the water lost through pipe breaks and leakage, overflows of distribution tanks and house connection leaks. Commercial losses are water consumed but not paid for due to meter under-registration, illegal connections or unbilled authorized consumption (IWA, 2000). NRW in major cities in Asia are shown in Figure 2.10 (ADB, 2004). The NRW of these cities are more than 10% except for Osaka. However, the American Water Works Associations (AWWA) benchmark for NRW is 10% (AWWA, 1998).

The level of losses from water systems is often considered by observers from outside the industry to be unacceptable. Environmentalists and regulators have expressed concerns at the level of losses, and believe that lower levels should be achievable. However, any water company has to work within current operating budgets and seek additional finance if these are not sufficient. Leakage control can be expensive, and water companies will seek to achieve an economic balance between the costs of leakage control and the benefits that accrue. Economic Level of Leakage is the acceptable level of leakage, assessed considering this economic balance (Pearson and Trow, 2005).

The range of ELL for low and medium income countries is 155 - 310 L/connection/day (Frauendorfer and Liemberger, 2010).

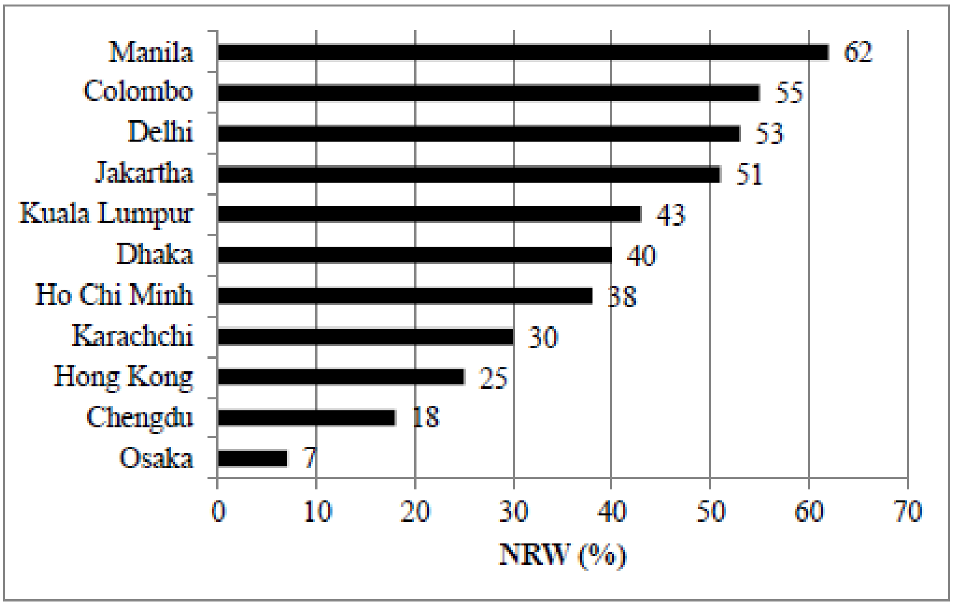


Figure 2.10: Non revenue water in major cities in Asia
Source: ADB,2004

3. METHODOLOGY

3.1 Introduction

The study targeted as stated in chapter 1, two main activities to reach the objectives. Activity one is to assess the potential for energy conservation by carrying out energy audits in selected Water Supply Schemes (WSSs) and second is to develop benchmarks for energy consumption processes in water supply schemes using primary and secondary data collected. Figure 3.1 shows the overall research plan.

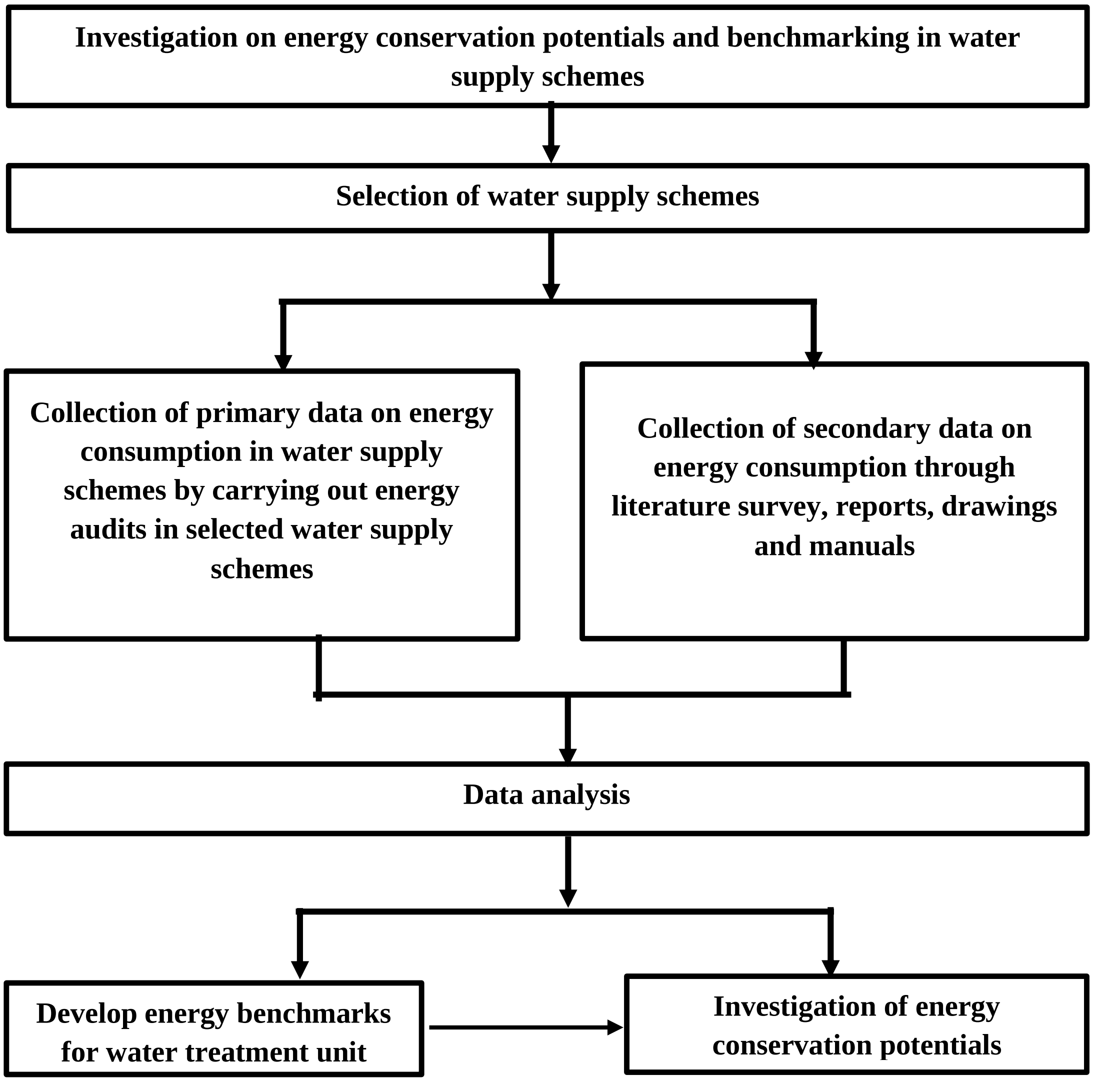


Figure 3.1: Overall research plan

3.2 Selection of Water Supply Schemes for the Study

Five WSSs from Southern Region were selected for the study. Selected WSSs are Greater Galle – Hapugala WTP, Malimbada WTP, Ruhunupura WTP, Hallala WTP and Tangalle WTP. The scheme data selected are presented in Table 3.1. Both technical and management aspects were considered when selecting these WTPs for the study.

Selected water supply schemes use surface water from rivers and tanks as raw water. Tangalle WSS was commissioned in 2000 and all other selected Water Treatment Plants (WTPs) had been commissioned within last ten years. This was done to represent old and newly constructed WSSs in Southern Region. The schematic diagrams of the selected water supply schemes are shown in Figures A.1 to A.5 of Appendix A.

Selected WTPs produce drinking water which comply to SLS 614:1983. However, the standards are in the recommended ranges of WHO Drinking Water Guideline: 2008. Comparison of these standards with the WHO guideline is attached in Table A.1 in Appendix A (BOI, 2013; WEPA, 2013; WHO, 2011).

Design capacity ranges from 9000 m3/d to 43,000 m3/d and present production ranges from 8000 m3/d to 45,000 m3/d. Therefore, Greater Galle – Hapugala WTP and Malimbada WTP can be categorized as large scale and Ruhunupura WTP, Hallala WTP and Tangalle WTP can be categorized as medium scale according to the Sri Lankan context. All selected WTPs employ conventional water treatment process except Ruhunupura WTP where flocculation and sedimentation is performed using a pulsator clarifier and micro strainer and DAF system for algae removal. All the WTPs are situated in dry climate. Greater Galle – Hapugala WTP, Malimbada WTP and Ruhunupura WTP are operated using Supervisory Control And Data Acquisition (SCADA) systems. Other schemes are operated semi-automated.

3.3 Primary and secondary data collection through energy audit

Both primary and secondary data were collected by carrying out energy audits in selected WSSs to evaluate the specific energy consumption and to identify and quantify energy conservation potentials.

The energy audits were carried out in two stages; preliminary auditing stage and detailed auditing stage. In preliminary audit, energy consumption was analysed to identify the most likely areas for immediate improvement and estimate the scope for saving. In this stage an equipment inventory was created and the distribution of energy demand in the system was documented to find the most likely areas for immediate improvement. In addition to data required for quantifying energy consumption, data required to quantify water losses also collected. The primary and secondary data collected at preliminary audits are presented in table 3.2. The rated parameters of the equipment were collected to check whether the measured parameters were in acceptable range.

The detailed audit was carried out to check the potential for increased plant efficiency. Data required for evaluation of performance of the pumps and other energy utilizing equipment in the plants were collected at this stage. In addition, data required for quantifying the potential energy savings from reduction of leakage was also collected. The primary and secondary data collected at detailed energy audit is presented in table 3.3.

Table 3.1: Comparison of Selected Water Supply Schemes as at 31 December 2015

Water Supply Scheme	Hallala WTP	Hapugala WTP	Malimbada WTP	Ruhunupura WTP	Tangalle WTP
District	Matara	Galle	Matara	Hambantota	Hambantota
Type of source	Surface water	Surface water	Surface water	Surface water	Surface water
Name of the source	Nilwala River	Gin River	Nilwala River	Ridiyagama Tank	Kirama Oya
Year of commissioning	2012	2010	2008	2015	2000
Treated water quality standard	SLS 614:1983 drinking water standard				
Design capacity (m3/day)	8000	32000	45000	17500	9000
Present production (m3/day)	7600	32000	43000	11000	8000
Treatment process	• Rapid mixing (hydraulic jump) • Flocculator • Sedimentation tank • Rapid sand filters • Gas chlorination	• Aerator • Rapid mixing (hydraulic jump) • Flocculation & Sedimentation by Pulsater clarifier • Rapid sand filters • Gas chlorination	• Aerator • Rapid mixing (hydraulic jump) • Flocculator • Sedimentation tank • Rapid sand filters • Gas chlorination	• Aerator • Rapid mixing (hydraulic jump) • Flocculator • DAF • Sedimentation tank • Rapid sand filters • GAC • Gas chlorination	• Rapid mixing (hydraulic jump) • Flocculator • Sedimentation tank • Rapid sand filters • Gas chlorination
Number of connections	11000	45000	80000	9000	9000
Number of consumers	55000	225000	365000	45000	82690
Distribution length (km)	210	510	610	395	430
Topography	Plain	Plain	Plain	Plain	Plain
Highest elevation–MSL (m)	78	102	88	78	71
Lowest elevation-MSL(m)	10	40	32	20	18
Climate	Wet	Wet	Wet	Erid	Erid
Automation	Semi-automated	Semi-automated	Semi-automated	SCADA	Semi-automated

Table 3.2: Primary and Secondary Data Collected During the Preliminary Energy Audit

Secondary Data			**Primary Data**	
General	**Motors**	**Pumps**	**Motor**	**Pump**
Electricity bills	Rated power	Rated head	Actual power	Actual head
Schematic diagram	Rated voltage	Rated discharge	Actual voltage	Actual discharge
Inventory of equipment	Rated current		Actual current	
Monthly production	Rated power factor		Actual power factor	
Monthly consumption	Operating hours		Operating hours	

Table 3.3: Primary and Secondary Data Collected During the Detailed Energy Audit

Secondary Data			**Primary Data**	
General/ NRW	Motors	Pumps	Motors	pump
Pipe length	Rated efficiency	Manufacturers Pump characteristic curve	Actual input power	Actual pump characteristic curve
Number of house connections		Manufacturers Pump efficiency curve	Actual output power	Actual Pump efficiency curve
Length of house connection		System characteristic curve for pumping main	Actual efficiency	
Average pressure		Hydraulic profile		

As per the table 3.2 and 3.3 following parameters were measured during energy audits including basic electrical parameters; voltage (V), current (I), power factor, energy consumption (kWh), flow rate (m^3/h) and pump head (Bar).

Non – contact type flow meters such as Doppler Effect flow meters or ultra-sonic flow meters and volumetric meters were used to measure the flow rate where available. Measurements of parameters namely current, voltage, power factor, active power, energy consumption related to flow were done using clip-on meters without stopping the equipment. The pump pressure head was measured using pressure gauge.

3.4 Secondary Data Collection for Creating Benchmarks

To create the benchmarks for energy consumption in water treatment unit processes, the specific energy consumption of water supply schemes in countries such USA, Canada, UK, Australia, New Zealand, Spain and Taiwan was collected by literature review.

3.5 Calculation of Energy Consumption and Efficiencies

The calculation procedure for efficiencies is as follows:

$$Water\ power = P_H = Q\rho gh \quad \text{Equation (3.1)}$$

$$Electric\ input\ power = P_I = \sqrt{3}.V.I.cos\phi \quad \text{Equation (3.2)}$$

$$Pump\ Efficiency = \eta_p = P_H/P_T \quad \text{Equation (3.3)}$$

$$Motor\ Efficiency = \eta_M = P_T/P_I \quad \text{Equation (3.4)}$$

$$Overall\ Efficiency = \eta_r = \eta_p * \eta_M \quad \text{Equation (3.5)}$$

Where:

Q	: Flow rate (m^3/s)	PI	: Input electrical power
H	: Total head (m)	η_M	: Motor efficiency
ρ	: Density (kg/m^3)	P_T	: Motor output power
G	: Specific gravity (ms^{-2})	η_r	: Overall efficiency
V	: Voltage (V)	η_P	: Motor efficiency
I	: Current (A)	P_H	: Water power
CosØ	: Power factor		

3.6 Energy Balance of Water Supply Schemes

Following performance indicators were considered during benchmarking;

Energy consumption of treated water produced per unit volume in kWh/m^3. Considered individual unit processes.

For energy balance calculations, typical energy consumption points in a WSS are shown in Figure 3.2.

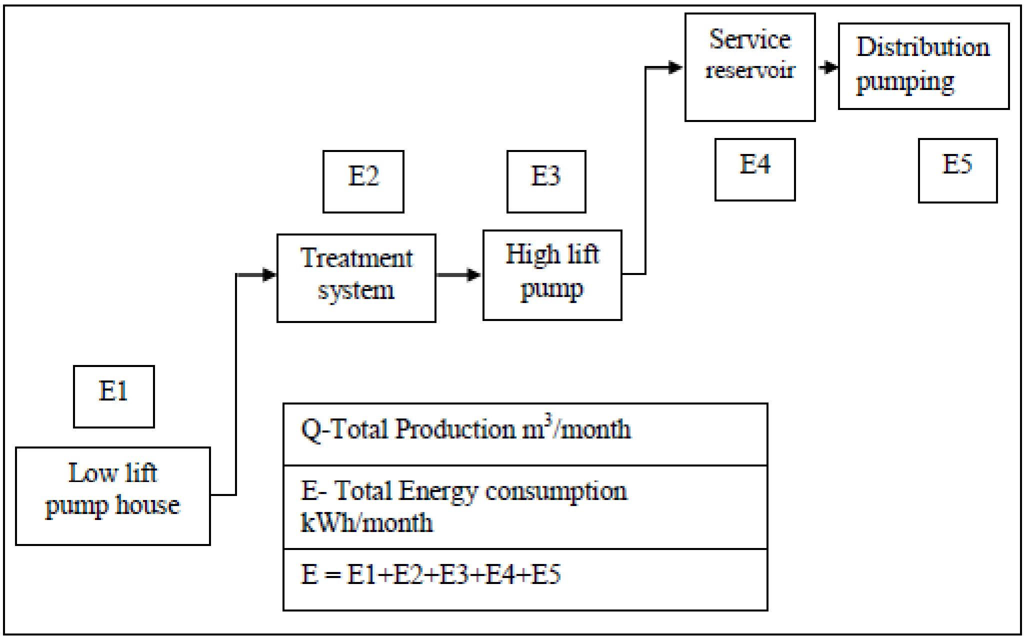


Figure 3.2: Typical energy consumption points in WSS

The Specific Energy Consumption:

$$Total\ Energy\ Consumption\ (E) = E_1 + E_2 + E_3 + E_4 + E_5 \quad \text{Equation (3.6)}$$

$$Energy\ Consumption\ for\ Unit\ Volume = E/Q \quad \text{Equation (3.7)}$$

Where:

Q : Total volume of water produced in m^3

E : Total Energy consumption (kWh)

3.7 Benchmarking of Energy Consumption in Unit Processes

Likewise, for unit volume, specific energy consumption consumed at each unit process for individual unit processes were identified separately for benchmarking. The energy consumption for each unit process was estimated from the electricity readings directly when available or else from other measurements such as bulk meter readings and pressure gauge readings. When all of the above measurements were not available, the energy consumption was estimated using rated power consumption of the particular equipment being used. The sum of the energy consumption of each unit process estimated was compared with the total energy consumption of said water treatment scheme obtained from electricity meter readings. Typical energy consumption points in a water treatment model plant are illustrated in Figure 3.3.

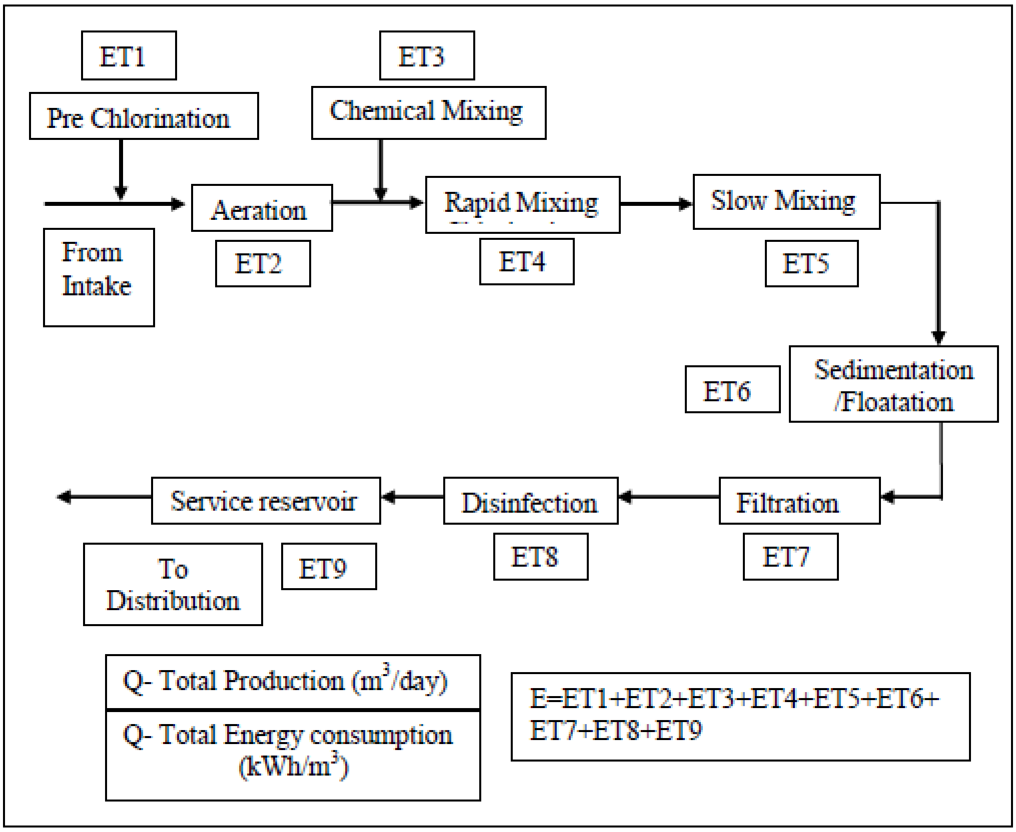


Figure 3.3: Typical energy consumption points in a drinking water treatment plant

The energy consumption was calculated as follows:

$$Total\ energy\ consumption\ (E) = ET1 + ET2 + ET3 + ET4 + ET5 + ET6 + ET7 + ET8 + ET9 \qquad \text{Equation (3.8)}$$

$$Energy\ consumption\ for\ treatment\ of\ unit\ volume = E/Q \qquad \text{Equation (3.9)}$$

Where:

Q : Total volume of water produced in m^3)

E : Total Energy consumption (kWh)

ETT1-T8 : Energy consumption of unit processes (kWh)

The energy assessed for unit processes was adjusted so that total calculated energy consumption (E) was equal to total measured from electricity meter.

3.8 Calculation of Energy Conservation Potential of Reducing Non-Revenue Water

Non-Revenue Water (NRW) is the difference in the quantity of water produced and the quantity of water sold and it was calculated using equation 3.10.

$$NRW(\%) = \frac{(Net\ waterquantity\ produced - Net\ water\ quantity\ sold) \times 100}{Net\ water\ quantity\ produced}$$ Equation (3.10)

The major components of NRW are physical losses and commercial losses. The physical losses are the water lost through pipe breaks and leakage, overflows of distribution tanks and house connection leaks. Commercial losses are water consumed but not paid for due to meter under-registration, illegal connections or unbilled authorized consumption (IWA, 2000).

The total NRW was apportioned to above components of water losses and the potentials for reduction of water loss in above components was estimated. The potential to reduce real losses was calculated using equation 3.11 utilizing the Economic Level of Leakage (ELL) concept. The range of ELL for low and medium income countries is 155- 310 L/connection/day (Frauendorfer and Liemberger, 2010).

$$Reduction\ potential\ of\ real\ losses\ \left(\frac{L}{day}\right) = Real\ Losses - ELL$$ Equation (3.11)

Where:

Np = number of service connections

The energy conservation potential of reducing NRW is calculated using equation 3.12.

$$Energy\ saving\ potential\ of\ NRW\ reduction = (Quantity\ of\ water\ saved\ in\ m^3) \times (Specific\ energy\ consumption\ in\ kWh/m^3)$$ Equation (3.12)

3.9 Investigate the Energy Conservation Methods

Using the results of benchmarking study and energy audit, opportunities for energy conservation using following technical options were assessed.

- Adjusting pump operation schedules – Method discussed in section 2.12.1
- Reduce resistance in pipe lines and avoid pump throttling – Calculation method discussed in section 2.12.2
- Adjusting of operation schedules to get the advantages of electricity tariff structures – Only preliminary assessment was done
- Introduction of Variable Speed Drives (VSD) - Calculation method discussed in section 2.12.6

In addition to the above direct energy savings methods, the indirect energy saving which could be gained by reducing water losses was also assessed as discussed in section 3.8.

4. RESULTS AND DISCUSSION

This research was conducted by carrying out energy audits in Ruhunupura, Hapugala, Malimbada, Tangalle WSSs and Hallala to benchmark the energy consumption of water treatment unit processes and to identify the energy conservation potentials in WSSs. The schematic diagrams of the treatment processes of these WSSs are shown in Figures A.1 to A.5 of Appendix A. Preliminary energy audits were carried out to figure the different energy consumption components and water treatment unit processes of the selected WSSs. The quantified energy consumption was used to determine the values of the KPI for energy benchmarking; specific energy consumption of the unit process expressed in kWh/m^3. During the preliminary audit energy conservation potentials in the audited WSSs were identified and detailed audits was carried out as per the methodology stipulated in Chapter 3.

4.1 Electricity Consumption of Schemes and Benchmarking of Power Consumption in Water Treatment Unit Processes

There are three major energy consuming components in a WSS as shown in Figure 4.1. This study investigated the energy consumption of all components of the selected WSSs to identify the energy conservation potentials. However, benchmarking was carried out for treatment unit processes only since raw water and distribution pumping varies with many factors such as topography, length of pumping mains, characteristics of pumps and characteristics of pumping mains.

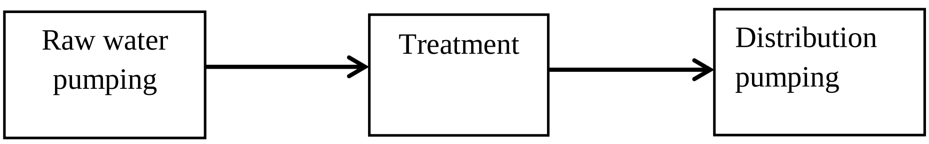


Figure 4.1: Major components of energy consumption in a water supply scheme

4.1.1 Preliminary audit of energy consumption in water supply schemes

Preliminary energy audits were carried out in all selected WSSs to evaluate the energy consumption and primary and secondary data were collected as stipulated in the Chapter 3. A volume balance analysis and an energy balance analysis were carried out to check whether the collected data were acceptable.

- **Volume flow balance analysis**

The volume flow balance analysis was carried out for the boundary from intake pump inlets to the treated water pump outlets of the WTPs using the data presented in tables B.1 to B5 of Appendix B. The volume flow balance was analyzed based on the following equation 4.1.

$$\begin{aligned} &Total\ raw\ water\ volume\ pumped \\ &= Total\ treated\ water\ volume\ pumped \\ &+ Total\ volume\ of\ backwash\ water \\ &+ Volume\ of\ sludge\ water, losses\ and\ increase\ in\ stored\ volume \end{aligned} \quad \text{Equation (4.1)}$$

Table 4.1: Volume Flow Balance and Energy Balance of Selected Water Supply Schemes during Preliminary Energy Audit

Description	**Water Supply Scheme**				
	Hallala	**Ruhunupura**	**Hapugala**	**Malimbada**	**Tangalle**
Preliminary audit duration					
From	09.00 15/12/2015	09.00 4/01/2016	7.00 7/01/2015	07.00. 16/01/2016	09.00 19/01/2016
To	09.00 16/12/2015	09.00 5/01/2016	07.00 8/01/2016	07.00 17/01/2016	09.00 20/01/2016
Volume flow balance					
Raw water quantity (m^3)	9680	8250	18100	36570	10632
Treated water quantity (m^3)	9655	8030	17768	36007	10464
Backwash water quantity (m^3)	From service reservoir*	201	225	450	136
Sludge water, losses & change of storage (m^3)	25	19	107	113	32
% Losses & Change of storage (m^3)	0.26	0.23	0.59	0.31	0.30
Energy balance					
Total input energy (kWh)	3857	5776	10785	21598	4371
Total energy consumption (kWh)	3830	5719	10666	21346	4331
Miscellaneous and losses (kWh)	27	57	119	252	40
% Miscellaneous and losses (kWh)	0.7	0.98	1.1	1.4	0.92

Note *: Backwash water is supplied from service reservoir. Therefore it has to be considered as an outflow/consumption from service reservoir

The volume flow data of preliminary audits of selected WSSs are presented in Table B.1 to B.5 of Appendix B and the volume flow balance analysis of selected WSSs are presented in Table 4.1. The volume of sludge water was considered as part of the losses since the volume of sludge water is small compared to the volume of backwash water. The component of sludge water, losses and increase in stored volume is less than 1.4% as shown in Table 4.1. Therefore, the volume flow balance was acceptable and the quantity of treated water pumped was considered for calculation of specific energy consumption.

- **Energy balance analysis**

The energy balance analysis was carried out for the boundary from intake pump inlets to the treated water pump outlets of the WTPs. The energy consumption of all the equipment were calculated using measured parameters and assigned to the equation 4.2 to check the energy balance.

$$\begin{aligned} &Total\ power\ consumption \\ &= Power\ consumption\ of\ raw\ water\ pumps \\ &+ Power\ consumption\ of\ treated\ water\ pumps \\ &+ Power\ consumption\ for\ water\ treatment \\ &+ Unmeasured\ miscellaneous\ power\ consumptions\ and\ losses \end{aligned} \quad \text{Equation (4.2)}$$

The miscellaneous and loss component consisted of energy consumption of air conditioning, lighting, small equipment like hoists, SCADA panel and losses.

The inventory of energy consuming equipment, energy consumption data of above equipment and energy balance diagrams of selected WSSs are presented in Tables B.6 to B.23 and Figures B.1 to B.5 of Appendix B, and the summary of energy balance analysis of selected WSSs are presented in Table 4.1. The energy consumption of miscellaneous and losses component is around 1% as shown in Table 4.1. Therefore, the energy balance was acceptable.

4.1.2 Boundary and the time frame for total specific energy consumption for drinking water supply schemes using surface water sources

The analysis in sections 4.1.3, 4.1.4 and 4.1.5 are carried out for the following boundary and time frame. The energy consumed in a WSS consists basically of three major components: energy for pumping raw water, energy for water treatment and energy for distribution pumping. The boundary for this analysis is from the intake screens to the water meter of consumer. Energy consumption from intake screens to treated water pumps in the treatment plant was assessed using energy audits. The energy consumption of the pump houses in the distribution was assessed using the electricity bills (specific energy consumption calculated using annual cumulative production and energy consumption data). The time frame was the relevant audit time presented in relevant data tables.

4.1.3 Total specific energy consumption for drinking water supply schemes using surface water sources

The total SEC of water supply for the studied WSSs and other referenced countries in Chapter 2 are shown in Figure 4.2. As per the Figure 4.2, the total SEC for the selected WSSs varies from 0.48 kWh/m^3 at Tangalle WSS to 0.851 kWh/m^3 at Ruhunupura WSS. This is mainly due to the topographical variations in the areas where these WSSs are located. There is a considerable variation between the total SEC of Hallala WSS and Bankhen WSS. The Bangkok Metropolis is located at latitude 13.45° North and longitude 100.28° East with a mean elevation of about 2.31m above mean sea level (Babel and Rivas, 2011). Therefore, the mean elevation difference for Bankhen WSS is 2.31m. Whereas for Hallala WSS, the elevation difference is 54 m. This large variation in elevation difference of the service area is the main reason for the considerable variation in SEC between Hallala and Bankhen WSSs. Sydney and North California shows higher values compared to Asian countries. The variation in these values depends on many factors such as topography, distribution network length, pump and motor efficiencies, pumping main characteristics and service level etc.

The relevant calculations for specific energy consumption are shown in Tables B.17 to B.25 of Appendix B. A summary of specific energy consumption is shown in Table B.26 of Appendix B.

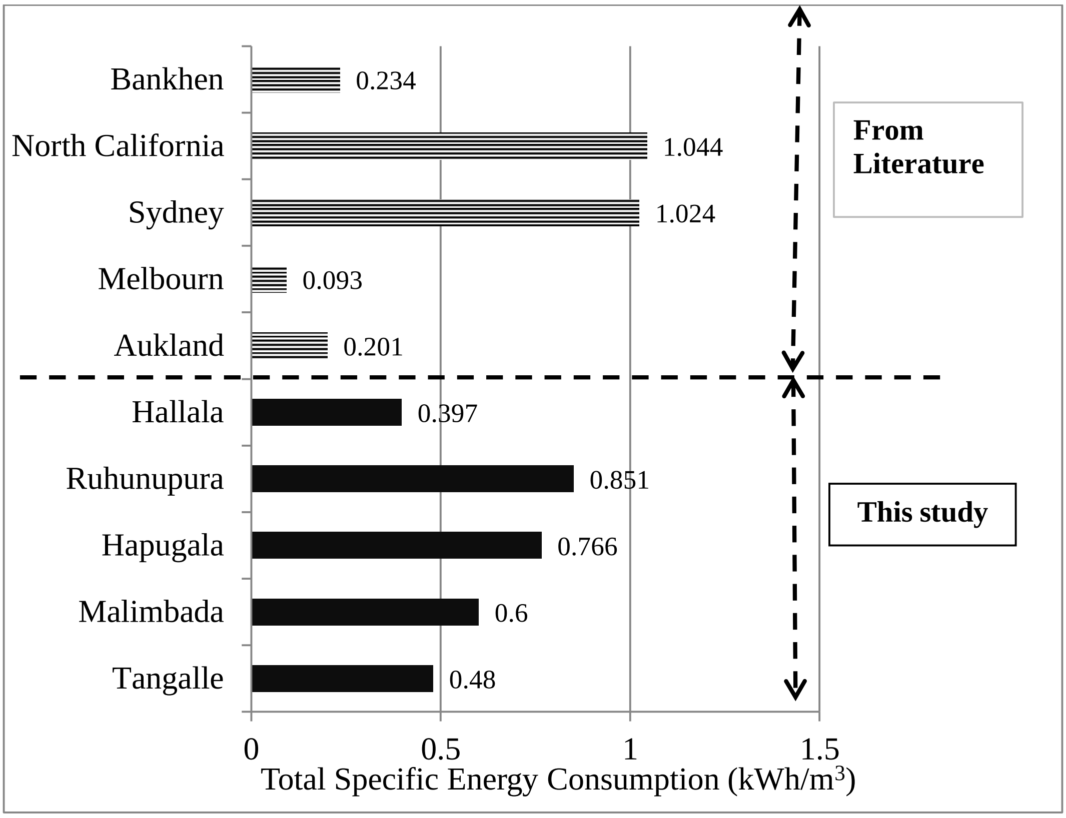


Figure 4.2: Total specific energy consumption for water supply schemes using surface water sources

4.1.4 Energy consumption of major components in water supply schemes

The energy consumed in a WSS consists basically of three major components: energy for raw water pumping, energy for water treatment and energy for distribution pumping. The percentages of energy consumption for the above components in selected WSSs are shown in Figure 4.3. According to the above Figure, in all studied WSSs the major portion of energy was consumed for raw water and treated water pumping. The energy consumption for water treatment varies from 0.4 to 3.3 % and this shows that any attempt on reducing energy consumption in WSSs has to concentrate more on energy conservation in raw water and treated water pumping. The percentage energy consumption for raw water pumping is significantly high at Hallala WSS because the Hallala WSS is located at the top of a mountain which is about 1 km away from the intake. In all other audited WSSs the WTP is located near the intake.

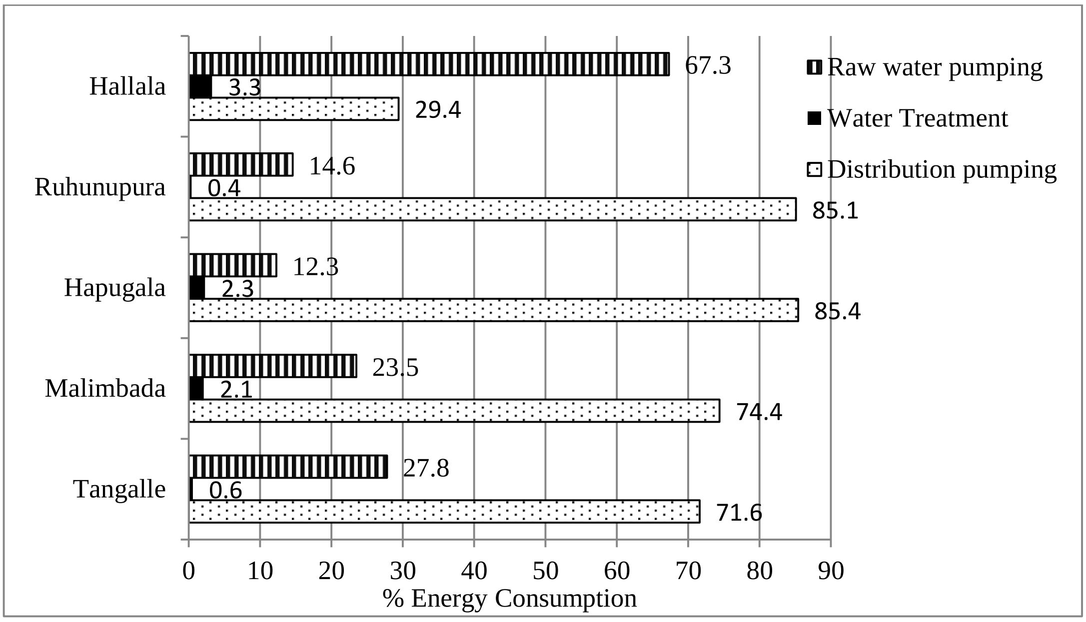


Figure 4.3: Energy consumption of major components in selected water supply schemes

4.1.5 Energy consumption for raw water and distribution pumping

Specific energy consumption of raw water and treated water pumping can be expressed in several units: energy consumption per unit volume produced expressed in kWh/m^3, energy consumption per unit volume pumped per unit lift in elevation expressed in kWh/m^3/m lift and energy consumption per unit volume pumped per unit lift in height per unit length of pumping main expressed in kWh/m^3/ m lift/ km. The following section analyses the SEC of raw water and treated water pumping according to above units.

- **Specific energy consumption per unit volume produced**

The SEC of raw water and treated water pumping in kWh/m^3 for the studied WSSs and other referenced countries in chapter two are shown in Figure 4.4. The SEC of raw water pumping varies from 0.095 kWh/m^3 in Hapugala WSS to 0.146 kWh/m^3 in Malimbada WSS. Hallala WSS show the highest SEC for raw water pumping. This is partially due to the reason that Hallala has the highest elevation difference between intake and WTP from the audited WSSs. Bankhen WSS shows the minimum SEC for raw water pumping WTP. South California shows a lower SEC for raw water pumping compared to Asian countries except Bankhen WSS.

The SEC of distribution pumping varies from 0.344 kWh/m^3 in Mawanalle WSS to 0.724kWh/m^3 in Ruhunupura WSS. This can be justified since the Ruhunupura distribution pumping main has the highest elevation difference of the audited WSSs. The SEC of distribution pumping in Hallala WSS and South California were also within the Sri Lankan range except the Bankhen WSS, which has the lowest SEC for distribution pumping.

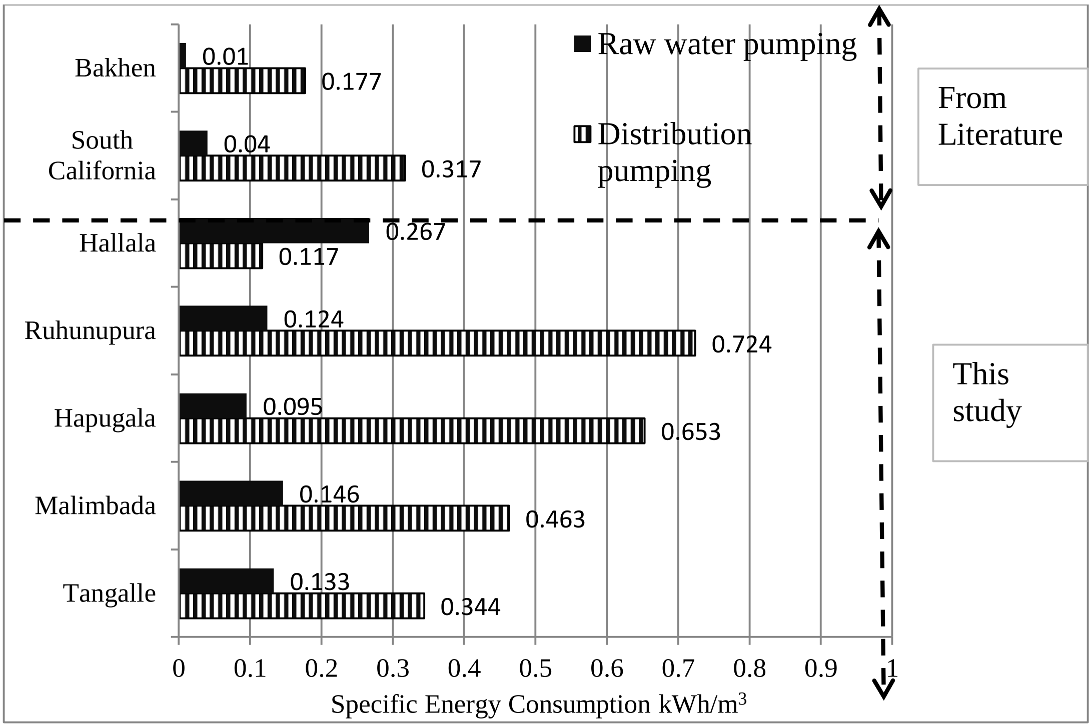


Figure 4.4: Specific energy consumption for raw water and distribution pumping in kWh/m^3

The SEC for raw water and distribution pumping expressed in kWh/m^3 depends on many factors such as topography, service level, pump and motor efficiencies and pumping main characteristics and therefore it is not a successful indicator to compare the energy efficiency of raw water and treated water pumping.

- **Energy consumption per unit volume produced per unit elevation**

The SEC of raw water and treated water pumping in kWh/m^3/ m lift for the studied WSSs are shown in Figure 4.5. The SEC for raw water pumping and distribution pumping show less variation, when it is normalized for the elevation difference. The SEC for raw water pumping varies from 0.004 kWh/m^3/ m lift to 0.008 kWh/m^3/ m lift. The SEC for distribution pumping varies from 0.005 kWh/m^3/ m lift to 0.006 kWh/m^3/ m lift. These variations are due to length of pumping main, the characteristics of pipes and efficiency of the pump and motors used for pumping etc.

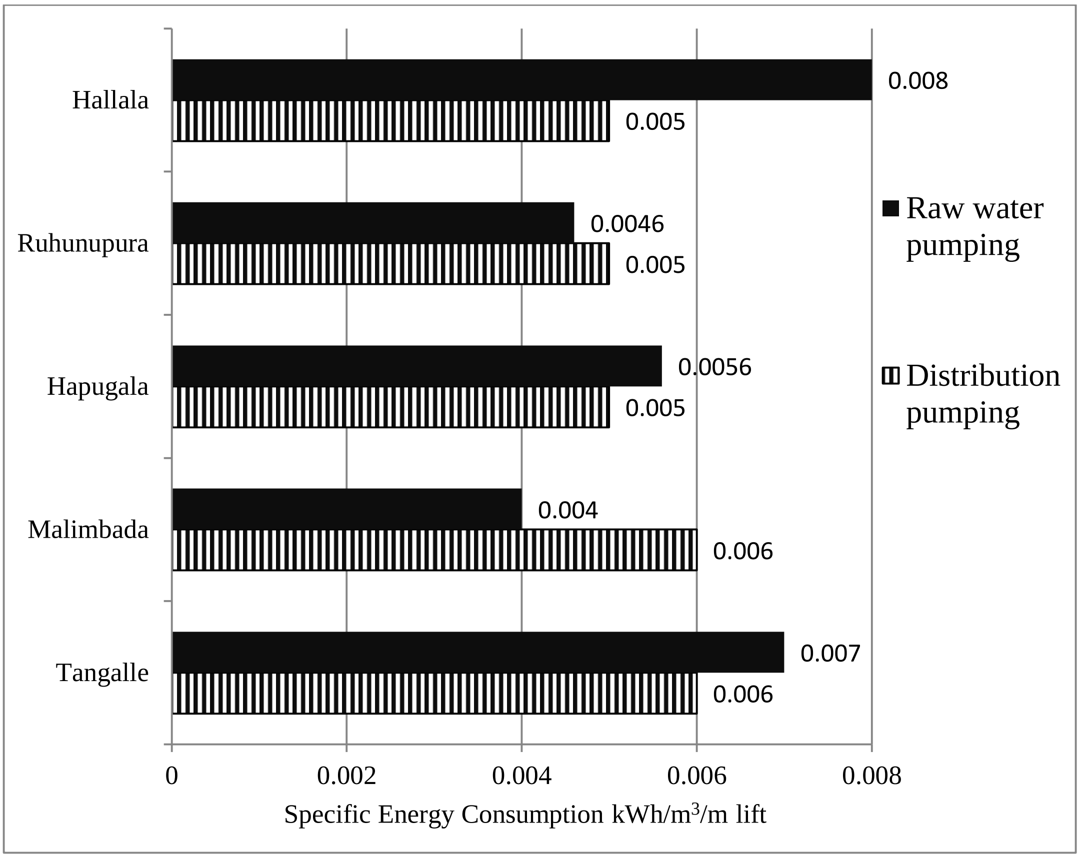


Figure 4.5: Specific energy consumption for raw water and distribution pumping in kWh/m^3/m lift

- **Energy consumption per unit volume produced per unit lift in elevation per unit length in pumping main**

The SEC of raw water and distribution pumping in kWh/m^3/m lift/km for the studied WSSs are shown in Figure 4.6. The length of the pumping main was indicated in kilo meters because some pumping mains are several kilo meters long. The SEC for raw water pumping varies from 0.003 kWh/m^3/m lift/km in Tangalle and Ruhunupura WSSs to 0.033 kWh/m^3/m lift/km in Hapugala WSS. The SEC for distribution pumping varies from 0.001 kWh/m^3/m lift/km in Ruhunupura WSS to 0.005 kWh/m^3/m lift/km in Hallala WSS. These variations are mainly due to overall motor and pump efficiencies and pumping main characteristics such as bends, throttles and friction of pipes. Since the above factors can be controlled by designer, the above indicators can be used to benchmark energy consumption of raw water and distribution pumping. The water pumping mains have to be operated at high pressure heads because the pumping head depends on the elevation differences.

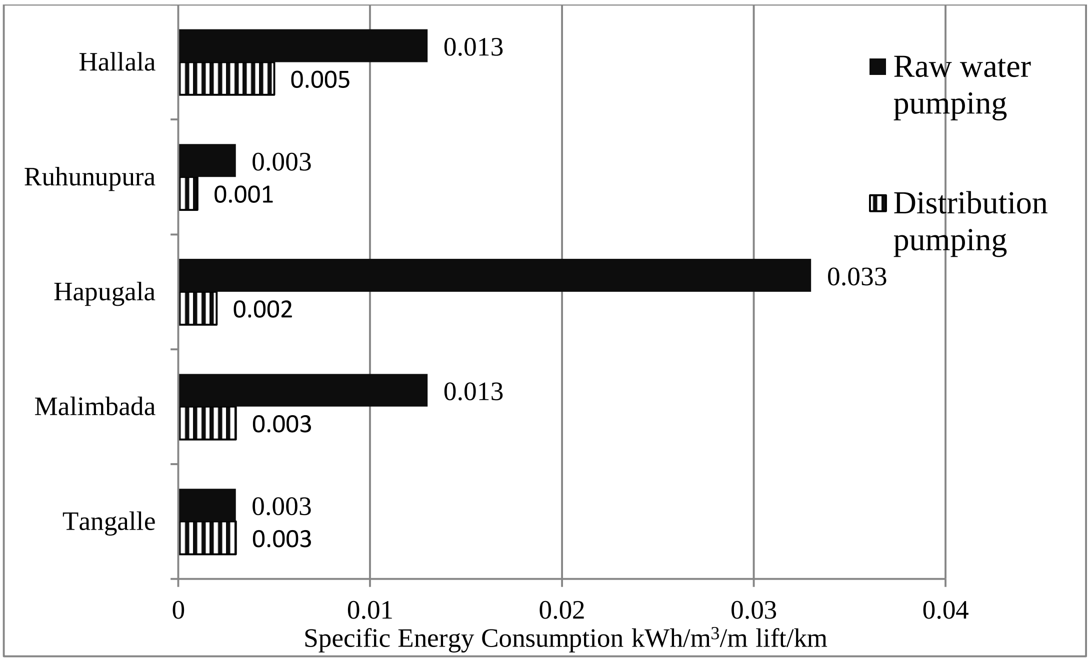


Figure 4.6: Specific energy consumption for raw water and distribution pumping in kWh/m^3/m lift /km

4.1.6 Energy consumption for surface water treatment

The SEC for conventional surface water treatment process in the audited WTPs are shown in Figure 4.7. The relevant calculations for specific energy consumption are shown in Tables B.17 to B.25 of Appendix B. A summary of specific energy consumption is shown in Table B.26 of Appendix B. The SEC varies from 0.003 kWh/m^3 in Ruhunupura and Tangalle WTPs to 0.018 kWh/m^3 in Hapugala WTP. For Sri Lankan context the SEC for water treatment varies between 0.003 and 0.018 kWh/m^3.

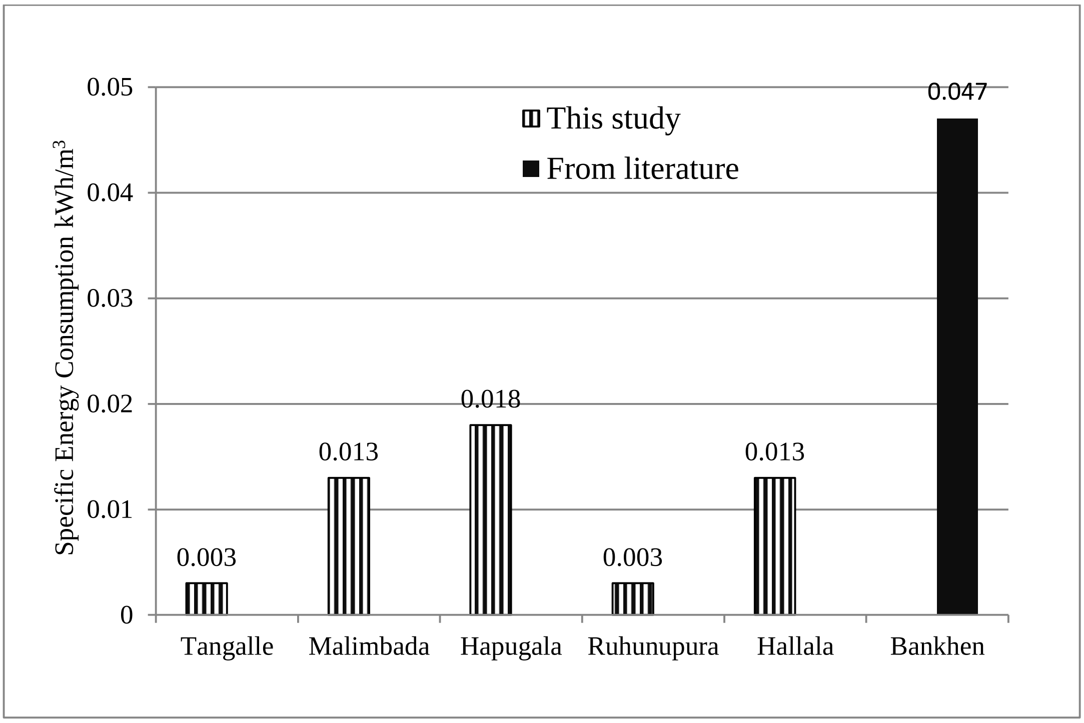


Figure 4.7: Specific energy consumption of conventional drinking water treatment for surface water sources

Chlorine is widely used to disinfect drinking water. Chlorine can be used as a gas or as a liquid. Calcium hypochlorite is the dry form of chlorine which can be mixed to prepare a liquid chlorine solution. The gas form of chlorine is 2.5 times heavier than air. The effectiveness of chlorine increases as temperature increases. Conversely, longer contact duration is required to disinfect treated water at lower temperatures. Selected WSSs use gas chlorine feeding arrangements with gas detection and neutralization arrangements for safety as shown in Figures 4.8.

Figure 4.8: Conventional gas chlorination arrangement

The Omohundro and K. R. Harrington conventional surface water treatment plants that provide drinking water to metropolitan Nashville the capital of Tennessee are operating new chemical feed systems. The feed systems at both plants were designed with a single brand of peristaltic feed pumps, helping to simplify maintenance, reduce parts inventories, and make it easy for staff to move between plants without requiring additional training on the chemical feed equipment shown in Figure 4.9. Both systems were installed without interrupting either plant's operations and have enhanced energy efficiency and chemical feed accuracy.

Figure 4.9: The Omohundro plant alum feed system, showing the feed pumps, pulsation dampeners, flow meters, carrier water system, isolation valves, and pressure relief valves

Hallala and Malimbada WTPs utilize motive chlorinator booster pumps for chlorinators and chemical feeding pumps to feed Alum and PAC. Therefore, the SEC of Hallala and Malimbada WTPs are higher than the Ruhunupura and Tangalle WTPs. Hapugala WTP has the highest SEC due to the pulsator clarifier in addition to motive water pumps and chemical feeding pumps.

4.1.7 Benchmarking of energy consumption of water treatment unit processes of surface water sources

The conventional surface water treatment process consists of course screening, fine screening, aeration, chemical feeding, rapid mixing, slow mixing, sedimentation, filtration and disinfection. The SEC for individual unit processes for audited WTPs is shown in Figure 4.10. Chemical feeding is the highest energy consuming unit process in Tangalle and Hapugala WTPs and second largest in Hapugala and Hallala WTPs. Slow mixing is the largest energy consuming unit process for Hapugala WTP. For Hallala and Ruhunupura WTPs the largest energy consuming unit processes respectively are sedimentation and filtration.

The comparison of observed range of variation in SEC of these unit processes and the recommended value range by relevant references is presented in Table 4.2 and the reasons for variations are discussed below.

- **Course screening**

Generally, the course screens are cleaned manually and therefore there is no energy consumption for course screening. In all the audited WTPs, course screens did not consume any energy.

- **Fine screening**

Fine screening is available at Malimbada and Hapugala WTPs. In Hapugala WTP fine screen is cleaned manually. But in Malimbada WTP the fine screen is cleaned mechanically and the SEC is 0.0002 kWh/m^3.

- **Aeration**

Cascade type aeration is available at Ruhunupura, Hapugala and Malimbada WTPs. These processes do not consume electrical energy.

- **Chemical feeding**

Chemical preparation mixers are available at all WTPs but chemical feeding pumps are available only at Hallala, Hapugala and Malimbada WTPs. At Ruhunupura and Tangalle constant head gravity chemical feeding systems are used. The SEC for chemical feeding ranges from 0.00003 kWh/m^3 in Ruhunupura WTP to 0.0055 kWh/m^3 in Malimbada WTP. The range of energy consumption recommended by World Environment Foundation (2009) is 0.0005 - 0.001 kWh/m^3. Accordingly, Ruhunupura WTP shows a lesser SEC than the lower limit but Malimbada WTP shows a higher value than the upper limit. These variations are due to the differences in elevation and the age of the equipment and the characteristics of chemical feeding line.

- **Rapid mixing**

In all audited WTPs rapid mixing is performed using hydraulic jump. Therefore, this process does not consume electrical energy.

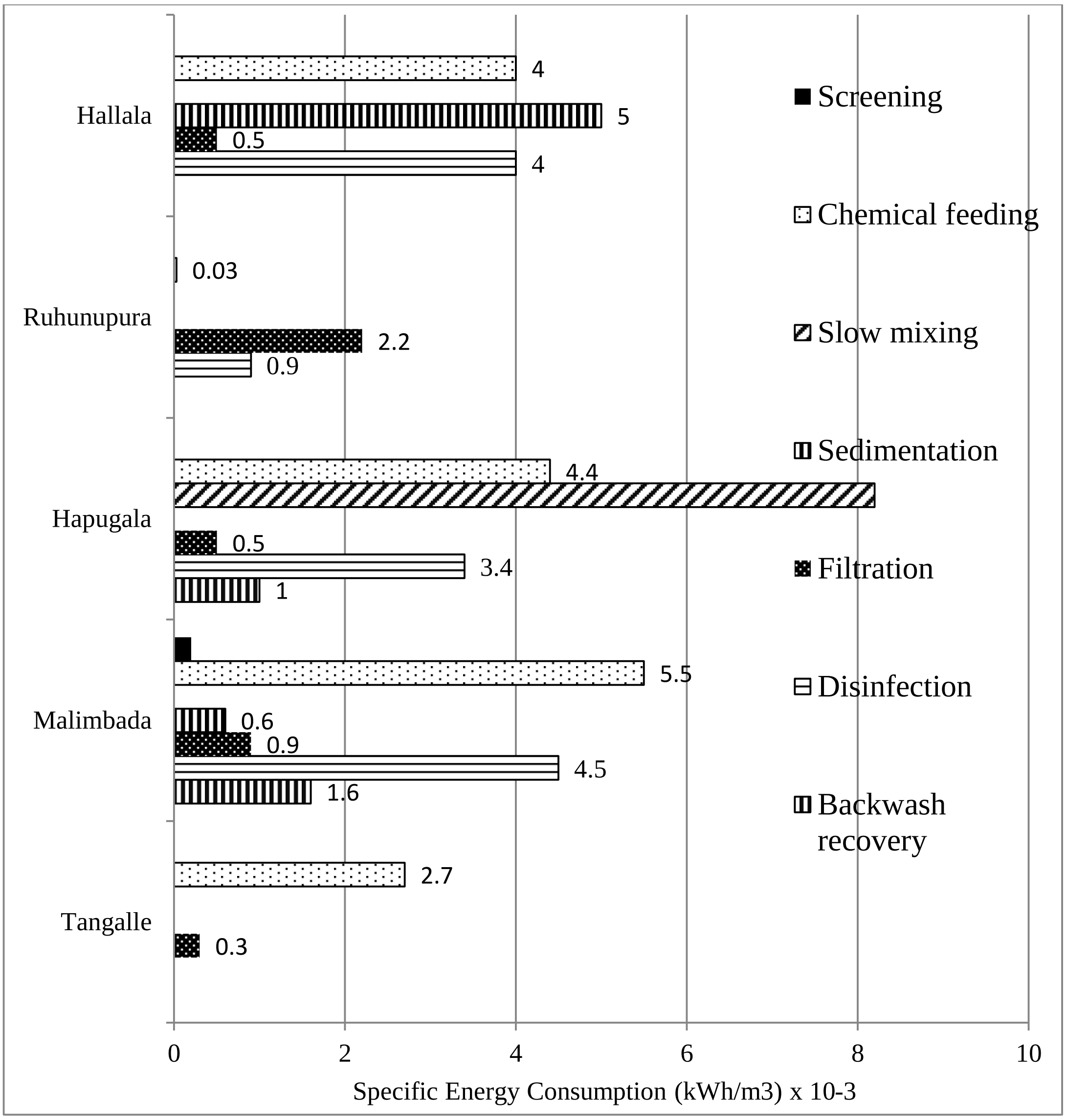


Figure 4.10: Specific energy consumption of water treatment unit processes in audited water supply schemes

- **Slow mixing**

In all audited WTPs slow mixing is performed using baffled flocculators except for Hapugala WTP where a pulsator is installed. Baffeled flocculation is a hydraulic process and does not consume electrical energy. However, pulsator consumes a considerable amount of energy compared to the energy consumption of other unit processes. The range of energy consumption recommended by Cammerman (2009) is 0.001 - 0.004 kWh/m^3. The observed value for Hapugala is 0.0082 kWh/m^3 and it is higher the recommended range by Cammerman (2009).

Table 4.2: Comparison of Observed Range of Variation in Specific Energy Consumption of Water Treatment Unit Processes with Literature

Unit Process	**Observed Specific Energy Consumption Range (kWh/ m^3) x 10^{-3}**	**Specific Energy Consumption Range as per Literature (kWh/ m^3)**	
		(kWh/ m^3) x 10^{-3}	**Reference**
Fine screening	0.2	-	-
Chemical feeding	0.03 - 5.5	0.5 - 1	World Environment Foundation, 2009
Rapid mixing	-	8 - 22	World Environment Foundation, 2009
Flocculation	8.2	1 - 4	Cammerman, 2009
Sedimentation	0.6 - 4.7	0.5 - 1	World Environment Foundation, 2009
Filtration	0.3 - 2.2	5 - 1.4	World Environment Foundation, 2009
Chlorination	0.9 - 4.5	2.4 - 2.5	Arpke and Hutzler, 2006
Backwash recovery	1 - 1.6	-	-

- **Sedimentation**

In all audited WTPs sedimentation is performed using plain sedimentation tanks. Sludge scrapers are installed in Hallala and Malimbada WTPs which utilize electrical energy. In other WTPs sludge is removed hydraulically. Malimbada WTP utilizes 0.0006 kWh/m^3 and Hallala WTP utilizes 0.0047 kWh/m^3. The range of energy consumption recommended by World Environment Foundation (2009) is 0.0005 - 0.001 kWh/m^3. Accordingly, Malimbada WTP shows a lesser SEC than the lower limit but Hallala WTP shows a higher value than the upper limit. The difference in the SEC is due to the type of equipment used.

- **Filtration**

Supplying backwash air and backwash water for filter backwashing is a considerable energy consuming unit process in any WTP. The observed range of SEC is from 0.0003 kWh/m^3 at Tangalle WTP to 0.0022 kWh/m^3 at Ruhunupura WTP. At Tangalle WTP backwash water is obtained from the backwash water tank which is fed by the treated water pumping main which reduces the energy consumption. The

SEC is high at Ruhunupura WTP due to the higher elevation difference between filters and the clear water sump. The range of energy consumption recommended by World Environment Foundation (2009) is 0.005 – 0.014 kWh/m^3. Accordingly, Tangalle WTP shows a lesser SEC than the lower limit but Ruhunupura WTP shows a higher value than the upper limit.

- **Disinfection**

Gas chlorination is the technology used for disinfection in all selected WTPs. Chlorinator booster pumps is the energy consuming component of the gas chlorination process. All the selected WTPs are installed with Chlorinator booster pumps except Tangalle WTP where motive water is supplied via a tapping from the treated water main. The observed range of SEC is from 0.0009 kWh/m^3 at Ruhunupura WTP to 0.0045 kWh/m^3 at Malimbada WTP. The range of energy consumption recommended by Arpke and Hutzler (2006) is 0.0024 – 0.0025 kWh/m^3. Accordingly, Ruhunupura WTP shows a lesser SEC than the lower limit but Malimbada WTP shows a higher value than the upper limit. The differences in SEC mainly depends on the elevation difference of pumping which depends on the location of chlorinator house and clear water tank, the pipe characteristics and the overall energy efficiency of pumping set.

- **Backwash recovery**

The filter backwash and sedimentation sludge treatment is carried out only in Malimbada and Hapugala WTPs and the supernatant from the sludge thickener is pumped back to aerator. The SEC for pumping back the supernatant water of sludge settling tank/sludge thickener is 0.001 kWh/m^3 in Hapugala WTP and 0.0016 kWh/m^3 in Malimbada WTP. The difference is mainly due to the elevation difference of sludge thickener/sludge thickener and aerator.

4.1.8 Benchmarks for energy consumption in water treatment unit processes for surface water sources

The study was conducted in five water treatment plants which were utilizing technologies from basic technology to state of the art modern technology. The benchmarks for energy consumption in drinking water treatment unit processes for surface water sources context are presented in Table 4.3.

Table 4.3: Benchmarks for Energy Consumption in Drinking Water Treatment Unit Processes for Surface Water Sources

Unit Process	**Observed Specific Energy Consumption Range (kWh/ m^3) x 10^{-3}**
Fine screening	0.2
Chemical feeding	0.03 - 5.5
Rapid mixing	-
Flocculation	8.2
Sedimentation	0.6 - 4.7
Filtration	0.3 - 2.2
Chlorination	0.9 - 4.5
Backwash recovery	1 - 1.6

The potentials for energy conservation in WSSs can be broadly classified in to three categories as follows:

- Potentials of energy conservation through modification of the water treatment process
- Potentials for energy conservation through improving the energy efficiency of equipment such as pumps and motors
- Potentials for energy conservation through reduction of NRW

4.1.9 Potentials of energy conservation through modification of the water treatment process

(a) Removing chlorinator booster pump of gas chlorinator at Hallala WSS

The second highest energy consuming unit process in Hallala WSS is chlorination as shown in Figure 4.10. The gas chlorination system in Hallala WSS consists of chlorine gas cylinder, chlorinator booster pump and chlorinator as shown in Figure 4.11. The water is supplied to the chlorinator through a tapping from the inlet pipe of the clear water sump and pressurized using a booster pump. If the water supply for the chlorinator is taken from the treated water pumping main the booster pump can be removed from the system as shown in Figure 4.12.

This modification will save 0.004 kWh/m^3 and 1% energy saving could be obtained for the treated water produced. The annual energy saving is about 12800 kWh/year. To use this technical option, the treated water pumping main should have a pressure head of less than 6 bars due to the maximum pressure limitations of chlorinators which is about 6 - 7 bars. This technique is already used at Tangalle WSS. This technique cannot be used at the other audited WSSs since the treated water pumping mains operates under high pressure heads. The distribution pumps in the other audited WSSs had to be operated under high pressures due to high elevation differences.

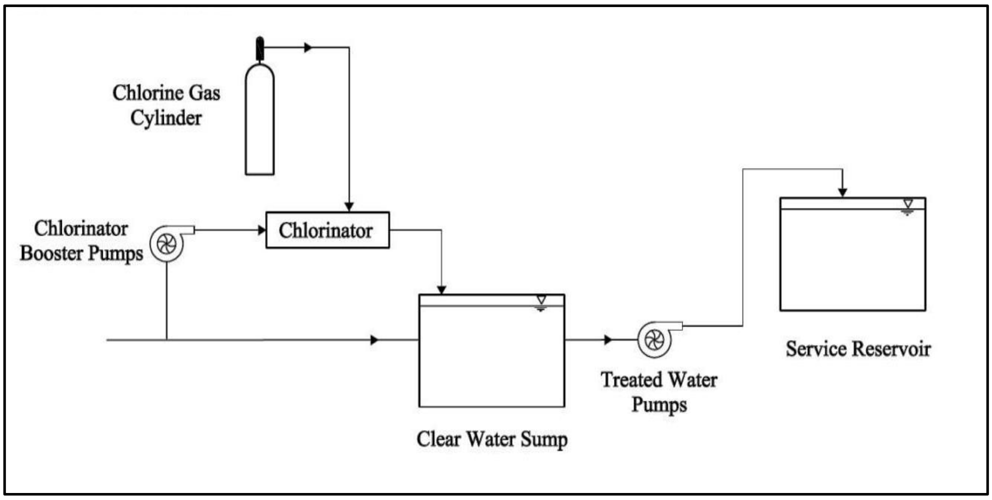


Figure 4.11: Existing chlorinator arrangement at Hallala WSS

(b) Adjusting the filter backwash frequency of Tangalle and Ruhunupura WSSs

Rapid sand filtration is the second highest energy consuming process in Tangalle and Ruhunupura WSSs as shown in Figure 4.10. The energy consumption for filtration is mainly due to the air and water requirements of the filter backwash operation. The filter backwashing frequencies of the audited WSSs are presented in Table 4.4.

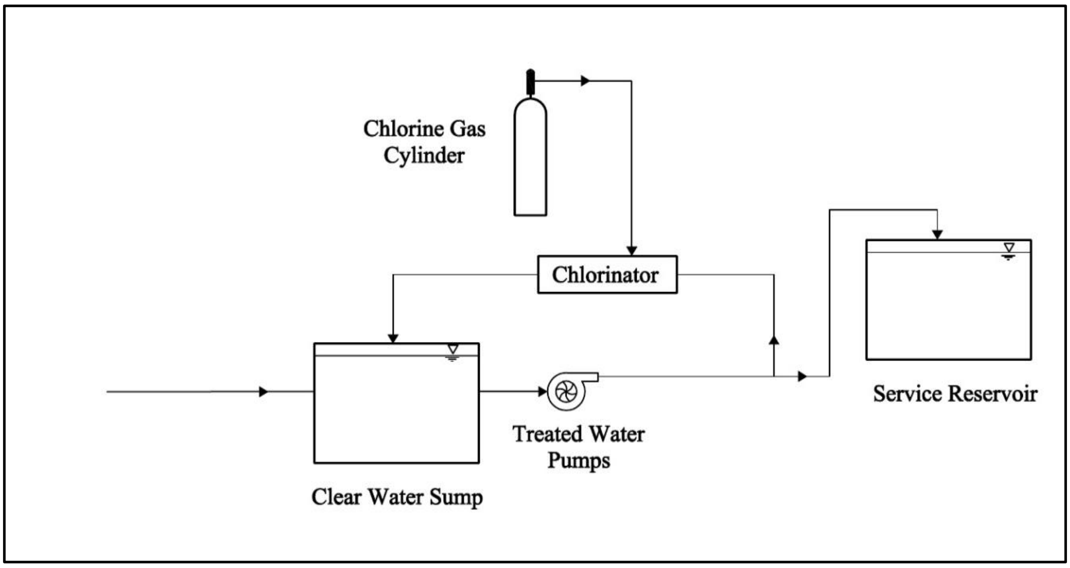


Figure 4.12: Modification of chlorinator arrangement at Hallala WSS

Table 4.4: Filter Backwash Frequency of Audited Water Supply Schemes

Water Supply Scheme	**Duration between Filter Backwash**	**Mode of Operation**
Hallala	48 hours	Automated
Ruhunupura	24 hours	Automated
Hapugala	48 hours	Automated
Malimbada	48 hours	Automated
Tangalle	24 hours	Automated

The effects of running the filters for 48 hours at Hallala, Hapugala and Malimbada WTPs were investigated during the audit. The results showed that the effluent quality and the flow rate of the filters did not show a significant difference compared to 24 hour run as shown in Table 4.5.

Table 4.5: Effect on Filter Performance due to Changing of Filter Backwash Frequency

Parameter	**Duration between Filter Backwash**	
	24h	**48h**
Influent Turbidity (NTU)	12	12
Effluent Turbidity (NTU)	1	1
Flow Rate (m^3/h)	73	71

The energy saving potential of this operation modification is presented in Table 4.6 and it shows that the amount of energy saved is not significant when compared with the total energy consumption.

The water level in the feed side was increased with the increased time but it was within the hight provided in the structure and the backwashing time of filter back wash operation was not adjusted so the energy consumption per one filter backwash was remained constant.

Table 4.6: Energy Saving Potential of Changing Filter Backwash Frequency

Energy Saving Potential	**Tangalle WSS**	**Ruhunupura WSS**
Total energy saving per month (kWh/month)	92	126
Total energy saving per year (kWh/year)	1117	1530
Per unit volume energy saving of treated water (Specific Energy /kWh/m^3)	0.0003	0.0004
Per unit volume Energy saving of treated water(%)	0.07	0.06

(c) Energy conservation potential of backwash recovery

Backwashing filters is a must with sacrificing significant amount of treated water. Recovering of this water gives an opportunity to save energy because the recovered water has to be pumped for a lesser distance and lesser head.

The major concern in backwash water recovery is the removal of *Cryptosporidium and Giardia* which is concentrated in filer backwash waters. To meet the challenges of the stringent drinking water regulations established to improve controlling of Cryptosporidium and Giardia, additional physical and chemical water treatment processes are required. Pressure-driven membrane processes such as microfiltration and ultrafiltration are playing an important role in backwash water recovery (Betancourt and Rose, 2004).

The proposed arrangement for filter backwash recovery is shown in Figure 4.13 including the additional treatment process of ceramic micro filtration. The SEC for ceramic micro filtration was considered as 0.15 kWh/m^3 as per Willemse and

Brekvoort (1999). The assessment of energy saving potentials of backwash recovery is presented in Table C.2 of Appendix C.

The assessment shows that there is a 0.5% energy conservation potential at Hallala WSS through filter backwash water recovery. In other audited WTPs, recovery of filter backwash water facilitates only water conservation. If the WTP is located far away from the surface water source with large elevation difference and distance, filter backwash water recovery could be an attractive option for energy conservation. If the WTP is located near the surface water source the filter backwash water recovery is not an energy conservation potential.

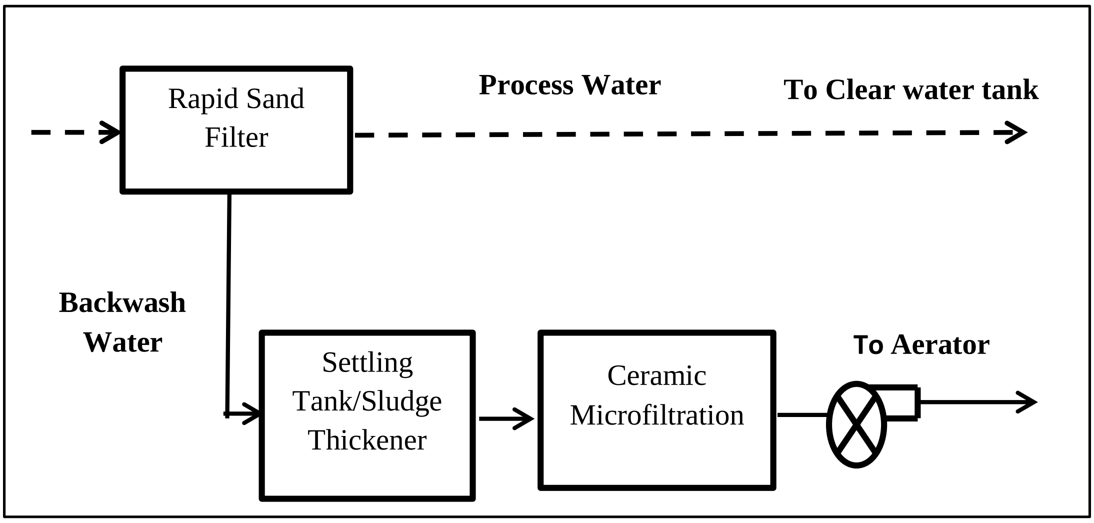


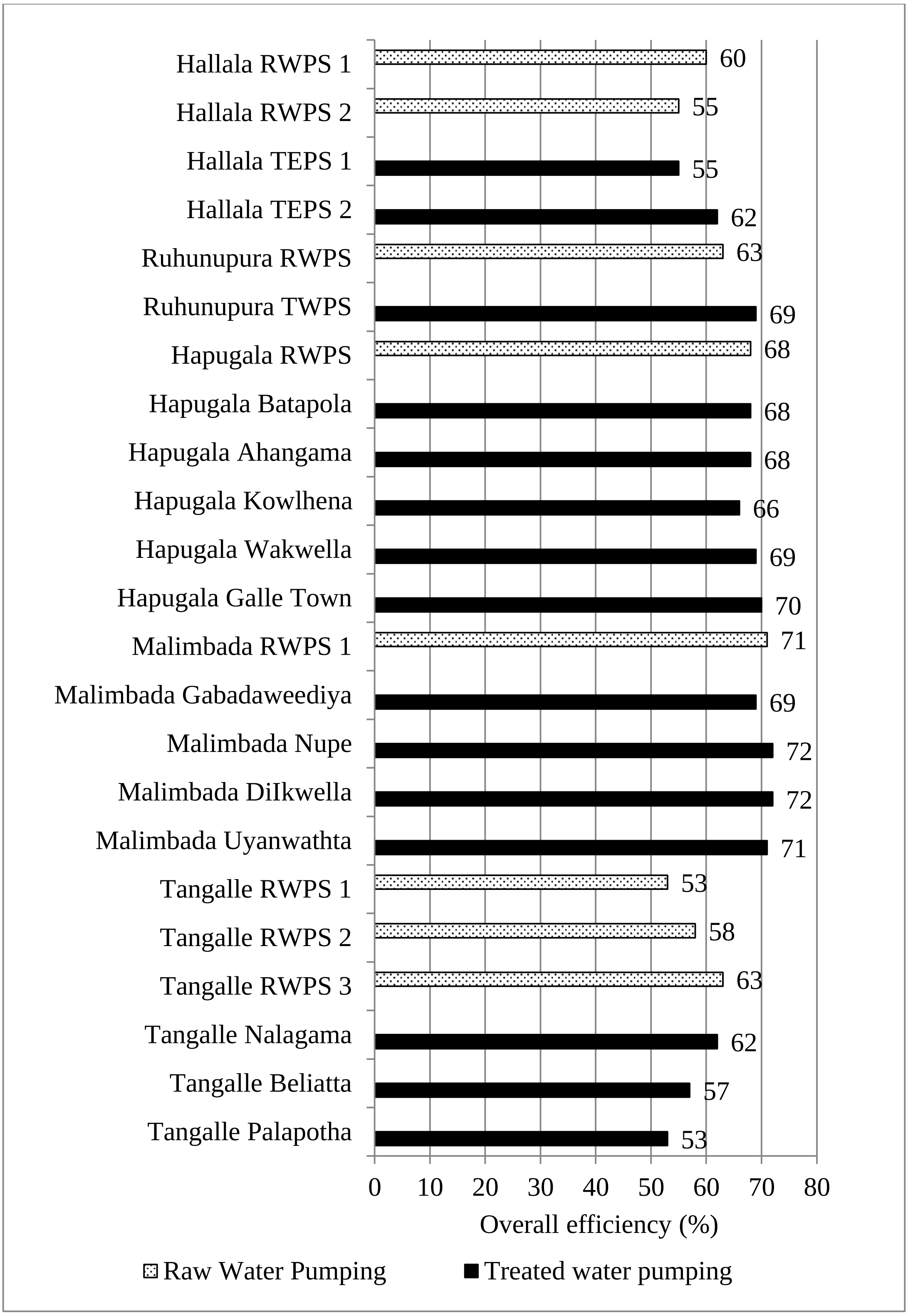
Figure 4.13: Proposed process for filter backwash recovery

4.1.10 Potentials for energy conservation through improving the energy efficiency of equipment such as pumps and motors

Raw water and treated water pumping consumes more than 96% of the energy consumed by the audited WSSs as shown in Figure 4.3. The energy consumption of the pumping operation mainly depends on the overall operating efficiency of the pump and motor system. At present the minimum overall efficiency prescribed when purchasing new pumps for surface water pumping at the NWSDB is 70% at the specified operating point (NWSDB, 2013). The overall operation efficiencies of the raw water and treated water pumps in the audited WSSs are calculated in Table C.3 and Table C.4 of Appendix C and shown in Figure 4.14.

The overall efficiencies of pump and motor systems in Hapugala and Malimbada WSSs are around 70%, which is the recommended value by the NWSDB at present. The overall efficiency of pump and motor systems in pumps in Hallala WSS vary from 55 to 63%. In Ruhunupura WSS, only the treated water pumping shows acceptable overall efficiency. In Tangalle WSS all the pumps operate much below the expected overall efficiency. This is due to the age of the equipment and the unplanned modifications.

The potential energy saving from improving the overall pump and motor efficiency up to 70% is shown in Figure 4.15. Tangalle and Hallala WSSs shows comparatively high energy saving potential by improving overall efficiency since the range of efficiency improvement is higher. Although the potential for improving overall pump and motor efficiency is limited at Hapugala and Malimbada WSSs, the energy conservation potential was high since the quantity of production is larger compared to the other audited WSSs.



Note: RWPS –Raw Water Pumping Set; TWPS – Treated Water Pumping Set

Figure 4.14: Overall efficiency of pump and motor systems in audited water supply schemes

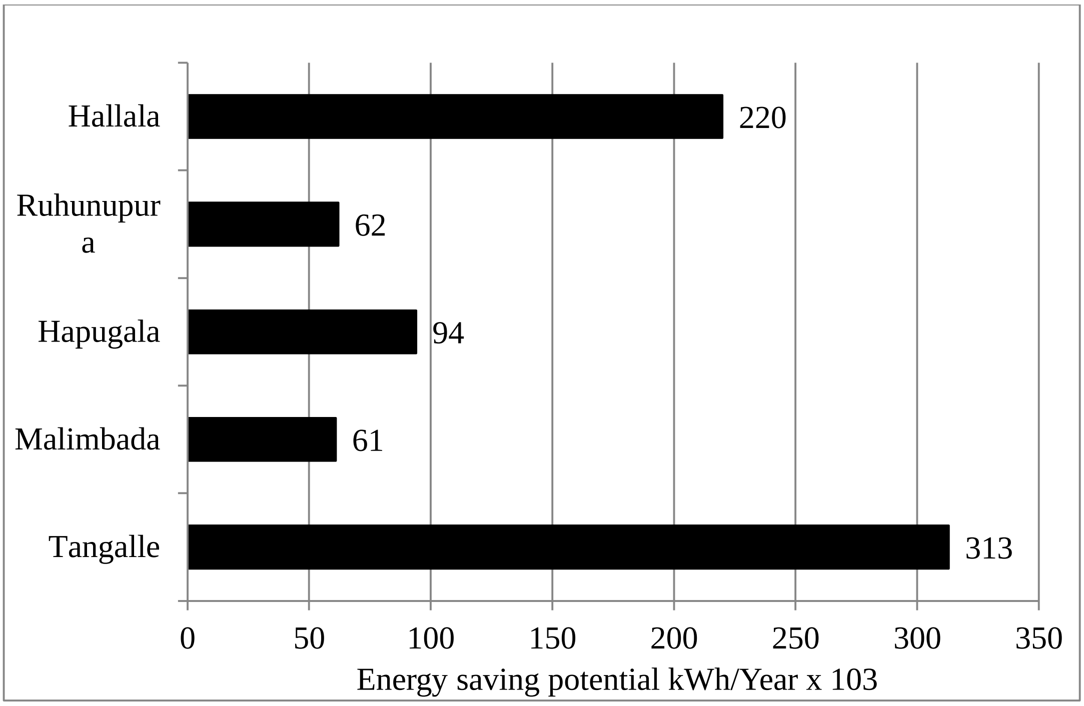


Figure 4.15: Annual energy saving potential of improving overall efficiency of pumps and motors

The percentage energy saving per unit volume of treated water is shown in Figure 4.16. Hallala and Tangalle WSSs show significant potentials of 15% and 14% reductions in the total specific energy by improving the overall efficiency of pump and motor systems.

The overall efficiency of the pump and motor system can be improved by improving the mechanical and electrical performance of equipment and modifying the characteristics of pumping main.

The mechanical and electrical performance of the pumps and motors can be improved by technical options such as overhauling of pumps and motors, trimming of impellers, installation of Variable Speed Drives, and installations of new pumps and motors. Modifications to pumping main to reduce energy losses due to pipe friction, pipe specials and throttles also contributes to improve the overall efficiency of the pump and motor system by adjusting the operating point. Implementing Planned Preventive Maintenance programs immensely helps to preserve and improve the overall energy efficiency of the pump and motor systems. The identified potentials for improving the overall efficiency of pump and motor systems in the audited WSS are presented in Table 4.7.

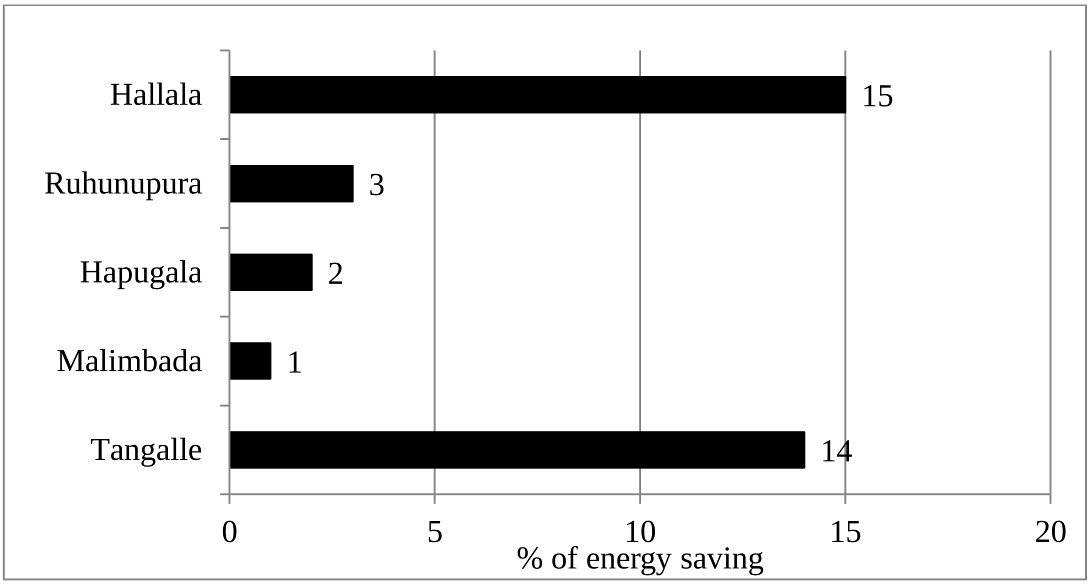


Figure 4.16: Percentage energy saving potential of improving overall efficiency of pump and motor systems

Table 4.7: Identified Potentials to Improve Overall Pump and Motor Efficiency

Water Supply Scheme	**Energy Conservation Potentials**
Hapugala	**Introducing a VSD to raw water pumps:** The raw water pump house operates 2 duties and 1 stand by. The pumps are throttled to control the flow rate around 1500 m^3/h. But it was observed that the pump can deliver about 1800 m^3/h without throttling. Therefore, by introducing a VSD the energy wasted on the throttling can be saved. This energy saving could be obtained through increase of efficiency gained through shifting the pump and efficiency curves.
Malimbada	**Introducing a VFD to raw water pumps:** The LL pump house operates 1 duty and 3 stand by. The pumps are throttled to control the flow rate around 1000 - 2100 m^3/h. But it was observed that the pump head does not change significantly with the flow rate at the current flow rates. But it was observed that the river level has an annual variation of four meters. Therefore, by introducing a VSD the energy consumption changes due to river level changes can be managed properly. The pump head in general is 34m. Therefore, around 12% reductions in pump head could be achieved. The discharge head was not measured.
Ruhunupura	**Changing treated water pumping main:** Changing the pipe stretch of the first 100m from the treatment plant reducing bends. There are about seven, 90^0 bends at this pipe stretch. Therefore, there was a potential to save energy by reducing bends.
Tangalle	**Efficiency of pumps:** The pumps are about 15 years old therefore energy conservations could be obtained by improving efficiencies of the pumps by overhauling or purchasing new pumps.

4.1.11 Energy conservation potential of reducing NRW

The highest energy consuming process of all the audited WSSs is treated water and distribution pumping with more than 70% of the total energy consumption as shown in Figure 4.3. It also shows that in Ruhunupura and Hapugala WSSs, the energy consumed in treated water and distribution pumping is more than 85%. Therefore, strict measures have to be taken to conserve the water pumped using such high proportion of energy. Therefore, reduction of NRW has a very high potential for energy conservation in WSSs. The relevant data and calculations for assessing the energy conservation potential of reducing NRW are shown in Tables C.5 to C.8 in Appendix C and average NRW Figures for audited WSSs for year 2012 is shown in Figure 4.17. Hallala WSS was not considered for NRW analysis.

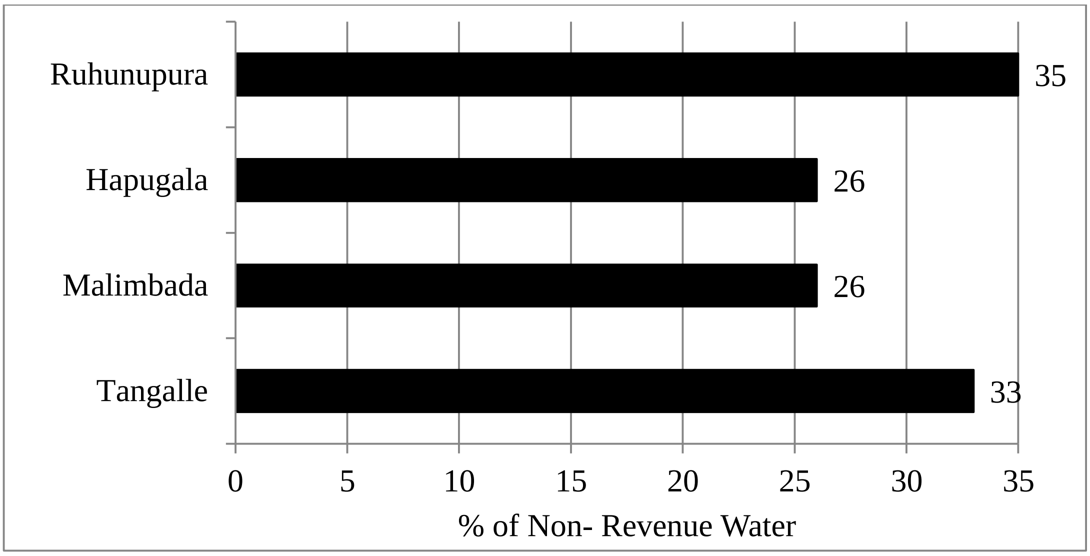


Figure 4.17: Percentage of average non-revenue water in audited water supply schemes in 2012

All the audited WSSs operate with comparatively high NRW percentages compared to cities such as Osaka with 7% as shown in Figure 2.10.

NRW mainly consists of two main categories: physical losses and commercial losses. Physical losses consist of losses due to pipe breakdowns, leakage, and service connection leakage and reservoir overflow. Commercial losses consist of losses due to incorrect water meters, illegal connections and free water.

The potential to reduce NRW is the difference between the average real losses and Economic Level of Leakage. The percentage of average real losses, ELL and potential savings for audited WSSs are shown in Figure 4.18. The possible reduction of physical losses ranges from 5% at Tangalle to 12% at Ruhunupura. Since all the audited WSSs are equipped with electronic level monitoring and communication systems the water loss through reservoir overflows is negligible. Therefore, strategies have to be implemented to reduce the water loss through breakdowns, leakage and service connections.

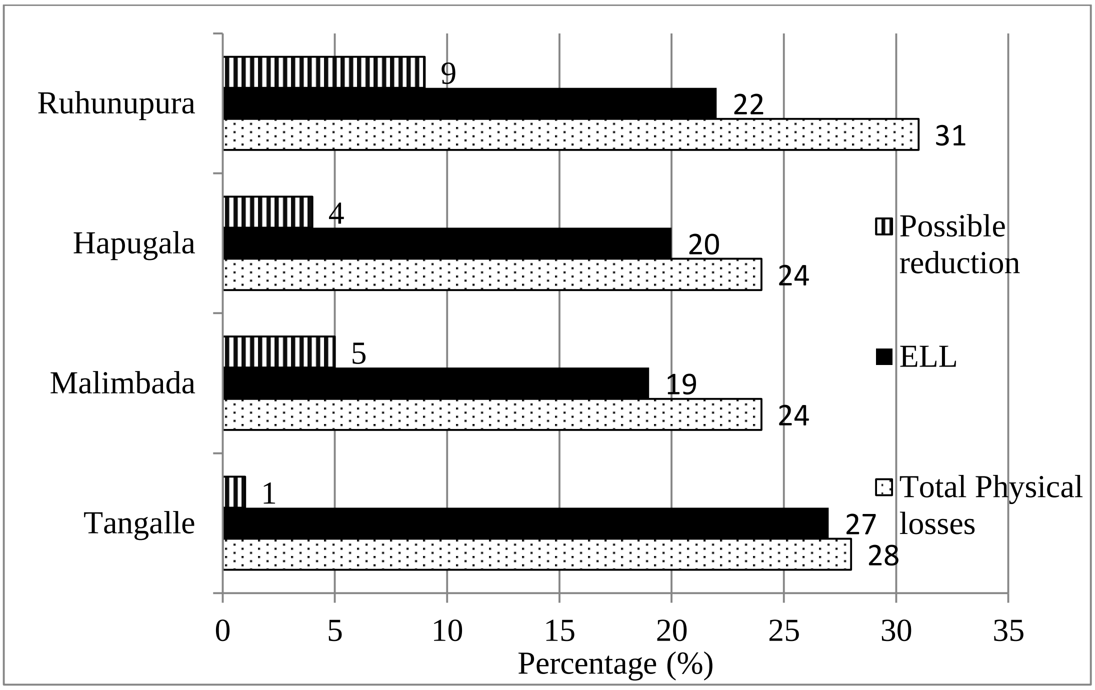


Figure 4.18: Reduction potential of physical losses in audited Water Supply Schemes

The reduction potential of commercial losses through reduction of defective meters down to 1% and reduction of illegal connection up to 0.1% as per the accepted practice of NWSDB is shown in Figure 4.19. All the water supplied by the WSSs operated under NWSDB is billed and therefore the losses due to free water are negligible. The possible reduction of commercial losses ranges from 1.7% at Hapugala and Malimbada WSSs to 3.8% at Tangalle WSS as shown in Figure 4.19.

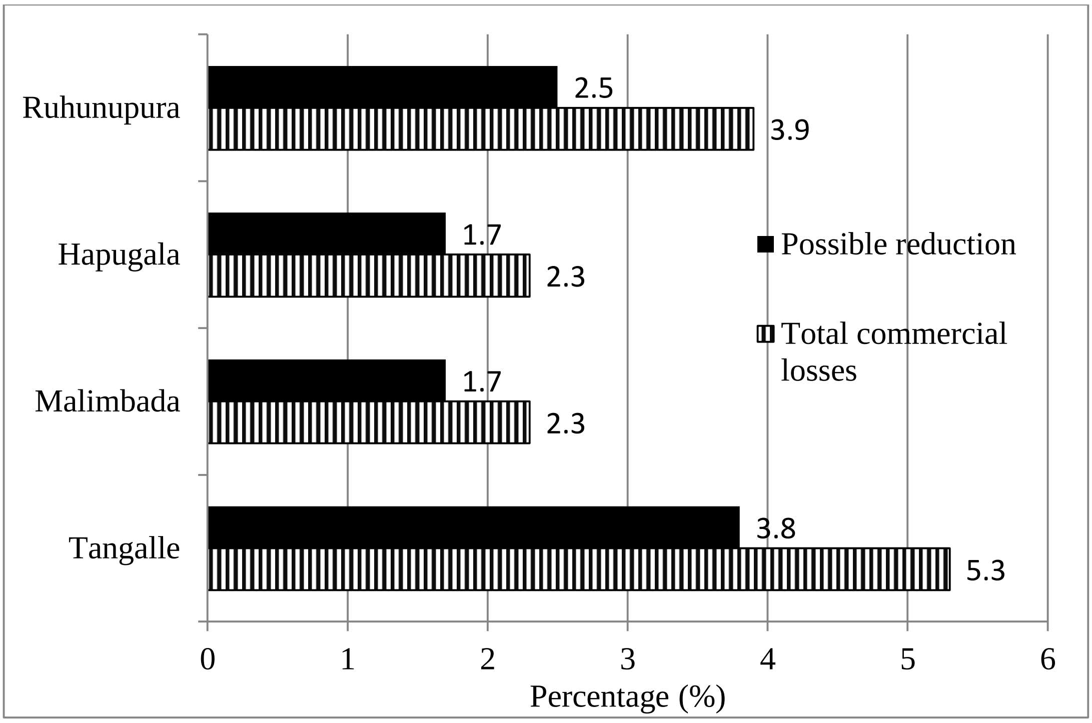


Figure 4.19: Reduction potential of commercial losses in audited Water Supply Schemes

The energy saving potential from reduction of NRW by reducing physical and commercial losses is shown in Figure 4.20. The energy saving potential of reducing NRW is significant compared to the previously discussed potentials and it varies from about 0.08 million kWh/Year at Tangalle WSS to 0.93 million kWh/Year at Malimbada WSS. This assessment was done using the data obtained from Commercial Management Information System and daily data recorded book of audit water treatment plant.

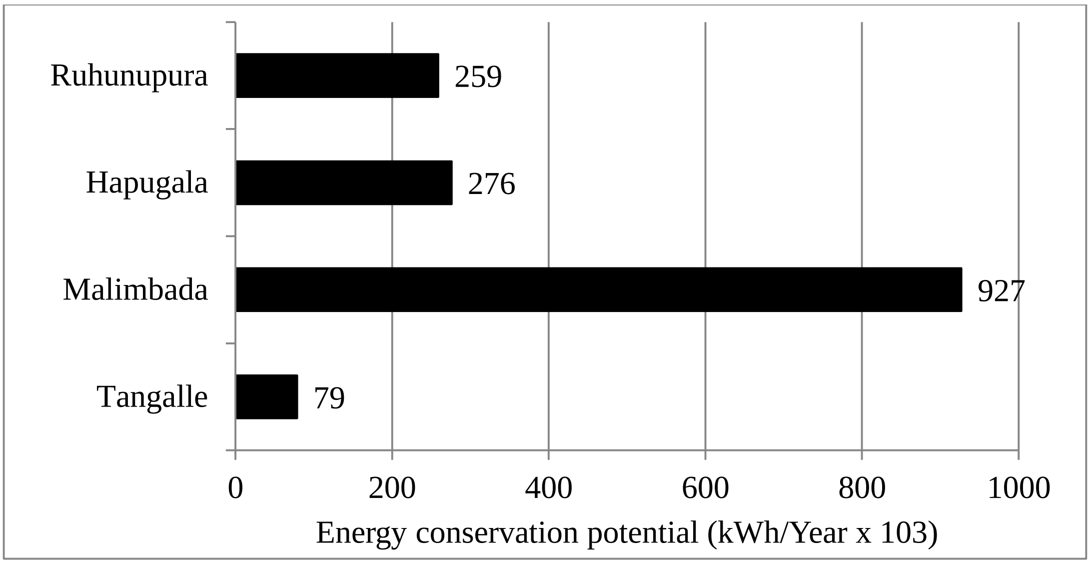


Figure 4.20: Energy conservation potential for reducing NRW

The percentage energy saving varied from 5% at Tangalle WSS to 12% at Ruhunupura WSS as shown in the Figure 4.21. Therefore, reduction of NRW shows significant energy saving potential for all the audited WSSs.

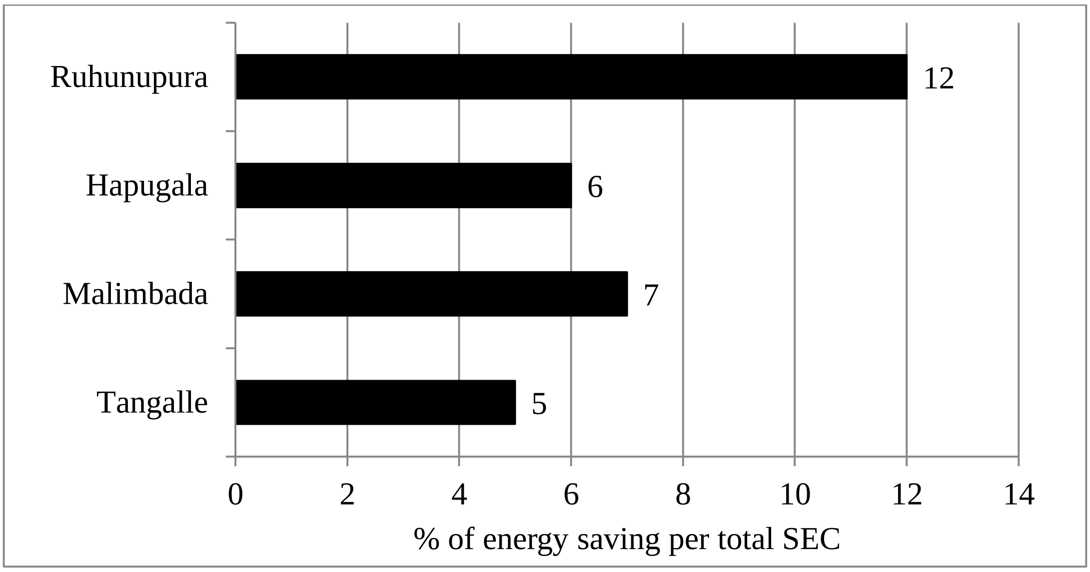


Figure 4.21: Percentage energy saving potential of reducing NRW for unit volume of treated water

The possible technical and management solutions that could be applied to achieve the above NRW reductions are presented in Table 4.8.

Table 4.8: Possible Technical and Management Solutions to Reduce NRW

Reduction of Physical Losses	Reduction of Commercial Losses
• Pressure management • Reduction of time taken to repair leaks • Using leak detection equipment to identify undetectable leakage • Using good quality pipes and fittings • Proper pipe laying at construction stage including proper fittings and thrust blocks • Covering of the service connection pipes properly	• Maintaining the defective meters below 1% by continuous monitoring and defective meter replacement programs • Vigilant monitoring, public campaigns and incentives to keep illegal connections below 0.01% • Using good quality and durable water meters • Auditing of billing function to reduce errors by meter readers

4.1.12 Cost Saving from Ceylon Electricity Board Tariff Structure

The electricity tariff structure of CEB has three different charges for day time, peak time and off peak time. The day and off peak time electricity charge is lower than the peak time charge. The objective of this strategy is to promote peak clipping and the consumers can gain cost reductions by shifting the electricity consuming operations to day or off peak time. The CEB tariff structure is presented in Table 4.9 (CEB, 2015).

Table 4.9: Tariff Structure of Ceylon Electricity Board

Tariff Category	Time Period	Charge (LKR / kWh)
Peak	18.30 – 22.30	20.50
Off peak	22.30 – 05.30	6.85
Day	05.30 – 18.30	11.00

The analysis of potential for shifting the water treatment and pumping operations of the audited WSSs from peak time to day or off peak time is shown in Tables C.9 to C.12 of Appendix C. The analysis shows that in Tangalle and Ruhunupura WSSs the intake pumps and WTP operation can be stopped for 1.5 hours in the peak time. In Hapugala and Malimbada WSSs the intake pumps and WTP operation can be stopped for 3 hours. The reduced production capacity due to this action has to be recovered by increasing the production during off peak period.

The potential annual cost saving from above modification to the operation schedule is presented in Figure 4.22. Possible annual cost saving ranges from LKR 0.7 million in Ruhunupura and Tangalle WSSs to LKR 2.9 million in Malimbada WSSs. The percentage cost saving in term of annual electricity is 2.7, 4.9, 3.1, and 2.9% at Ruhunupura, Hapugala, Malimbada, and Tangalle WSS, respectively. This analysis is a preliminary analysis and implementation of this strategy has to be planned considering the storage capacity and daily demand pattern.

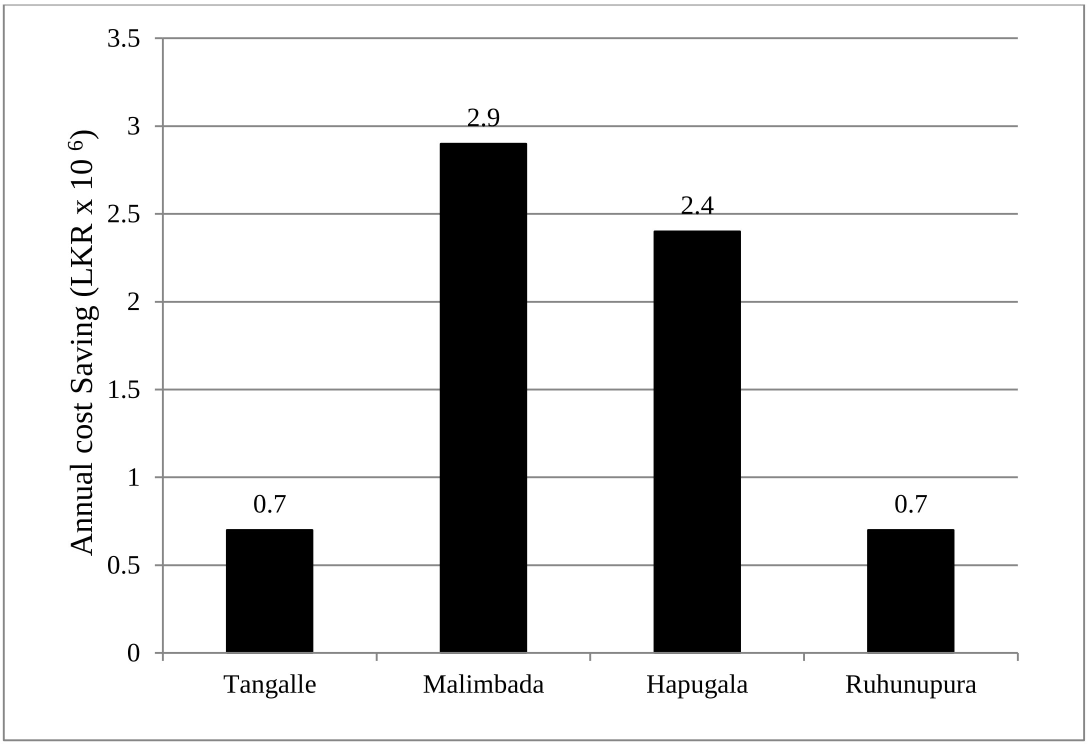


Figure 4.22: Annual cost saving from shifting the operation from peak to off Peak

4.1.13 Comparison of identified energy conservation potentials in the audited WSSs

The effect of identified energy conservation potentials is summarized in Table 4.10. As per Table 4.10 the significant energy conservation potentials for all the audited WSSs are improving overall pump and motor efficiency and reduction of NRW with up to 14 and 12% reduction potentials respectively.

Backwash water recovery is also possible energy conservation potential where the WTP is located far away from the water intake with significant elevation difference between the source and the WTP. However, the reduction potential is not significant. Modifying the chlorinator arrangement and backwash frequency are also possible options at identified WSSs, but these methods also have less conservation potential compared to NRW reduction and pump and motor efficiency improvement. Therefore, NRW reduction and improving the overall efficiency of pump and motors are the most significant energy conservation potentials.

4.1.14 Total energy conservation and cost reduction potentials of identified options in audited water supply schemes

The cumulative effect of the identified energy conservation potentials is discussed in this section and the relevant calculations for total energy conservation analysis are attached in Table C.13of Appendix C. The percentage total energy conservation potential in audited WSSs are shown in Figure 4.23 and it shows a variation from 7.8% in Malimbada WSS to 12% at Tangalle WSS.

Table 4.10: Comparison of the Effect of Identified Energy Conservation Potentials in Audited Water Supply Schemes

Description	**Specific Energy Saving and Percentage Energy Saving Potential**									
	Hallala		**Ruhunupura**		**Hapugala**		**Malimbada**		**Tangalle**	
	kWh/m^3	**%**	**kWh/m^3**	**%**	**kWh/m^3**	**%**	**kWh/m^3**	**%**	**kWh/m^3**	**%**
Total Specific Energy Consumption	0.397		0.851		0.766		0.622		0.48	
Energy Saving Potentials										
Removing chlorinator booster pump	0.0038	1	-	-	-	-	-	-	-	-
Adjusting filter backwash frequency	-	-	0.0003	0.04	-	-	-	-	-	-
Backwash water recovery	0.002	0.5	-	-	-	-	-	-	-	-
Improving overall pump and motor efficiency	0.0624	15.7	0.0212	2.5	0.0146	1.9	0.0047	0.8	0.0684	14
Reduction of NRW	-	-	0.1021	12	0.0459	6	0.0435	7	0.024	5
Total specific energy saving	**0.0682**	**17.2**	**0.1236**	**14.5**	**0.0605**	**7.9**	**0.0482**	**7.8**	**0.0924**	**19**

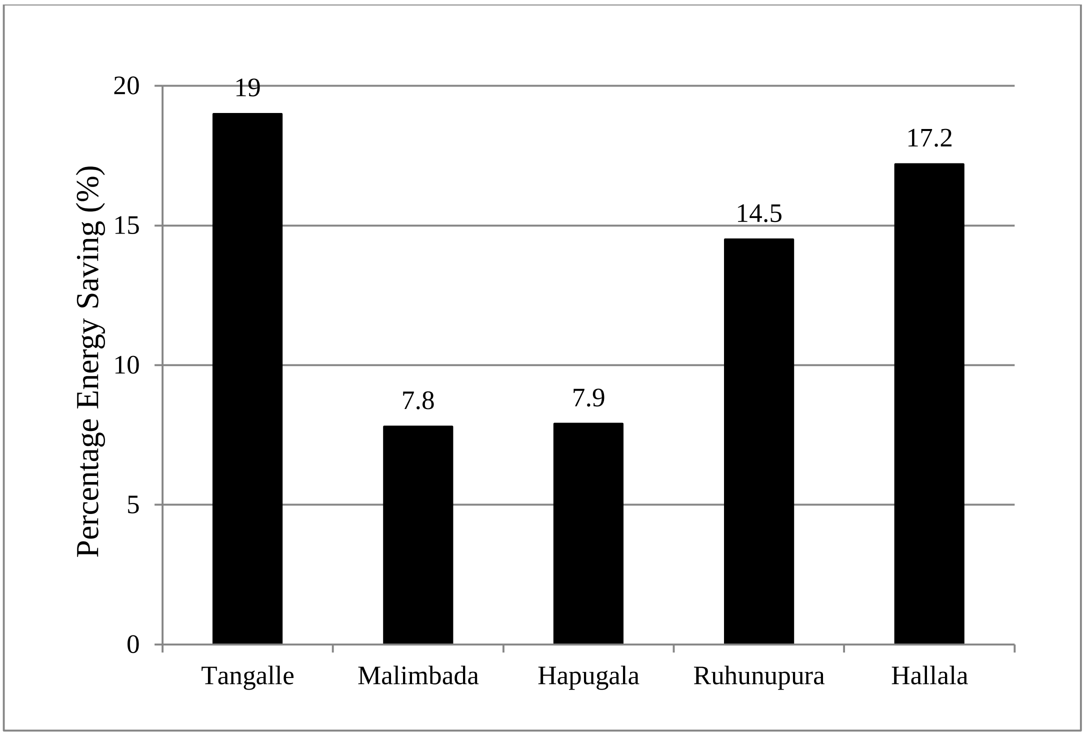


Figure 4.23: Percentage of total energy conversation potential in audited water supply schemes

The major contribution for energy saving in Hallala is from improving overall efficiency of pump and motors. For Ruhunupura, Hapugala and Malimbada WSSs, the major contribution for energy saving is NRW reduction. Both NRW reduction and improving efficiency of pump and motors contribute to the highest energy conservation potential at Tangalle WSS.

Total annual energy conversation potential for audited water supply schemes varies from 0.23 million kWh at Hallala WSS to 0.74 million kWh at Malimbada WSS as shown in Figure 4.24. At Malimbada WSS the energy conservation potential was high since the quantity of production is larger compared to the other audited WSSs.

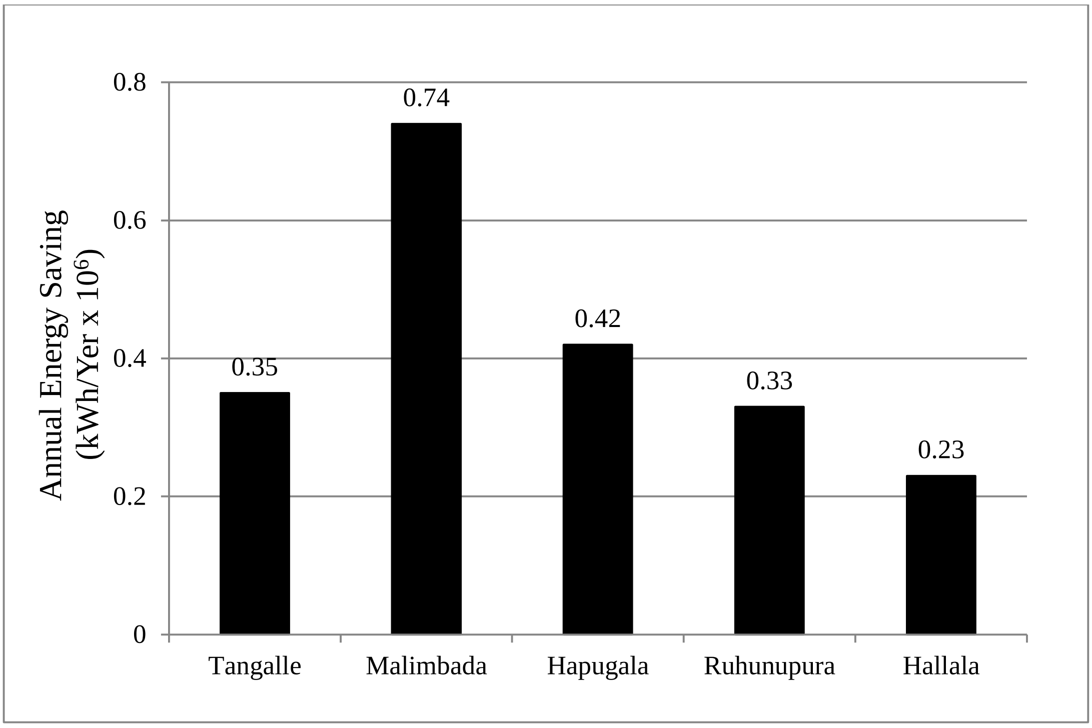


Figure 4.24: Annual total energy conversation potential for audited water supply schemes

Total annual cost reduction potential for audited water supply schemes varies from LKR 4.5 million at Ruhunupura WSS to LKR 10.4 million at Malimbada WSS as shown in Figure 4.25. The cost savings were calculated using average cost of electricity as shown in Table C.13 of Appendix C.

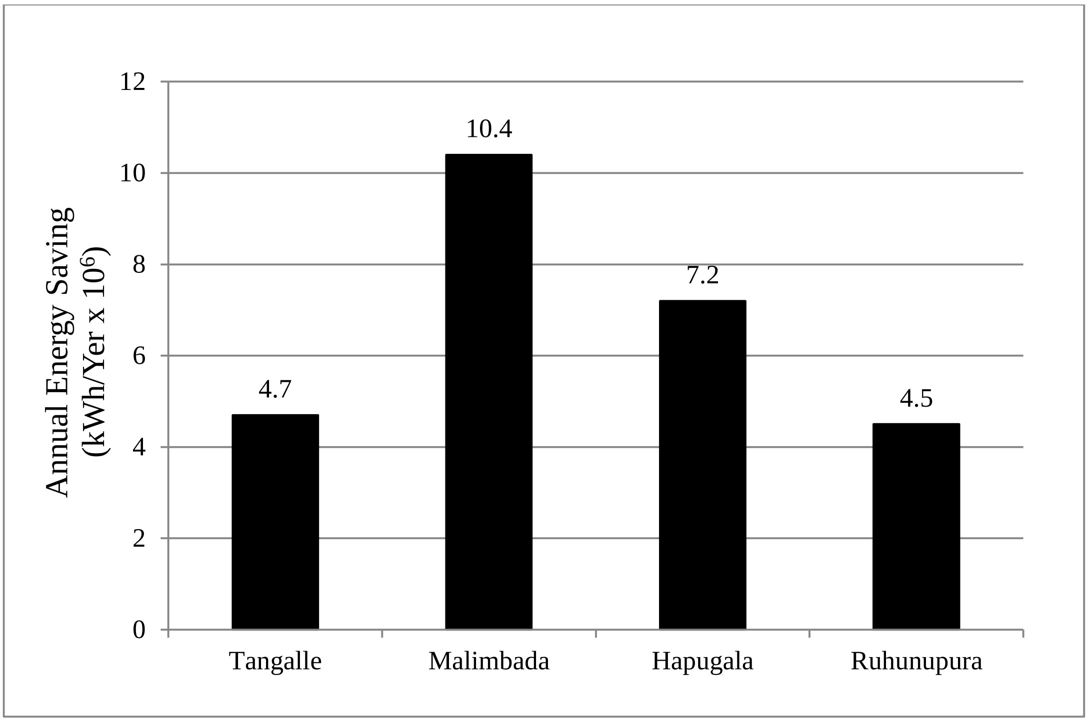


Figure 4.25: Annual total cost saving potential for audited water supply schemes

The potential annual cost saving for Hallala WSS is approximately LKR 2.4 million.

The effect of the identified energy conservation potentials on the annual energy cost of the water supply regions which manage the audited WSSs are shown in Figure 4.26. As per Figure 4.26, percentage cost savings vary from 5.2 to 10.1% and therefore the identified energy saving potentials can significantly improve the financial performance of the water supply regions.

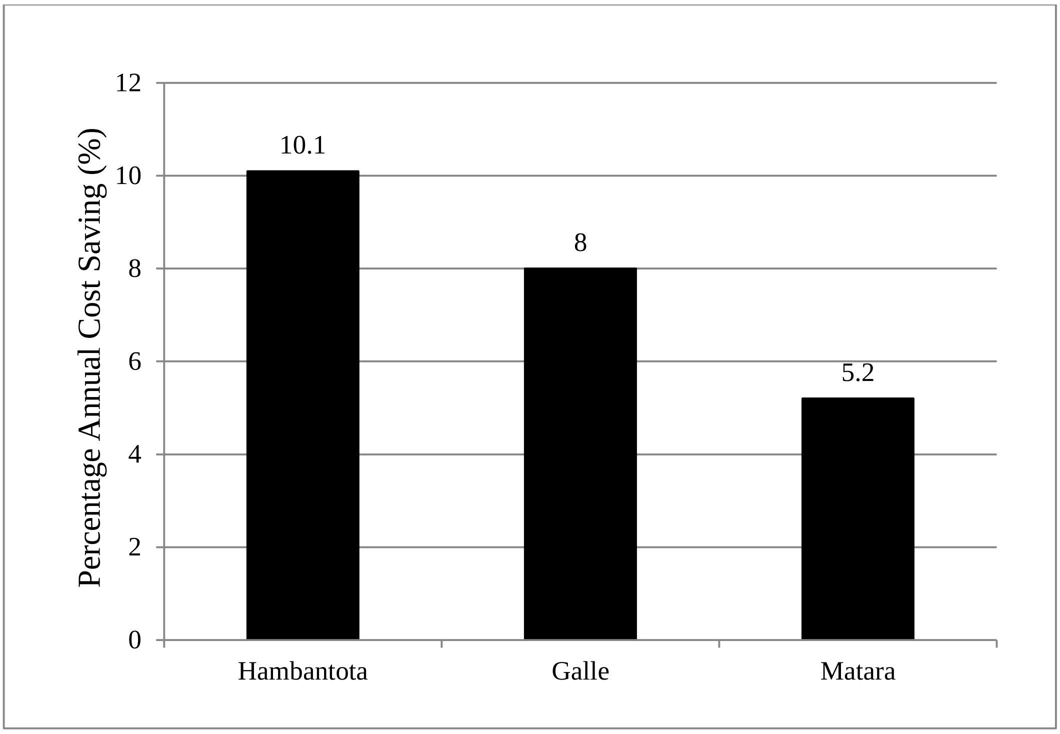


Figure 4.26: Annual total cost reduction potential for water supply regions

5. CONCLUSIONS AND RECOMMENDATIONS

There were two main targets behind this study. One of the target was to achieve energy conservation potentials for drinking water supply schemes to reduce the energy consumption on water treatment and supply by conducting energy audits in selected water supply schemes in Southern Province. Second task was to benchmark the energy consumption of water treatment and supply processes. Having targeted the main objectives preliminary and detailed energy audits were continued in NWSDB schemes, Ruhunupura, Hapugala, Malimbada, Tangalle and Hallala WSS. Based on the outcome of the study, target was further carried out for benchmarking for individual unit processes of water treatment. The potentials for energy conservation identified at the preliminary audit were investigated in depth at the detailed audits.

5.1 Conclusion

The following conclusions can be drawn based on the study:

- Specific energy consumption for water supply schemes in low land areas in Sri Lanka similar to Southern Province behave around 0.3 kWh/m^3
- Operation and maintenance cost is the highest cost component in drinking water treatment procedure and as a percentage from total cost, that amount is 25% and it is unavoidable for a given situation.
- Not less than 70% from entire energy consumed for drinking water process is paid out for distribution process. It's in the range of 71.6 to 85.4 %.
- Treatment process of raw water has a big energy impact when it is compared with surface water treatment where energy consumption for surface water treatment is as less as 3 % compared to energy consumption for raw water distribution and pumping for treatments.
- More attention is vigilant to draw on handling raw water treatments for their saving component is bigger compared to surface water treatment.

- Specific energy consumption figures for raw water pumping for studied schemes: 0.095 – 0.267 kWh/m^3, 0.004 – 0.008 kWh/m^3/m lift, 0.003 -0.033 kWh/m^3/m lift/ km
- Specific energy consumption for distribution pumping for studied WSSs: 0.117 – 0.724 kWh/m^3, 0.004 – 0.006 kWh/m^3/m lift, 0.001 – 0.005 kWh/m^3/m lift/ km
- Specific energy consumption for surface water treatment: 0.003 kWh/m^3 to 0.0.047 kWh/m^3
- Created benchmarks for energy consumption of drinking water treatment unit processes for surface raw water sources:
  - Screening : 0.0002 kWh/m^3
  - Chemical feeding : 0.0027 - 0.0044 kWh/m^3
  - Slow mixing : 0.0082 kWh/m^3
  - Sedimentation : 0.005 kWh/m^3
  - Filtration : 0.0005 – 0.0022 kWh/m^3
  - Chlorination : 0.0009 -0.0045 kWh/m^3
  - Backwash recovery : 0.001 -0.0016 kWh/m^3
- Chlorinator booster pumps consume energy 1% of the total energy and supporting utility could be obtained for schemes with distribution lesser than 60m
- Backwashing frequency reduces energy consumption by 0.06% and applicable to time durations between backwashing less than 48 hours.
- As large as 1% to 14% energy conservation potentials are possible with overall efficiency of the pumping unit in 70% s
- NRW hides an energy conservation potential in a range of 5% to 12%.

5.2 Recommendations and proposals

Further research and improvement proposals;

- Studying for water source improvement with keeping them free from algae, impurities, pollution and contamination through community awareness, national policy planning and programmed long term vision is worth to focus in several ways not only to meet huge energy conservation in future but also to harvesting healthy generation out in danger with numerous diseases

- Direct pumping system of treated water by eliminating distribution through elevated towers is better option to focus to save energy in vigorous amounts yet not ready to be implemented with prevailing electricity pattern in the country
- Further expansion of this type of investigations with similar countries in Asia for improvement of benchmarks in energy conservation concept
- Explore the study towards electricity usage patterns with CEB tariff structure so as to look for better possibilities to improve national power utility while saving power and equipment
- Explore the study aiming world latest technology on modern industrial pumping equipment towards improved usage of VFD, improved impeller profiles, materials and textures, frictionless motion technics, case-vise equipment design, efficient power transmission technics and material etc.
- Expand the study for better possibilities for reduction of energy loss in transmission due to friction through selection of improved materials, surface textures and profiles, associate pipe specials, flow velocities and system curves
- Further expansion of the study on monitoring for production and usage treated water quantities and to work out on areas and occasions losses occur and to implement master plan on elimination of the opportunities for the losses due to leaks or otherwise
- Expand the study towards standardizing water usage with purification level and possibilities to educate population to re-usage of water depending upon the degree of clarity of water for gardening, washing etc.

References

ADB. (2004). Water Utilities Data Book: Asian and Pacific Region. Manila: Asian Development Bank. ISBN 978-9-715-611-251.

Alliance to save Energy. (2005). Energy Audit Guidebook for Water Utilities in the Philippines. Manila: Alliance to save Energy.

Anusart, K. (2012). Water - energy nexus: an application to the Bangkok water supply system, Thailand. (Masters Thesis No. WM. 12-16, Asian Institute of Technology 2012). Bangkok: Asian Institute of Technology.

Arpke, A., & Hutzler, N. (2006). Domestic water use in United States. Industrial Ecology, 10, 169-184.

AWWA. (1998). Report of AWWA Leak Detection and Accountability Commitee. Journel of American Water Works Association, 108-111.

Babel, M. S., Aldrin A. R., Seetharam K. (2010). Municipal Water Supply Management in Bangkok: Achievements and Lessons, International Journal of Water Resources Development, Vol. 26 (2), pages 193-217.

Betancourt, W. Q., & Rose, J. B. (2004). Drinking water treatment processes for removal of Cryptosporidium and Giardia. Vetarinary Parasitology, 126, 219 -234.

Binnie, C., Kimber, M., & Smethurst, G. (2002). Basic Water Treatment (3rd ed.). London: Thomas Telfard. ISBN 0-8540-4989-4

Bogan, C. E., & Michael, J. (1994). Benchmarking for Best Practices: Winning through Innovative Adaptation. New York: McGraw-Hill. ISBN 0-0700-6375-3.

BOI. (2013). Retrieved March 31, 2013, from Board of Investments Sri Lanka Website: http://www.investsrilanka. com/pdf/environmental_norms.pdf.

Bunn, S. M., & Reynolds, L. (2009). The energy efficiency benifits of pump scheduling optimisation for potable water supplies. IBM Journal of Research and Development, 53 (3), 1-5.

Cammerman, N. (2010). Urban Water Security Research Alliance Technical Report No. 39. Queensland: The University of Queensland.

Camp, R. C. (2006). Benchmarking: The Search for Industry Best Practices that Lead to Superior Performance. Milwaukee: ASQC Quality Press. ISBN 1-5632-7532-7.

CEB. (2013). Demand Side Manegement. Retrieved Apri 7, 2013, from Ceylon Electricity Board Website: http://www.ceb.lk/sub/knowledge/demandside.html.

CEB. (2013). Home page. Retrieved April 7, 2013, from Ceylon Electricity Board Website: http://www.ceb.lk.

Chang, C. L. (2002). Study of the interralationship between water use and energy conservation for a building. Energy and buildings, 34, 261-266.

Cohen, R., Nelson, B., & Woff, G. (2004). Energy down the drain:The hidden costs of California's water supply. Oakland: Natural Resources Defence Council.

Cornwell, D. A., Macaphee, M. J., & Brown, R. A. (2003). Demonstrating Cryptosporidium removal using spore monitoring at lime-softning plants. J. AWWA, 95, 125-133.

Edzwald, J. K., & Kelley, M. B. (1998). Control of Cryptosporidium: from reservoirs to clarifiers to filters. Water Science and Technology, 37, 1-8.

EGAT. (2013). Economic and Electricity Overview. Retrieved April 7, 2013, from Electricity Generating Authority of Thailand Website: http://www.egat.co.th/ images/stories/annual/reports/2554/annual2011_eng_p18.pdf.

Elliott, T., Zeier, B., Xagoraraki, I., & Harrington, G. W. (2003). Energy Use of Wisconsin's Drinking Water Facilities. Madison: Energy Center of Wisconsin. Report 222-1.

EPRI. (1994). Energy Audit Manual for Water/Waste Water Facilities. Washington: Electrical Power Research Institute. Report CR-104300.
Fox, K. R. (2006). Water quality in source water,treatment, and distribution systems. In Mannual of water supply and Practices: AWWA M 48 Water Borne Pathogens (2nd ed.). Denver: American Water Works Association. ISBN 1-5832-1403-8.

Frauendorfer, R., and Liemberger, R. (2010). The issues and challenges of reducing non-revenue water. Manila: Asian Development Bank. ISBN 978-92-9092-398-5.

Gao, B. Y., Hahn, H. H., & Hoffman, E. (2002). Evaluation of Aluminium Silicate polimer composite as a coaggulant for water treatment. Water Research, 36, 3573 - 3581.

Geldereich, E. E. (1996). Microbial Quality of Water Supply in Distribution Systems. Boca Raton: CRC Press. ISBN 1-5667-0194-5.

IWA. (2000). IWA Blue Pages. Retrieved December 24, 2012, from International Water Association Website: http://www.iwahq.org /content suite/ upload/ iwa/ Document/ Losses_ from_Water_Supply_Systems_2000.pdf.

James, K., Campbell, S. L., & Godlove, C. E. (2002). Watergy: Taking Advantages of Untrapped Energy and Water Efficiency Opportunities in Municiple Water Systems. Washington: Allaiance to Save Energy.

Jantzen, J. (2009). National dialogue on financing strategy for urban and rural water supply and sanitation in Georgia. Georgia: Organisation of Economic Corporation and Development.

Jeppsson, U., Rosen, C., Alex, J., Copp, J., Gernaey, K. V., Pons, M. N., et al. (2006). Towards a bendmark simulation model for plant-wide control strategy performance evaluation of WWTPs. Water Sicence and Technology, 35, 287-295.

Kalaimathie, S. N. (2012). Investigation on ceramic membrane based filter backwash water recycling and energy conservation potential for water treatment plants . (Masters Thesis No. EV-12-18, Asian Institute of Technology, 2012). Bangkok: Asian Institute of technology.

Karlof, B., & Ostblom, S. (1993). Benchmarking: A Signpost to Excellence in Quality and Productivity. New York: Wiley. ISBN 978- 0-471-941-804.

Kenway, S. J., Priestley, S., Cook, S., Seo, S., Inman, M., Gregory, and Hall, M., (2008). Energy use inthe provision and consumption of urban water in Australia and New Zealand. Sydney: CSIRO. ISBN 978-0-643-096-165.

McNair, J., & Leibfried, K. J. (1995). Benchmarking: A Tool for Continuous Improvement. New York: Harper Business Press. ISBN 978-0-471-132-066.

Mo, W., Zhang, Q., Mihelsic, J. R., & Hokanson, D. R. (2011). Embodied energy comparison of surface water ground water supply options. Water Research, 45(17), 5577-5586.

Monthakanthi, N. (2012). Influence of dissolved organic matter in ceramic membrane filtration performance in drinking water treatment. (Masters Thesis No EV-11-08, Asian Institute of Technology, 2012). Bangkok: Asian Institute of Technology.

Munoz, I., Mila, I. C., & Fernandoz-Alba, A. R. (2010). Life cycle assessment of water supply plants in mediterranean Spain. Journel of Industrial Ecology, 14, 902-918.

National Water Supply & Drainage Board. (2012). History of National Water Supply and Drainage Board. Retrieved 08 18, 2012, from National Water Supply & Daringe Board Website: www.waterboard.lk.

NWSDB. (2013). History of National Water Supply and Drainage Board. Retrieved 03 20, 2013, from National Water Supply & Daringe Board Website: www.waterboard.lk.

NWSDB. (2013). Specifications for water pumping sets and accesaries. Retrieved April 16, 2013, from Natinal Water supply and Drainage Board Website: http://www.waterboard.lk/ scripts/ASP/Documentation_Section.asp.

Olson, B. E., Olson, M. E., & Wallis, P. M. (2002). Giardia: the cosmopolitan parasite. Wellingford: CABI Publishing. ISBN 0-8519-9612-4

Parena, R., & Smeets, E. (2001). Benchmarking initiatives in the water industry. Water Science and Technology, 44, 103-110.

Pearson, D., & Trow, S. W. (2005). Calculating the Economic Levels of Leakage. In Leakage 2005 Conference Proceedings.

Peeters, J. E., Masschelein, W. J., & Maturana, I. V. (1989). Effect of disinfection of drinking water with ozone or chlorine dioxide on survival of Cryptosporidium Pavrum oocysts. J Applied Environmental Microbialogy, 55, 1519-1522.

Plappaly, A. K., & Lienhard, V. J. (2012). Energy requirements for water production,treatment,end use,recclamation and disposal. Journal of Renewable and Sustainable Energy Reviews, 16, 4818 - 4868.

Racoviceanu, A. I., Karney, B. W., Kennedy, C. A., & Colombo, A. F. (2007). Life cycle energy use and greenhouse gas emmisions inventory for water treatment systems. Journal of Infrastructure Systems, 13, 261-270.

Rothausen, S. G., & Conway, D. (2011). Greenhouse Gas Emmisions from Energy Use in Water Sector. Nature Climet Change, 1, 210-219.

Stapenhurst, T. (2009). The Benchmarking Book: A How to Guide to Best Practices for Managers and Practitioners. London: Taylor and Francis. ISBN 978-0-750-689-052

Stokes, J., & Horvarth, A. (2009). Energy and air emmision effects in water supply. Environmental Technology and Science, 43 (8), 2680-2687.

Stowa. (2013). Microfiltration. Retrieved April 30, 2013, from Dutch Foundation for Water Research Web Site: http://www.stowa-selectedtechnologies.nl/Sheets/Sheets /Microfiltration.html.

Troyan, J. J., & Hansen, S. P. (1989). Treatment of Microbial Contaminants in Potable Water Supplies: Technologies and Costs. New Jersy: Noyes Data Corporation. ISBN 0-8155-1214-7

Venetucci, R. (1992). Benchmarking: a reality check for strategy and performance objectives. Production and Inventory Management, 33, 32-36.

Venkatesh, G., & Brattebo, H. (2011). Energy consumption, costs and environmental impacts for urban water cycle services: Case study of Oslo(Norway). Energy, 36, 792-800.

Water Environment Foundation. (2009). Energy Conservationin of Water and Wastewater Facilities. New York: McGraw Hill. ISBN 978-0-071-667-944.

WEPA. (2013). Retrieved March 31, 2013, from Water Environment Partnership of Asia: http://www.wepa-db.net/policies/law/thailand/std_drinking.htm.

WHO. (2011). Guidlines for Drinking Water Quality (3rd ed.). Geneva: World Health Organisation.

Willemse, R. J. N., & Brekvoort, Y. (1999). Full-scale recycling of backwash water from sand filters using dead-end membrane filtration. Water Research,33 (15), 3379-3385.

Appendix A

Data on Selected Water Supply Schemes and Overall Energy Cost of Drinking Water Supply

Table A.1: Comparison of Drinking Water Quality Standards

Parameter	Sri Lanka Standard 614: Part 1 and Part 2: 1983		WHO guideline:2008
	Maximum acceptable	**Maximum allowable**	
Bacteriological			
Coliform (MPN/100ml)	3	3	Not specified
E Coli (MPN/100ml)	0	0	0
Physical			
Colour	5 Hz	30 Hz	15 Pt-Co
Taste	Non objectionable	Non objectionable	Non objectionable
Odour	Non objectionable	Non objectionable	Non objectionable
Turbidity	2 NTU	8 NTU	5 NTU
Chemical			
pH	7.0 - 8.5	6.5- 9.5	6.5 - 8.5
Electrical conductivity	750 µS/cm	3500 µS/cm	250 mS/cm
Chloride (mg/L)	200	1200	250
Total Alkalinity (mg/L)	200	400	Not specified
Nitrate (mg/L)	10	10	50
Nitrite (mg/L)	0.01	0.01	0.5
Total Phosphate (mg/L)	2	2	Not specified
Total Hardness(mg/L)	250	600	500
Calcium (mg/L)	100	240	Not specified
Total Iron (mg/L)	0.3	1	0.3
Sulphate (mg/L)	200	400	500
Aluminium (mg/L)	0.2		0.2
Fluoride (mg/L)	0.6	1.5	1.5
Residual Chlorine (mg/L)	0.2	1	5

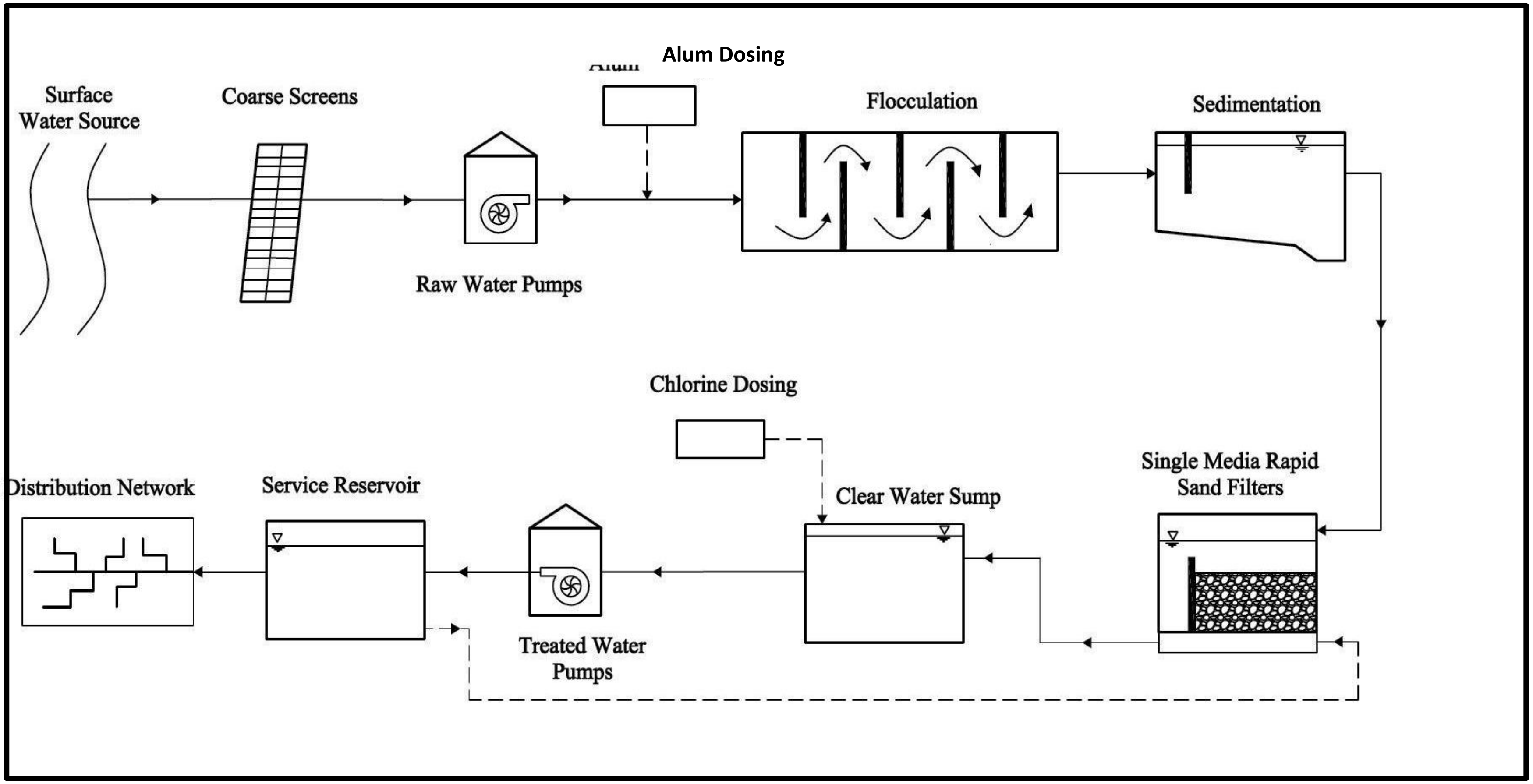


Figure A.1: Schematic diagram of Hallala water supply scheme

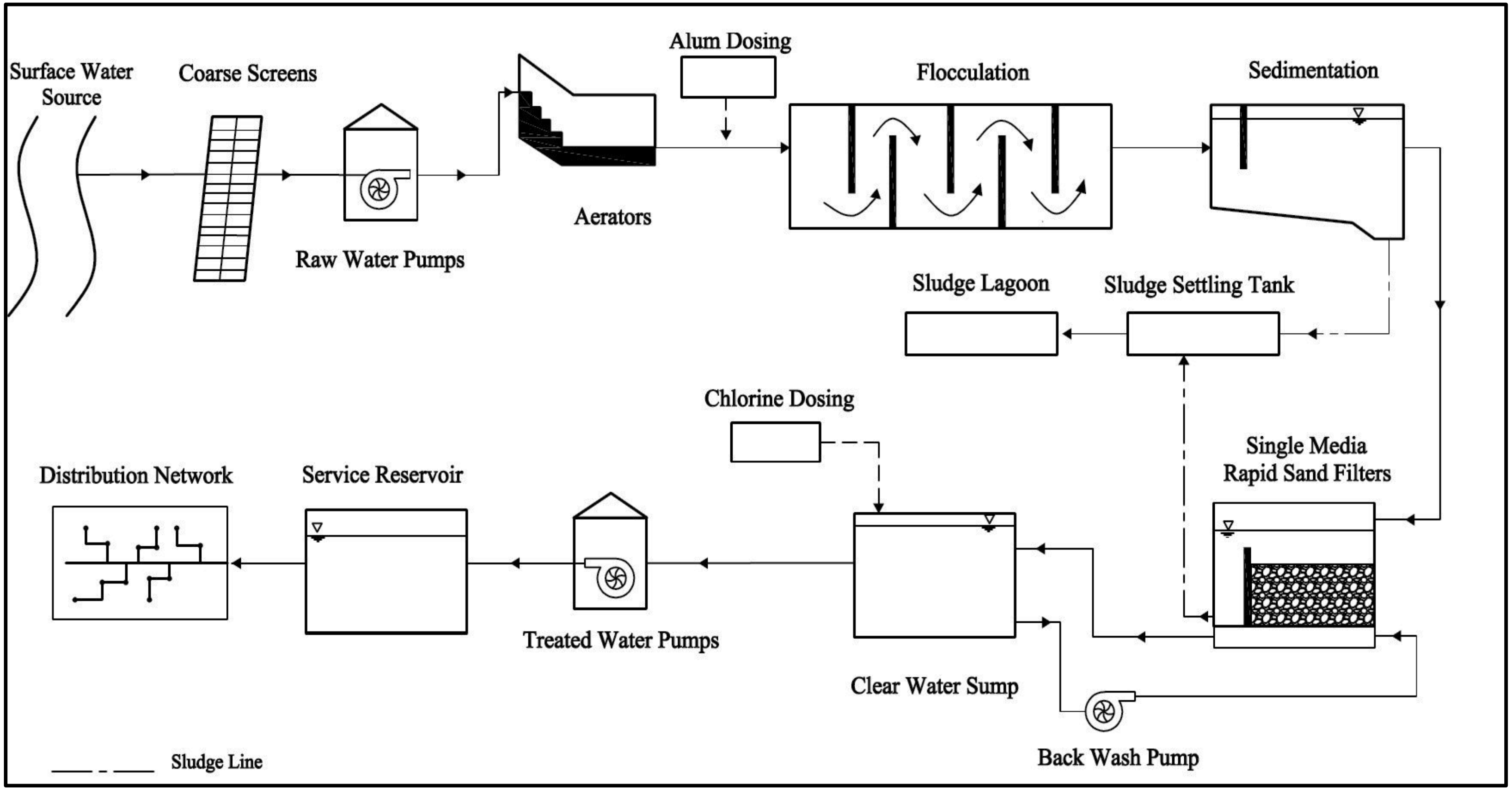


Figure A.2: Schematic diagram of Ruhunupura water supply scheme

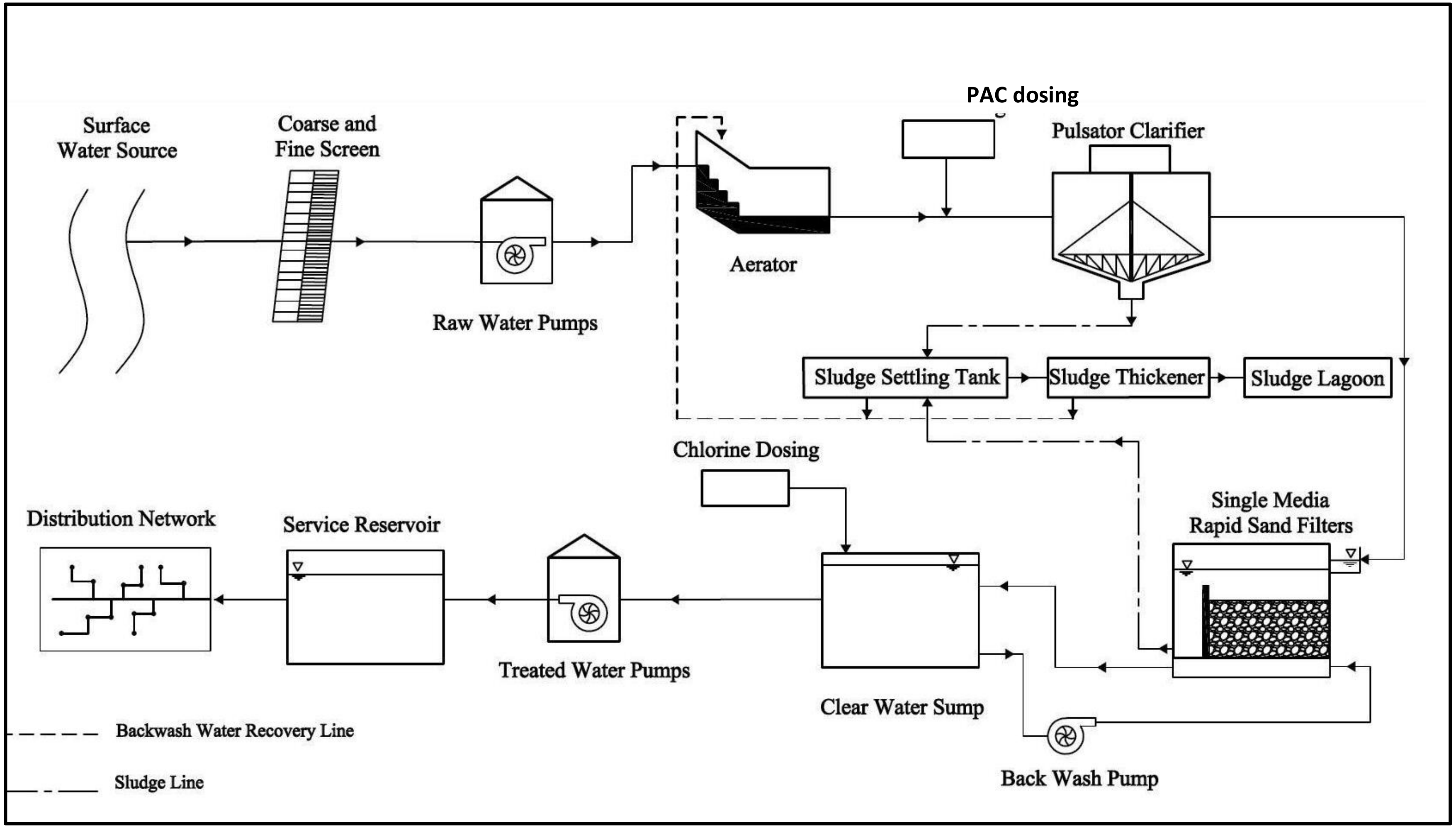


Figure A.3: Schematic diagram of Hapugala water supply scheme

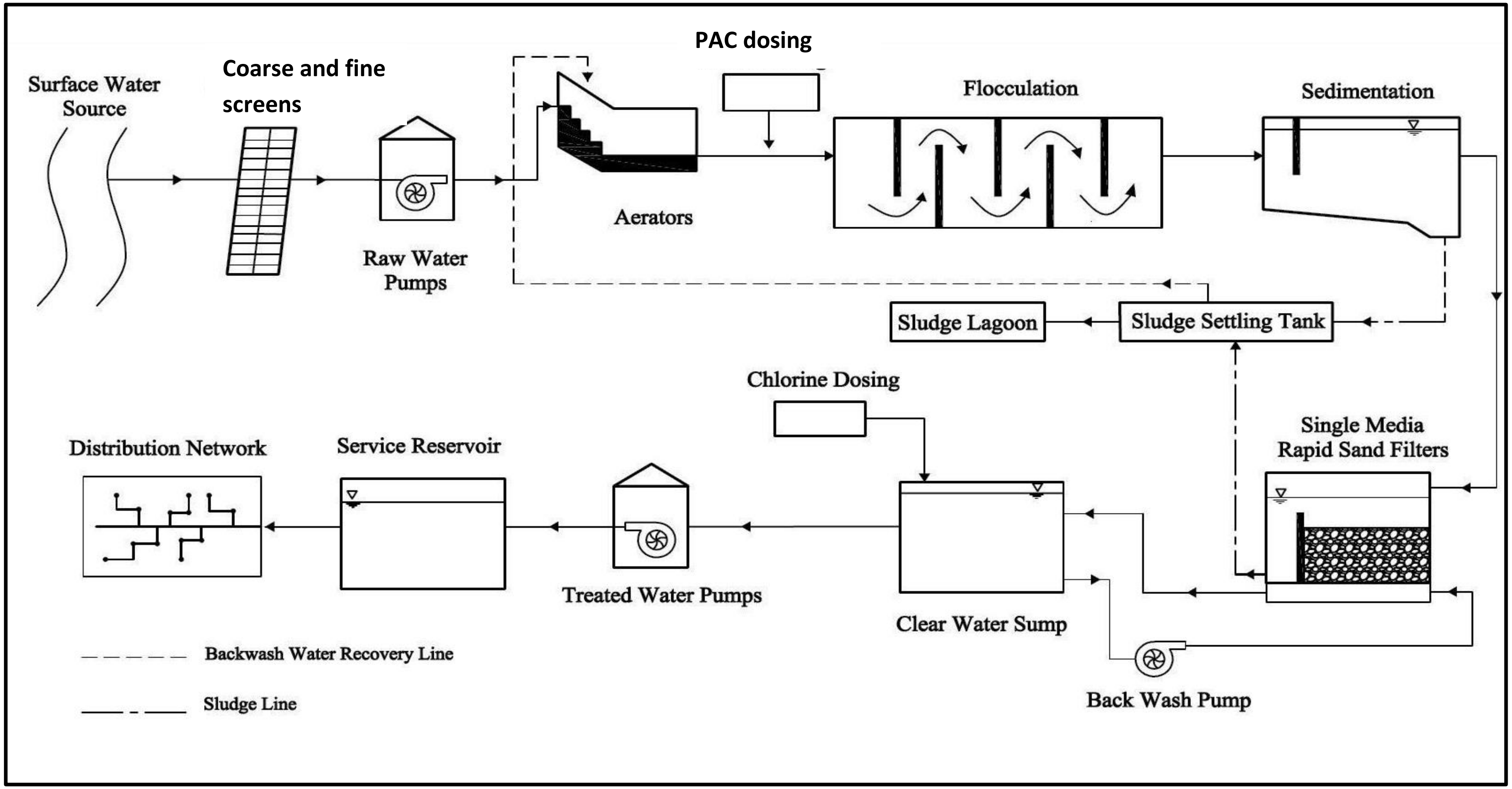


Figure A.4: Schematic diagram of Malimbada water supply scheme

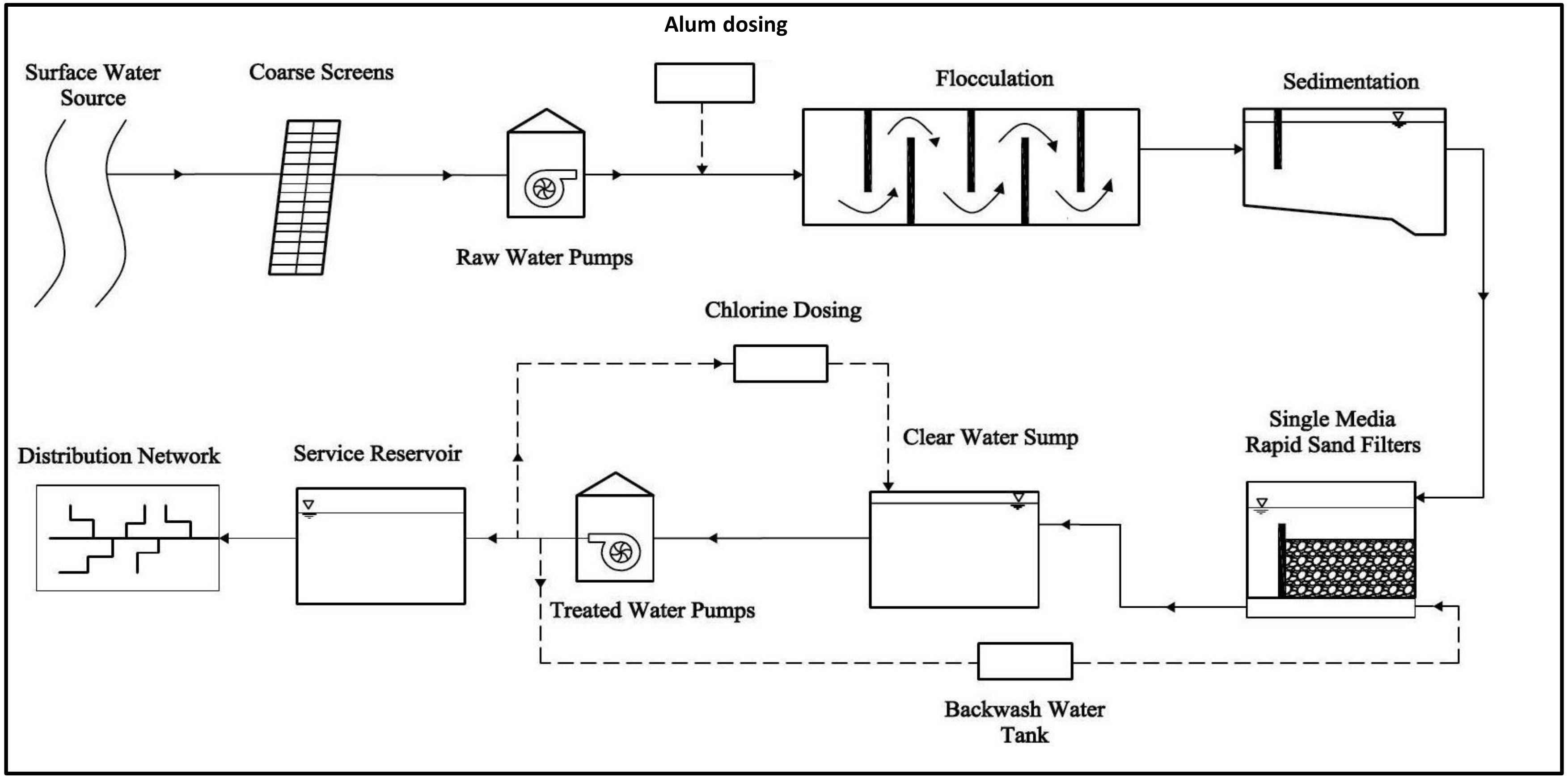


Figure A.5: Schematic diagram of Tangalle water supply scheme

Table A.2 Operation Cost Breakdown of National Water Supply and Drainage Board in 2012

Operation Cost Category	**Cost (LKR x 10^6)**	**Percentage Cost (%)**
Personnel	6465	53
Electricity	2891	24
Chemical	501	4
Repair & Maintenance	835	7
Establishment	797	7
Security and Finance	689	6

Table A.3: Operation Cost Breakdown of Selected Water Supply Regions

Operation Cost Category	**Operation Cost and Percentage**					
	Galle Region		**Matara Region**		**Hambantota Region**	
	LKR x 10^6	**%**	**LKR x 10^6**	**%**	**LKR x 10^6**	**%**
Personnel	222	46	189	34	155	43
Electricity	94	19	201	37	91	25
Chemical	118	2	18	3	63	17
Repair & Maintenance	96	20	83	15	19	5
Establishment	23	5	19	3	11	3
Security and Finance	40	8	39	7	25	7

Appendix B

Preliminary Audit Data and Benchmarking Calculations

Audit Duration – From: 09.00 on 15 Dec 2015 **To:** 09.00 on 16 Dec 2015

Table B.1: Flow Meter Readings of Hallala Water Supply Scheme

Description	**Flow meter reading (m^3)**	**Volume (m^3)**
Raw water flow meters		
Start	654897	
End	664577	9680
Backwash flow meters		
Start	87650	
End	87775	125
Treated water flow meters		
Start	765489	
End	775144	9655

Audit Duration – From: 09.00 on 4 Jan 2016 **To:** 09.00. on 5 Jan 2016

Table B.2: Flow Meter Readings of Ruhunupura Water Supply Scheme

Description	**Flow meter reading (m^3)**	**Volume (m^3)**
Raw water flow meters		
Start	205681	
End	213711	8030
Backwash flow meters		
Start	246908	
End	247109	201
Treated water flow meters		
Start	987546	
End	995796	8250

Audit Duration- From: 07.00 on 7 Jan 2016 **To:** 07.00 on 8 Jan 2016

Table B.3: Flow Meter Readings of Hapugala Water Supply Scheme

Description	**Flow meter reading (m^3)**	**Volume (m^3)**
Raw water flow meters		
Start	976762	
End	994862	18100
Backwash flow meters		
Start	14586	
End	14811	225
Treated water flow meters		
1 - Start	765908	
1 - End	769126	3218
2 - Start	564378	
2 - End	569506	5128
3 - Start	345097	
3 - End	345851	754
4 - Start	456985	
4 - End	462653	5668
5 - Start	765298	
5 - End	768298	3000

Audit Duration – From: 07.00 on 16 Jan 2016 **To:** 07.00 on 17 Jan 2016

Table B.4: Flow Meter Readings of Malimbada Water Supply Scheme

Description	**Flow meter reading (m^3)**	**Volume (m^3)**
Raw water flow meters		
Start	408267	
End	444837	36570
Backwash flow meters		
Start	34768	
End	35218	450
Treated water flow meters		
1 - Start	134598	
1 - End	150153	15555
2 - Start	986356	
2 - End	989613	3257
3 - Start	234987	
3 - End	247132	12145
4 - Start	76580	
4 - End	81630	5050

Audit Duration – From: 09.00 on 19 Jan 2016 **To:** 09.00 on 20 Jan 2016

Table B.5: Flow Meter Readings of Tangalle Water Supply Scheme

Description	**Flow meter reading (m^3)**	**Volume (m^3)**
Raw water flow meters		
Raw water pumping main 1- Start	125768	3480
Raw water pumping main 1- End	129248	
Raw water pumping main 2- Start	876908	4080
Raw water pumping main 2- End	880988	
Raw water pumping main 3- Start	234785	3072
Raw water pumping main 3- End	237857	
Backwash flow meters		
Start	36340	136
End	36476	
Treated water flow meters		
Pumping main 1- Start	380264	5280
Pumping main 1- End	385544	
Pumping main 2- Start	114029	4320
Pumping main 2- End	118349	
Pumping main 1- Start	80954	864
Pumping main 2- End	81818	

Table B.7: Electricity Consumption of Audited Water Supply Schemes

Description	Consumption (kWh/m^3)	Remarks
Hallala Water Supply Scheme		
Intake pump house	2587	From 09.00 on 15 Dec 2015 To 09.00 on 16 Dec 2015
Water treatment plant	1270	
Ruhunupura Water Supply Scheme		
Intake pump house	1009	From 09.00 on 04 Jan 2016 To 09.00 on 05 Jan 2016
Water treatment plant	4767	
Hapugala Water Supply Scheme		
Intake and water treatment plant	10785	From 09.00 on 07 Jan 2016 To 09.00 on 08 Jan 2016
Malimbada Water Supply Scheme		
Intake pump house	5290	From 09.00 on 16 Jan 2016 To 09.00 on 17 Jan 2016
Water treatment plant	16308	
Tangalle Water Supply Scheme		
Intake pump house	1407	From 09.00 on 19 Jan 2016 To 09.00 on 20 Jan 2016
Water treatment plant	2946	

Table B.7: Rated Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Hallala Water Supply Scheme

Unit Process	**Equipment**	**Brand/ Model**	**Rated Parameters**				
			Power (kW)	**Voltage (V)**	**Current (A)**	**Head (m)**	**Flow (m^3/h)**
Raw water pumping	Raw water pumps set 1	KSB	110	380	199	55	420
	Raw water pumps set 2	KSB	55	380	98	45	220
Chemical feeding	PAC Mixer	FLNDER	1.5	380	3.1	-	-
	PAC booster pumps	Milton Roy	0.25	380	0.83		0.4
	Air Compressor*	GSD	5.5	380	11.6	-	-
Rapid mixing	Hydraulic jump	-	-	-	-	-	-
Slow mixing	Baffled flocculator	-	-	-	-	-	-
Sedimentatio n	Sludge scraper	Pala Drive	0.75	380	1.7	-	-
Filtration	Back wash Air Blower	KFM	30	380	56.5	-	-
	Back wash Tank Pumping	KSB	55	380	102	28	400
Disinfection	Booster Pumps	KSB	1.5	380	3.74	54	5
Distribution pumping	Treated water pumps set 1	KSB	55	380	102	28	400
	Treated water pumps set 2	KSB	22	380	41	25	280

Note *: Air compressor is used to clean chemical tanks

Audit Duration From: 09.00 on 15 Dec 2015 **To:** 09.00 on 16 Dec 2015

Table B.8: Measured Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Hallala Water Supply Scheme

Unit Process	**Equipment**	**Measured Parameters**					**Operation Schedule**
		Voltage (V)	**Current (A)**	**Head (m)**	**Flow (m^3/h)**	**Power factor**	
Raw water pumping	Raw Water Pump set 1	390	180	54	420	0.85	1 duty, 1 standby, 22 h
	Raw Water Pump set 2	390	82	43	220	0.85	1 duty, 1 standby, 2 h
Chemical feeding	PAC Mixer	390	2.16	_	_	0.85	1 duty, 1 standby, 24 h
	PAC Booster Pupms	390	0.75	8.4	0.4	0.85	1 duty, 1 standby, 24 h
	Air Compressure	390	11.18	_	_	0.85	1 duty, 1 standby, 6 min
Sedimentation	Sludge scraper	390	1.63	_	_	0.85	2 duty, 24 h
Filtration	Back wash Air Blower	390	52	_	_	0.85	1 duty, 1 standby, 10 min
	Back wash water from tank	_	_	_	_		_
Disinfection	Booster Pumps	390	2.67	30	4.2	0.85	1 duty, 1 standby, 24 h
Distribution pumping	Treated Water Pump set 1	390	87	24	420	0.85	1 duty, 1 standby, 21 h 30 min
	Treated Water Pump set 2	390	38	19.8	250	0.85	1 duty, 1 standby, 2 h 30 min

Table B.9: Rated Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Ruhunupura Water Supply Scheme

Unit process	**Equipment**	**Brand**	**Rated Parameters**					
		Motor/ Pump	**Power (kW)**	**Voltage (V)**	**Current (A)**	**PF**	**Head (m)**	**Flow (m^3/h)**
Raw water pumping	Raw water pumps	KSB	45	400	80	_	_	_
Chemical Mixing	Alum mixer	Primo	0.75	415	3.4	_	_	_
	Constant head gravity feeder	_	_	_	_	_	_	_
	Feed water pump for mixer	Rotoflex	1.5	398	1.5	_	_	_
Rapid mixing	Hydraulic jump	_	_	_	_	_	_	_
Slow mixing	Baffled floccculator	_	_	_	_	_	_	_
Sedimentation	Sedimentation tanks	_	_	_	_	_	_	_
Filtration	Back wash air blower	Hico	30	400	59	0.8	_	_
	Back wash pump	Paco	75	400	132	0.85	22	774
Disinfection	Chlorination Booster Pump	Grundfos	0.37	400	0.8	0.80	37.6	1.8
Distribution pumping	Batampara	Grundfos	250	400	420	0.85	155	285
Sludge treatment	Sludge thickener	_	_	_	_	_	_	_
	Sludge drying beds	_	_	_	_	_	_	_

Audit Duration – From: 09.00 on 4 Jan 2016 **To:0** 9.00 on 5 Jan 2016

Table B.10: Measured Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Ruhunupura Water Supply Scheme

Unit process	**Equipment**	**Measured Parameters**						**Operation Schedule**
		Power (kW)	**Voltage (V)**	**Current (A)**	**PF**	**Head (m)**	**Flow (m^3/h)**	
Raw water pumping	Raw water pumps	_	400	78	0.85	28	375	1 duty, 2 standby , 22 h
Chemical Mixing	Alum mixer	_	408	3.3	0.82	_	_	1 duty, 1 standby, 4 min
	Constant head gravity feeder	_	_	_	_	_	_	_
	Feed water pump for mixer	_	405	1.5	0.85	_	_	1 duty, 1 standby , 9 min
Filtration	Back wash air blower	_	411	57	0.8	_	_	1 duty, 1 standby 6 min
	Back wash pump	_	410	110	0.85	18	861	1 duty, 1 standby, 14 min
Disinfection	Chlorination Booster Pump	_	400	0.6	0.8	38	_	1 duty, 1 standby 24 h
Distribution pumping	Intake	_	400	400	0.85	163	365	1 duty, 2 standby , 22h

Table B.11: Rated Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Hapugala Water Supply Scheme

Unit process	Equipment	Brand	Rated Parameters					
		Motor/Pump	**Power/(kW)**	**Voltage/(V)**	**Current/(A)**	**PF**	**Head/(m)**	**Flow/(m^3/h)**
Raw water pumping	Raw water pumps	Grundfos	70	400	134	_	39	400
Chemical feeding	PAC Booster Pumps	ProMinent	0.75	415	2	_	50	0.79
	Lime Booster Pump	Seepex	0.75	400	2	0.76	_	_
	Agitators	Crompton Greaves	2.2	415	4.5	_	_	_
Rapid mixing	Hydraulic jump	_	_	_	_	_	_	_
Pulsator/Slow mixing	Pulsator vacuum pump	Alstom	5.5	415	10.4	0.83	_	_
Sedimentation	_	_	_	_	_	_	_	_
Filtration	Back wash air blower	ABB	30	415	55	0.81	_	_
	Back wash air compressor	ABB	4	415	6	_	_	_
	Back wash pump	Grundfos	7.5	415	16.2	0.8	100	240
Disinfection	Chlorinator booster pump	Grundfos	2.2	415	8. 5	0.89	75	5.8
Distribution pumping	Pump 1	Grundfos	110	415	190	0.87	92	279
	Pump 2	Grundfos	150	415	290	0.89	130	274
	Pump 3	Grundfos	55	415	56.2	0.84	90	108
	Pump 4	Grundfos	220	415	357	_	105	417
	Pump 5	Grundfos	150	415	275	0.89	118	255
Sludge treatment	Settling Tank to Sludge Pit Pump	Grundfos	1.5	415	3.8	_	17	19.5
	Sludge pit to Sludge Thickener Pump	Grundfos	3.8	415	6.5	_	26.9	80
	Settling Tank to Aerator Pump	Grundfos	4	415	10.2	_	16.9	135
	Sludge Thickner to Sludge Lagoon Pump	Motovario	3	415	6.9	_		7

Audit Duration – Audit Duration- From: 07.00 on 7 Jan 2016 **To:** 07.00 on 8 Jan 2016

Table B.12: Measured Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Hapugala Water Supply Scheme

Unit process	**Equipment**	**Measured Parameters**						**Operation Schedule**
		Power (kW)	**Voltage (V)**	**Current (A)**	**Power Factor**	**Head (m)**	**Flow (m^3/h)**	
Raw water pumping	Intake pumps	69	406	125	0.79	23	1495	2 duty, 1 standby , 12 h 6 min
Chemical feeding	PAC booster Pump	-	405	0.7	0.86	-	-	1 duty, 1 standby, 12 h 6 min
	Lime booster Pump	-	409	1.1	0.82	-	-	1 duty, 1 standby ,12 h 6 min
	Agitator	-	408	4.2	0.83	-	-	2 duty ,2 standby, 12 h 6 min
Slow mixing	Pulsator vacuum pump	-	407	9.8	0.87	-	-	2 duty, 2 standby 12 h 6 min
Filtration	Back wash air blower	-	406	52.6	0.87	-	-	1 duty, 1 standby , 9 min
	Back wash air compressor	-	405	5.4	0.88	-	-	1 duty 1 standby 10 min
	Back wash pumps	-	408	15.7	0.83	-	-	1 duty 1 standby 24 min
Chlorination	Chlorination booster pump	-	409	8.2	0.87	-	-	1 duty 2 standby,12 h 6 min
Distribution pumping	Pump 1	100.8	407	168	0.86	93	271	1 duty 1 standby ,11 h 54 min
	Pump 2	155.8	400	245	0.87	128	285	1 duty 1 standby , 18 h
	Pump 3	42.3	400	72	0.88	94	98	1 duty 1 standby , 7 h 42 min
	Pump 4	168.5	405	278	0.83	100	405	1 duty 1 standby , 14 h
	Pump 5	125.8	408	214	0.86	112	244	1 duty 1 standby , 12 h 18min
Sludge treatment	Settling tank to sludge pit	-	406	3.7	0.86	-	-	1duty 1 standby, 1 h
	Sludge pit to thickener pump	-	409	6.5	0.85	-	-	1 duty 1 standby 1 h
	Settling tank to aerator pump	-	407	9.9	0.83	-	-	1 duty 1 standby 9 h
	Thickener to sludge lagoon	-	405	6.7	0.82	-	-	1 duty 1 standby 30 min

Table B.13: Rated Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Malimbada Water Supply Scheme

Unit process	Equipment	Brand	Rated Parameters					
		Pump/Motor	**Power (kW)**	**Voltage (V)**	**Current (A)**	**Power Factor**	**Head (m)**	**Flow (m^3/h)**
Screening	Course screen (50mm)	-	-	-	-	-	-	-
	Fine screen (10mm)	Toshiba	2.20	420	5	0.81	-	-
	Fine screen washing pumps	Toshiba/Teco	11	400	18	-	42	25
Raw water pumping	Raw water Pumps	Kubota/Teco	280	400	473	-	44	1600
Chemical feeding	PAC mixer	Cyclo drive	2.2	400	4.9	-	-	-
	Lime mixer	Teco	2.2	400	4.9	-	-	-
	PAC dosing	Iwaki/Toshiba	0.75	400	1.9	-	5	13
	Post Lime Booster Pump	Toshiba/Warman	5.5	400	11	-	60	12
	Post Lime Dosing Pump	Nord/Wetzsch	1.1	400	3	0.7	5	13
Rapid mixing	-	-	-	-	-	-	-	-
Slow mixing	-	-	-	-	-	-	-	-
Sedimentation	Sludge collector	Toshiba	1.1	400	2.8	0.83	-	-
Filtration	Back wash air blower	Toshiba	111.9	400	190	-	-	-
	Back wash pumps	Toshiba/Teco	37	400	69.1	-	-	730
Disinfection	Chlorination booster pump	Toshiba/Teco	5.5	400	10.3	-	45	132
Distribution pumping	Pump 1	Kubota/Teco	450	400	760	-	134	720
	Pump 2	Kubota/Teco	110	400	189	-	102	240
	Pump 3	Kubota/Teco	270	400	458	-	102	620
	Pump 4	Ibara/Teco	90	400	159	-	52	300
Sludge treatment	Backwash recovery pumps	Toshiba/Warman	22	400	-	0.98	16	270

Audit Duration – From: 07.00 on 16 Jan 2016 **To:** 7.00 on 17 Jan 2016

Table B.14: Measured Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Malimbada Water Supply Scheme

Unit process	**Equipment**	**Measured Parameters**						**Operation Schedule**
		Power (kW)	**Voltage (V)**	**Current (A)**	**PF**	**Head (m)**	**Flow (m^3/h)**	
Screening	Course screen (50mm)	–	–	–	–	–	–	2 duty
	Fine screen (10mm)	_	394	4.8	0.97	_	_	2 duty, 20 min/d
	Fine screen washing pumps	_	394	18	0.97	42	21	1 duty, 1 standby,20 min
Raw water pumping	Raw water pumps	_	394	353	0.97	38	1590	1 duty, 2 standby, 23h
Chemical feeding	PAC mixer	_	394	3.6	0.97	_	_	1duty, 1 standby, 8 h
	Lime mixer	_	394	3.5	0.97	_	_	1duty, 1 standby, 8 h
	PAC dosing	_	394	1.8	0.97	_	_	1 duty, 1 standby, 23 h
	Post lime booster pumps	_	394	5.5	0.97	_	_	1 duty, 1 standby, 23 h
	Post lime dosing Pump	–	394	2.6	0.97	_	_	1 duty, 1 standby, 23 h
Rapid mixing	_	–	–	–	0.97	_	_	_
Slow mixing	_	–	–	–	0.97	_	_	_
Sedimentation	Sludge collector	_	394	2.1	0.97	_	_	2 duty, 4 h
Filtration	Back wash air blower	_	394	125	0.97	_	_	1 duty, 1 standby, 3 m, 2 backwashes
	Back wash pump	_	394	60	0.97	_	720	1 duty, 7 m : 2 duty , 10m
Disinfection	Chlorinator booster pump	_	394	10	0.97	_	_	1 duty, 1 standby, 23 h
Distribution pumping	Pump 1	386	394	620	0.97	127	780	1 duty, 1 standby, 20 h 13 min
	Pump 2	95	394	159	0.97	96	220	1 duty, 1 standby, 20 h 45 min
	Pump 3	209	394	342	0.97	91	650	1 duty, 1 standby, 16 h
	Pump 4	62.5	394	113	0.97	56	260	1 duty, 1 standby, 20 h 17 min
Backwash recovery	Backwash recovery	_	394	37	0.97	12	180	1 duty, 1 standby, 2 h 15 min

Table B.15: Rated Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Tangalle Water Supply Scheme

Unit process	Equipment	Brand	Rated Parameters					
		Motor/Pump	**Power(kW)**	**Voltage(V)**	**Current(A)**	**PF**	**Head(m)**	**Flow(m^3/h)**
Raw water pumping	Intake Pumps	KSB	30	415	55	0.8	26	150
		KSB	30	415	55	0.8	30	175
		KSB	15	415	45	0.8	24	130
Chemical feeding	Alum mixer 1/2	Primo	0.85	415	2.1	0.9	_	_
	Constant head gravity feeder	_	_	_	_	_	_	_
Rapid mixing	Hydraulic jump	_	_	_	_	_	_	_
Slow mixing	Baffled flocculators	_	_	_	_	_	_	_
Sedimentation	Plain sedimentation tank s	_	_	_	_	_	_	_
Filtration	Back wash air blower	Hico	11	415	20.8	0.8	_	_
	Back wash water from back wash tank	_	_	_	_	_	_	_
Chlorination	Motive water from treated water pumping main	_	_	_	_	_	_	_
Distribution pumping	Pump 1	Grundfos	45	415	86	0.80	52	225
		Paco	45	415	77	0.80	64	185
	Pump 2	Paco	15	415	25	0.80	96	45

Audit Duration – From: 09.00 on 19 Jan 2016 **To:** 09.00 on 20 Jan 2016

Table B.16: Measured Electrical Energy Related Parameters, Pump Heads and Flow Rates of Equipment in Tangalle Water Supply Scheme

Unit process	**Equipment**	**Measured Parameters**						**Operation Schedule**
		Power (kW)	**Voltage (V)**	**Current (A)**	**PF**	**Head (m)**	**Flow (m^3/h)**	
Raw water pumping	Intake Pumps	_	400	39	0.75	27	145	1 duty, 24 h
		_	400	45	0.75	29	170	1 duty, 24 h
		_	400	28	0.75	26	128	1 duty, 24 h
Chemical feeding	Alum mixer	_	414	2.0	0.8	_	_	1 duty, 1 standby, 24 h
	Constant head gravity feeder	_	_	_	_	_	_	_
Rapid mixing	Hydraulic jump	_	_	_	_	_	_	
Slow mixing	Baffled flocculator	_	_	_	_	_	_	_
Sedimentation	Plain sedimentation tank	_	_	_	_	_	_	_
Filtration	Back wash air blower 1/2	_	414	18	0.9	_	_	1 duty, 1 standby, 15 min
	Back wash water from back wash tank	_	_	_	_	_	_	_
Chlorination	Motive water from treated water pumping main	_	_	_	_	_	_	_
Distribution pumping	Pump 1	_	414	84	0.97	60	220	1 duty, 2 standby ,24 h
		_	414	64	0.97	64	180	1 duty, 1 standby, 24 h
	Pump 2	_	414	26	0.97	98	36	1 duty, 1 standby ,24 h

Audit Duration – From: 09.00 on 15 Dec 2015 **To:** 09.00 on 16 Dec 2015

Table B.17: Specific Energy Consumption of Water Treatment Unit Processes in Hallala Water Supply Scheme

Unit Process	**Equipment**	**Energy Consumption (kWh)**	**Specific Energy Consumption (kWh/ m^3)**	**Specific Energy Consumption of Unit Process ((kWh/ m^3)**
Raw water pumping	Raw water pump set 1	2480	0.2569	0.2667
	Raw water pump set 2	94	0.0098	
Chemical feeding	PAC mixer	29.8	0.0031	0.0042
	PAC booster pumps	10.3	0.0011	
	Air compressor	0.64	0.0001	
Sedimentation	Sludge scraper	45	0.0047	0.0047
Filtration	Back wash Air Blower	4.98	0.0005	0.0005
Chlorination	Booster Pumps	36.8	0.0038	0.0038
Distribution pumping	Treated water pump set 1	1074	0.1112	0.1169
	Treated water pump set 2	54.5	0.0056	

Audit Duration – From: 09.00 on 4 Jan 2016 **To:** 09.00 on 5 Jan 2016

Table B.18: Specific Energy Consumption of Water Treatment Unit Processes in Ruhunupura Water Supply Scheme

Unit process	**Equipment**	**Energy Consumption**	**Specific Energy Consumption (kWh/ m^3)**	**Specific Energy Consumption of Unit Process ((kWh/ m^3)**
Raw water pumping	Intake Pumps	1010.55	0.1283	0.1283
Chemical Mixing	Alum mixer	0.13	0.00002	
	Feed water pump for mixer	0.13	0.00002	0.00003
Filtration	Back wash air blower	3.25	0.0004	
	Back wash pump	15.49	0.0020	0.0024
Chlorination	Chlorination booster pump	7.32	0.0009	0.0009
Distribution pumping	Highlift pump	5182.3	0.6577	0.6577

Audit Duration – Audit Duration- From: 07.00 on 7 Jan 2016 **To:** 07.00 on 8 Jan 2016

Table B.19: Specific Energy Consumption of Water Treatment Unit Processes in Hapugala Water Supply Scheme

Unit process	**Equipment**	**Energy Consumption (kWh)**	**Specific Energy Consumption (kWh)**	**Specific Energy Consumption of Unit Process ((kWh/ m^3)**
Raw water pumping	Intake pumps	1680.50	0.0946	0.0946
Chemical Mixing	PAC booster pumps	10.22	0.0006	
	Lime booster pumps	7.73	0.0004	
	Agitator	59.62	0.0034	0.0044
Slow mixing	Pulsator vacuum pumps	145.45	0.0082	0.0082
Filtration	Back wash air blower	4.83	0.0003	
	Back wash air compressor	0.56	0.0000	
	Back wash pumps	3.68	0.0002	0.0005
Chlorination	Chlorination booster pumps	61.15	0.0034	0.0034
Sludge treatment	Settling tank to sludge pit pumps	2.24	0.0001	
	Sludge pit to sludge thickener pump	3.91	0.0002	
	Settling tank to aerator pumps	9.84	0.0006	
	Sludge thickener to sludge lagoon pump	1.93	0.0001	0.0010
Distribution pumping	Pumps set 1	1544.3	0.0869	
	Pumps set 2	2718.3	0.1530	
	Pumps set 3	339.4	0.0191	
	Pumps set 4	2357	0.1327	
	Pumps set 5	1715.3	0.0965	0.4882

Audit Duration – From: 07.00 on 16 Jan 2016 **To:** 07.00 on 17 Jan 2016

Table B.20: Specific Energy Consumption of Water Treatment Unit Processes in Malimbada Water Supply Scheme

Unit process	**Equipment**	**Power consumption of equipment (kWh)**	**Specific Energy Consumption (kWh)**	**Specific Energy Consumption of Unit Process ((kWh/ m^3)**
Screening	Fine screen (10mm)	2.1	0.00006	
	Fine screen washing pumps	3.9	0.00011	0.0002
Raw water pumping	Raw water pumps	5257.6	0.14602	0.1460
Chemical feeding	PAC mixer	19.1	0.00053	
	Lime mixer	18.5	0.00051	
	PAC dosing	28.6	0.00079	
	Post lime booster pump	87.4	0.00243	
	Post lime dosing pump	41.3	0.00115	0.0054
Sedimentation	Sludge collector	22.2	0.00062	0.0006
Filtration	Back wash air blower	8.3	0.00023	
	Back wash pump	22.5	0.00063	0.0009
Disinfection	Chlorination Booster Pump	158.9	0.00441	0.0044
Distribution pumping	Pumps set 1	8297.2	0.23043	
	Pumps set 2	2184.0	0.06065	
	Pumps set 3	3622.2	0.10060	
	Pumps set 4	1517.2	0.04214	0.4338
Backwash recovery	Backwash recovery	55.1	0.00153	0.0015

Audit Duration – From: 09.00 on 19 Jan 2016 **To:** 09.00 on 20 Jan 2016

Table B.21: Specific Energy Consumption of Water Treatment Unit Processes in Tangalle Water Supply Scheme

Unit process	**Equipment**	**Energy Consumption (kWh)**	**Specific Energy Consumption (kWh/ m^3)**	**Specific Energy Consumption of Unit Process ((kWh/ m^3)**
Raw water pumping	Intake pumps	486	0.0465	0.1335
		561	0.0536	
		349	0.0334	
Chemical feeding	Alum mixer	28	0.0026	0.0026
Filtration	Back wash air blower	3	0.0003	0.0003
Distribution pumping	Pumping set 1	1402	0.1340	0.2776
		1068	0.1021	
	Pumping set 2	434	0.0415	

Table B.22: Specific Energy Consumption of Distribution Booster Pumping at Ruhunupura and Hapugala Water Supply Schemes

Month	Energy Consumption (kWh)	Monthly Production (m^3)	Specific Energy Consumption (kWh/m^3)
Ruhunupura Water Supply Scheme			
Jan-12	28596	226792	0.126
Feb-12	32166	202766	0.159
Mar-12	33379	222886	0.150
Apr-12	27353	214240	0.128
May-12	34630	248589	0.139
Jun-12	28107	216160	0.130
Jul-12	30431	221077	0.138
Aug-12	33587	240729	0.140
Sep-12	28310	237349	0.119
Oct-12	32288	229956	0.140
Nov-12	31811	215636	0.148
Dec-12	33616	220453	0.152
Average	**31190**	**224719**	**0.139**
Hapugala Water Supply Scheme			
Jan-12	86710	525515	0.165
Feb-12	91887	556892	0.165
Mar-12	92253	559107	0.165
Apr-12	98560	597335	0.165
May-12	98118	594652	0.165
Jun-12	104532	633527	0.165
Jul-12	94847	574828	0.165

Month	**Energy Consumption (kWh)**	**Monthly Production (m^3)**	**Specific Energy Consumption (kWh/m^3)**
Aug-12	98864	599175	0.165
Sep-12	94415	572215	0.165
Oct-12	102497	617000	0.166
Nov-12	98518	614163	0.160
Dec-12	98573	583828	0.169
Average	**96648**	**585686**	**0.165**

Table B.23: Specific Energy Consumption of Distribution Booster Pumping at Malimbada and Tangalle Water Supply Schemes

Month	**Energy Consumption (kWh)**	**Monthly Production (m^3)**	**Specific Energy Consumption (kWh/m^3)**
Malimbada Water Supply Scheme			
Jan-12	36926	1269873	0.029
Feb-12	32970	1205881	0.027
Mar-12	37521	1293815	0.029
Apr-12	35341	1253172	0.028
May-12	39610	1365878	0.029
Jun-12	37444	1291168	0.029
Jul-12	37954	1326022	0.029
Aug-12	37934	1308067	0.029
Sep-12	36483	1258029	0.029
Oct-12	37814	1329458	0.028
Nov-12	37958	1308884	0.029
Dec-12	34971	1205881	0.029
Average	**36910**	**1284677**	**0.029**

Month	**Energy Consumption (kWh)**	**Monthly Production (m^3)**	**Specific Energy Consumption (kWh/m^3)**
Tangalle Water Supply Scheme			
Jan-12	19671	308559	0.064
Feb-12	23274	335323	0.069
Mar-12	19561	343837	0.057
Apr-12	21308	324102	0.066
May-12	19911	350945	0.057
Jun-12	22786	308310	0.074
Jul-12	21016	309727	0.068
Aug-12	22759	315254	0.072
Sep-12	21204	302304	0.070
Oct-12	23541	311647	0.076
Nov-12	20148	308483	0.065
Dec-12	15594	298713	0.052
Average	**20898**	**318100**	**0.066**

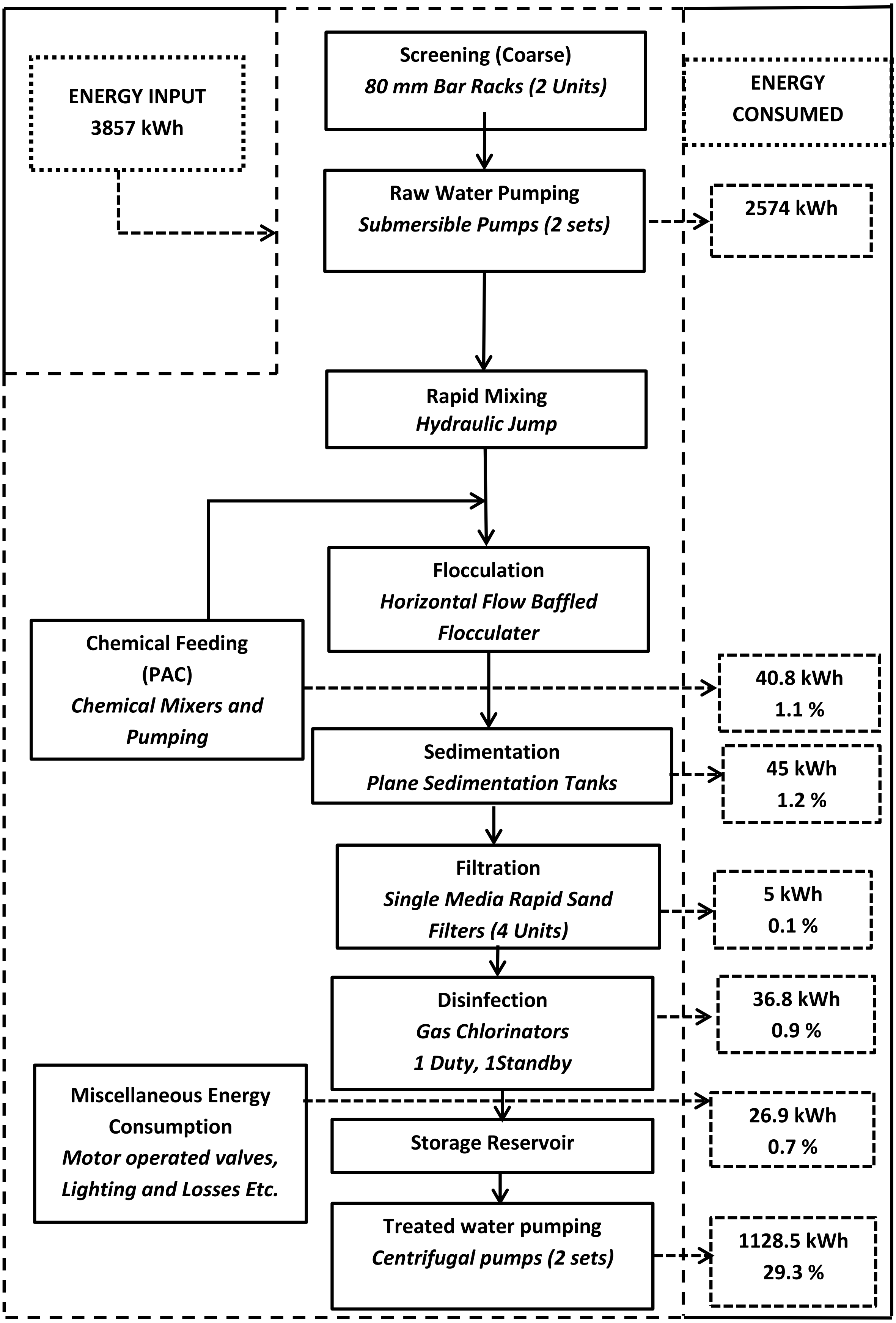


Figure B.1: Energy Balance Diagram of Hallala Water Supply Scheme

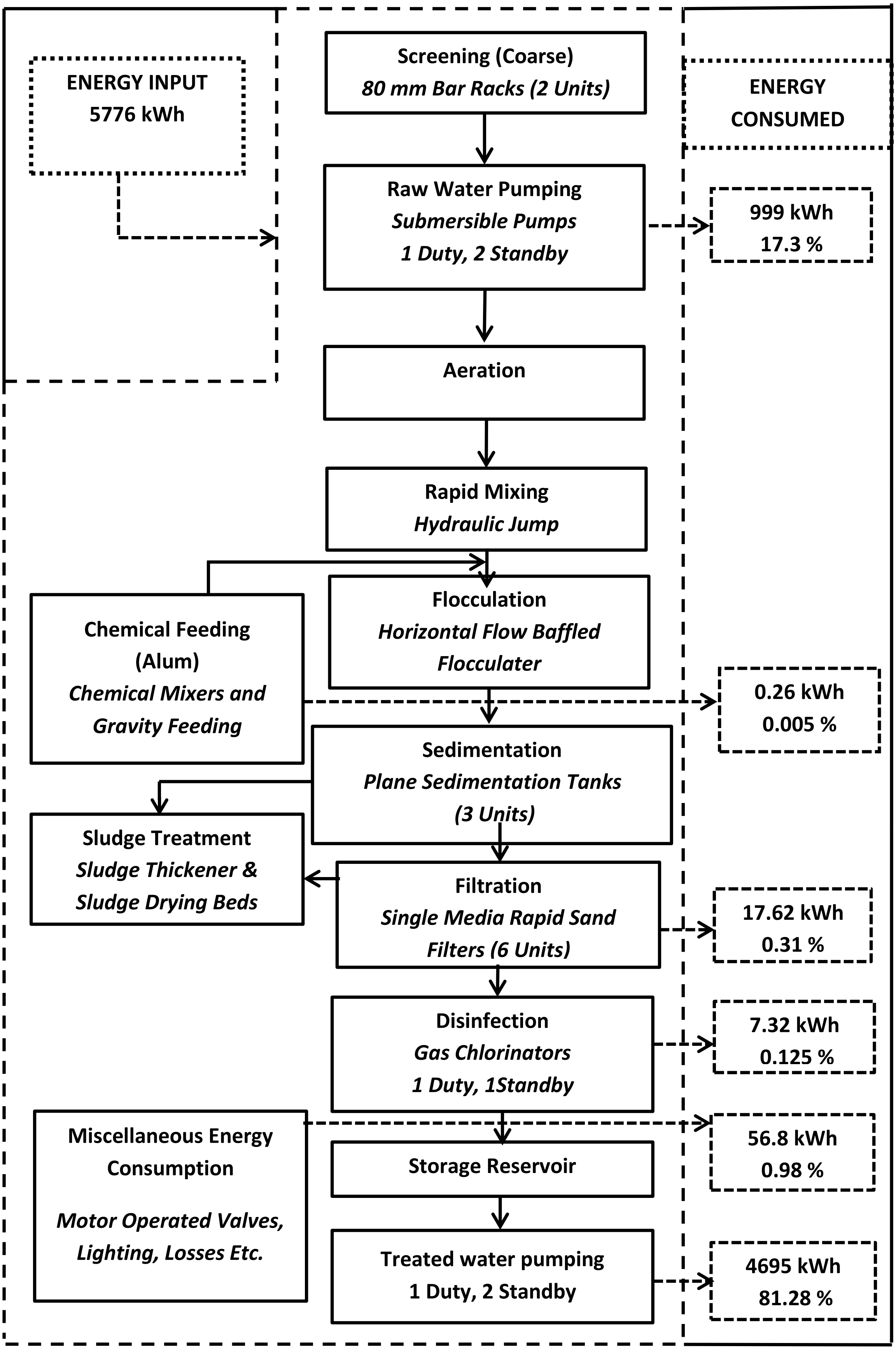


Figure B.2: Energy Balance Diagram of Ruhunupura Water Supply Scheme

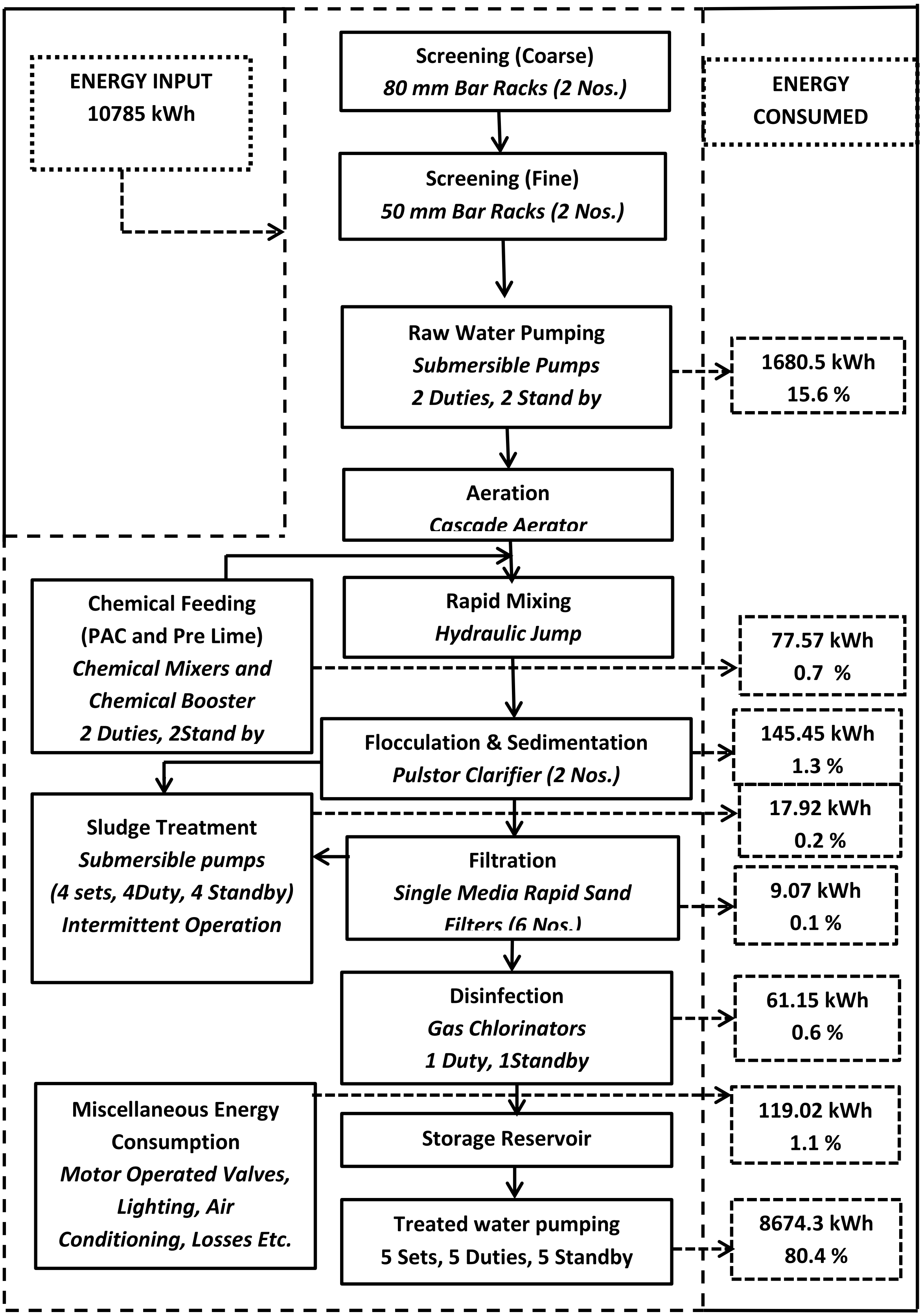


Figure B.3: Energy Balance Diagram of Hapugala Water Supply Scheme

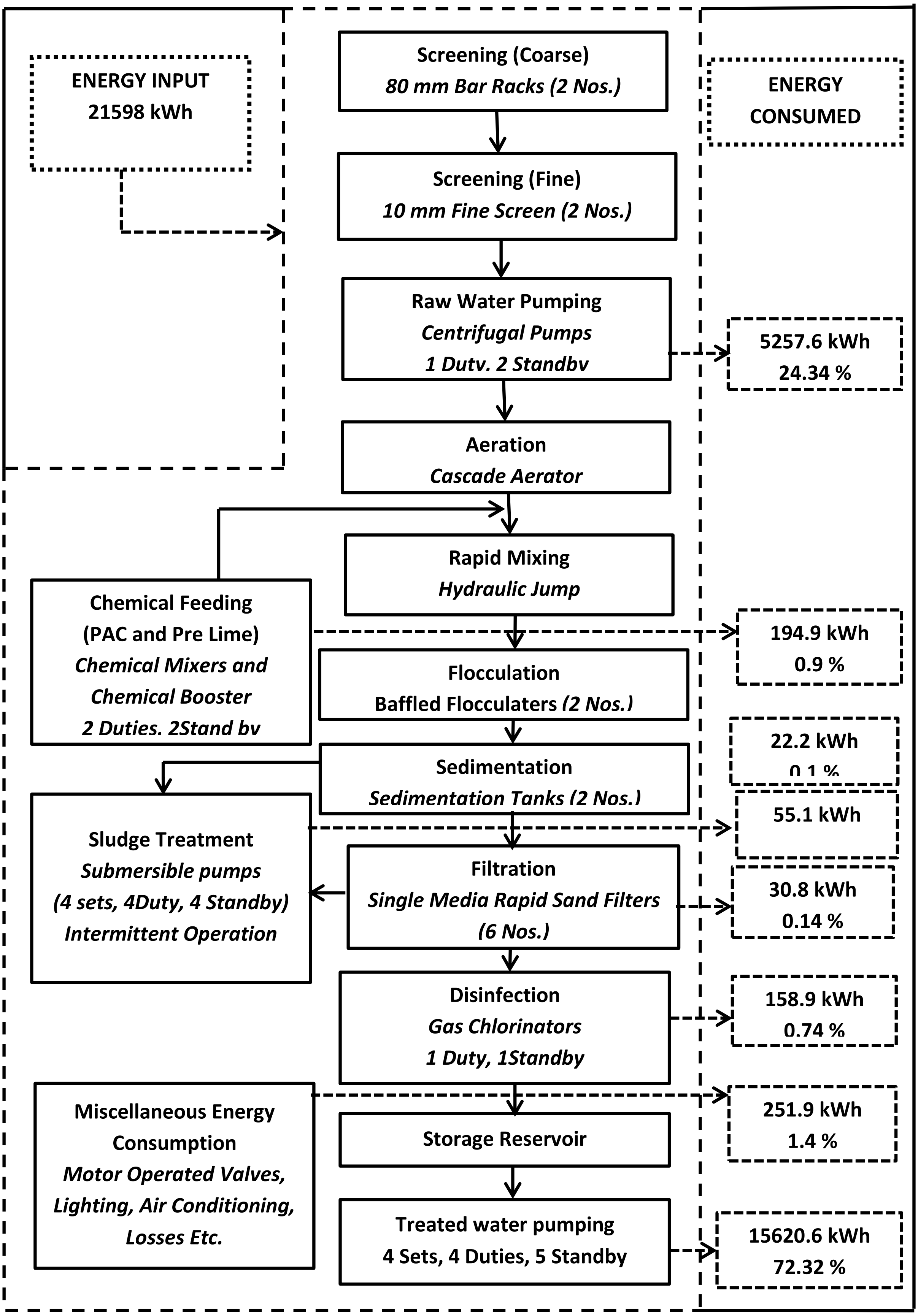


Figure B.4: Energy Balance Diagram of Malimbada Water Supply Scheme

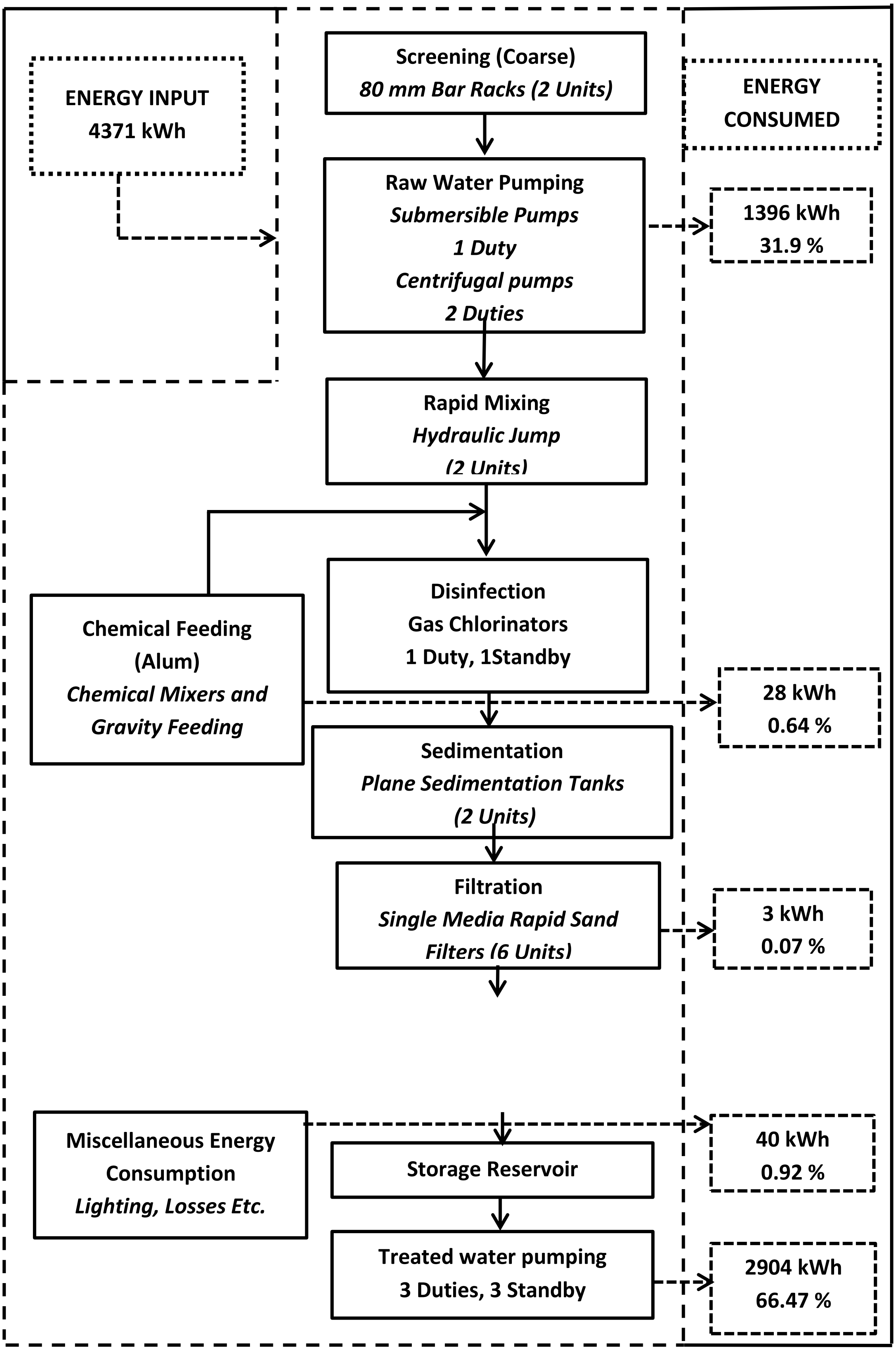


Figure B.5: Energy Balance Diagram of Tangalle Water Supply Scheme

Table B.24: Specific Energy Consumption of Distribution Pumping

Distribution Pumping Main	Energy Consumption (kWh)	Volume Pumped (m^3)	Elevation Difference (m)	Length* (km)	Specific Energy Consumption (kWh/m^3/m lift)	Specific Energy Consumption (kWh/m^3/m lift/km)
Hallala Water Supply Scheme : Duration - 9.00 A.M. (15/12/2013) - 9.00 A.M.(16/12 2012**)**						
Distribution 1	1074	9030	20	0.95	0.006	0.006
Distribution 2	55	625	20	0.95	0.004	0.005
Average					**0.005**	**0.005**
Ruhunupura Water Supply Scheme: Duration - 9.00 A.M. on 4 Jan 2013 - 9.00 A.M. on 5 Jan 2013						
Distribution 1	4695	8030	131	5.4	0.004	0.001
Distribution 2	476	520	128	3.2	0.006	0.002
Distribution 3	640	1596	80	2.8	0.005	0.002
Average					**0.005**	**0.001**
Hapugala Water Supply Scheme: Duration - 7.00 A.M. on 7 Jan 2013 - 7.00 A.M. on 8 Jan 2013						
Distribution 1	338	754	73.8	3.15	0.006	0.002
Distribution 2	1212	3218	75.8	3.99	0.005	0.001
Distribution 3	2266	5668	90	7.71	0.004	0.001
Distribution 4	1600	3000	107	3.12	0.005	0.002
Distribution 5	2658	5128	118.9	2	0.004	0.002
Distribution 6	1030	3180	78	4.2	0.005	0.001
Distribution 7	460	842	80	3.20	0.006	0.002
Distribution 8	1442	3878	88	3.00	0.005	0.002
Average					**0.005**	**0.002**

Note: BPH – Secondary booster pump house in the distribution

Table B.24: Specific Energy Consumption of Distribution Pumping (Continued)

Distribution Pumping Main	Energy Consumption (kWh)	Volume Pumped (m^3)	Elevation Difference (m)	Length (km)	Specific Energy Consumption ($kWh/m^3/m$ lift)	Specific Energy Consumption ($kWh/m^3/m$ lift/km)
Malimbada Water Supply Scheme: Duration -7.00 A.M. on 16 Jan 2013 - 7.00 A.M. on 17 Jan 2013						
Distribution 1	8297	15555	124	2.47	0.004	0.002
Distribution 2	2184	3257	92.5	2.26	0.007	0.003
Distribution 3	3622	12145	79.4	5.43	0.004	0.001
Distribution 4	1517	5050	49	1.83	0.006	0.003
Distribution 5	1044	1833	90	1.70	0.007	0.004
Average					**0.006**	**0.003**
Tangalle Water Supply Scheme: Duration - 9.00 A.M. on 19 Jan 2013 - 9.00 A.M. on 20 Jan 2013						
Distribution 1	1402	5280	53	1.3	0.005	0.004
Distribution 2	1406	4320	53	1.3	0.006	0.005
Distribution 3	434	864	90	4.5	0.006	0.001
Distribution 4	691	1315	80	2.8	0.007	0.002
Average					**0.006**	**0.003**

* The length was measured to normalize the energy consumption of pumping over the length of pumping main

Table B.25: Elevation Head and Length of Raw Water Pumping Mains

Description	**Water Supply Scheme**				
	Hallala	**Hapugala**	**Malimbada**	**Ruhunupura**	**Tangalle**
Raw water pumping mains					
Elevation head	35	18	34	27	18
Length	0.6	0.15	0.32	1.8	2.55

Table B.26: Summery of Energy Consumption for Audited Water Supply Schemes

Description	Energy consumption component			
	Raw water pumping	Treatment plant	Distribution pumping	
			Distribution pumping from WTP	Distribution booster Pumping
Hallala Water Supply Scheme				
Audit duration	9.00 A.M. on 15 Dec 2012 - 9.00 A.M. on 16 Dec 2012			
Production (m^3)	9655			
Energy consumption (kWh)	2574	127.6	1128.5	–
Total energy consumption (kWh)	3857			
Specific energy consumption (kWh/m^3)	0.267	0.013	0.117	
Specific energy consumption (kWh/m^3/m lift)	0.008	–	0.005	
Specific energy consumption (kWh/m^3/m lift/ km)	0.013	–	0.005	
Total specific energy consumption (kWh/m^3)	0.397			
% of total energy consumption	67.3	3.3	29.4	
Ruhunupura Water Supply Scheme				
Audit duration	9.00 A.M. on 4 Jan 2013 - 9.00 A.M. on 5 Jan 2013			
Production (m^3)	8030			
Energy consumption (kWh)	999	25.2	4695	1116
Total energy consumption (kWh)	6835			
Specific energy consumption (kWh/m^3)	0.124	0.003	0.724	
Specific energy consumption (kWh/m^3/m lift)	0.005	–	0.005	
Specific energy consumption (kWh/m^3/m lift/ km)	0.003	–	0.001	
Total specific energy consumption (kWh/m^3)	0.851			
% of total energy consumption	14.6	0.4	85.1	

Table B.26: Summery of Energy Consumption for Audited Water Supply Schemes (Continued)

Description	Energy consumption component			
	Raw water pumping	Treatment plant	Distribution pumping	
			Distribution pumping from WTP	Distribution booster Pumping
Hapugala Water Supply Scheme				
Audit duration	7.00 A.M. on 7 Jan 2013 - 7.00 A.M. on 8 Jan 2013			
Production (m^3)	17768			
Energy consumption (kWh)	1680.5	311.18	8674.3	2932
Total energy consumption (kWh)	13598			
Specific energy consumption (kWh/m^3)	0.095	0.018	0.653	
Specific energy consumption (kWh/m^3/m lift)	0.005	_	0.005	
Specific energy consumption (kWh/m^3/m lift/ km)	0.033	_	0.002	
Total specific energy consumption (kWh/m^3)	0.766			
% of total energy consumption	12.3	2.3	85.4	
Malimbada Water Supply Scheme				
Audit duration	7.00 A.M. on 16 Jan 2013 - 7.00 A.M. on 17 Jan 2013			
Production (m^3)	36007			
Energy consumption (kWh)	5257.6	467.9	15620.6	1044
Total energy consumption (kWh)	22390			
Specific energy consumption (kWh/m^3)	0.146	0.013	0.463	
Specific energy consumption (kWh/m^3/m lift)	0.004	_	0.006	
Specific energy consumption (kWh/m^3/m lift/ km)	0.013	_	0.003	
Total specific energy consumption (kWh/m^3)	0.622			
% of total energy consumption	23.5	2.1	74.4	

Table B.26: Summery of Energy Consumption for Audited Water Supply Schemes (Continued)

Description	**Energy consumption component**			
	Raw water pumping	**Treatment plant**	**Distribution Pumping**	
			Treated water pumping	**Distribution Pumping**
Tangalle Water Supply Scheme				
Audit duration	9.00 A.M. on 19 Jan 2013 - 9.00 A.M. on 20 Jan 2013			
Production (m^3)	10464			
Energy consumption (kWh)	1396	31	2904	691
Total energy consumption (kWh)	5022			
Specific energy consumption (kWh/m^3)	0.133	0.003	0.344	
Specific energy consumption (kWh/m^3/m lift)	0.007	_	0.006	
Specific energy consumption (kWh/m^3/m lift/ km)	0.003	_	0.003	
Total specific energy consumption (kWh/m^3)	0.48			
% of total energy consumption	27.8	0.6	71.6	

Appendix C

Detailed Audit Data and Calculations for Energy Conservation Potentials

Table C.1: Energy Saving Potential of Modifying Filter Backwash Frequency

Description	**Tangalle WSS**	**Ruhunupura WSS**
No. of operating hours of WTP per month (30 days)	720	720
No. of filter backwashing per month for 24h duration backwashing	30	30
No. of filter backwashing per month for 48h duration backwashing	15	15
Reduction in number of backwashing per month	15	15
Reduction in number of backwashing per month	45	66
Volume of water saved per month (m^3/month)	675	990
Specific energy consumption up to clear water sump (kWh/m^3)	0.136	0.127
Total energy saving per month (kWh)	92	126
Total energy saving per year (kWh)	1117	1530
Specific energy saving per unit volume of treated water (kWh/m^3)	0.0003	0.0004
Total specific energy consumption of WSS (kWh/m^3)	0.418	0.719
% Energy saving per unit volume of treated water	0.07	0.06

Table C.2: Energy Saving Potential of Modifying Filter Backwash Water Recovery

Description	**Water Supply Scheme**				
	Hallala	**Ruhunupura**	**Hapugala**	**Malimbada**	**Tangalle**
Time duration between filter backwash	48	24	48	48	24
Volume of backwash water (m^3/day)	130	195	225	450	135
Potential volume to recover (m^3/day)	117	175.5	202.5	405	121.5
Specific power consumption for backwash recovery (kWh/m^3)	0.067	0.067	0.051	0.067	0.067
Specific power consumption for raw water pumping (kWh/m^3)	0.267	0.124	0.095	0.146	0.133
Energy saving per day (kWh/day)	23.4	10	8.9	32	8
Energy saving per month (kWh/month)	702	300	267	960	241
Energy saving per year (kWh/year)	8541	3651	3252	11678	2927
Average treated water production per day (m^3/day)	9223	7388	19255	42236	10458
Specific energy saving per unit volume of recovered water (kWh/m^3)	0.2	0.057	0.044	0.079	0.066
Energy requirement for additional treatment (kWh/m^3)	0.15	0.15	0.15	0.15	0.15
Energy saving per unit volume of recovered water (kWh/m^3)	0.05	-	-	-	-
Energy saving per unit volume of treated water (kWh/m^3)	0.002	-	-	-	-
Total specific energy consumption (kWh/m^3)	0.399	-	-	-	--
% saving per unit volume of treated water	0.5	-	-	-	-

Table C.3: Overall Efficiency of Pump and Motor Systems in Audited Water Supply Schemes

Unit Process	**Pump**	**Measured Parameters**					**Water Power (kW)**	**Motor Power (kW)**	**Overall Efficiency of pump & motor system (%)**
		Voltage (V)	**Current (A)**	**Power Factor**	**Head (m)**	**Flow (m^3/h)**			
Hallala Water Supply Scheme : Audit Duration - 9.00 A.M. (15/12/2013) - 9.00 A.M.(16/12 2012**)**									
Raw water pumping	Raw water pump set 1	390	180	0.85	54	420	62	103	60
	Raw water pump set 2	390	82	0.85	43	220	26	47	55
Treated water pumping	Treated water pump set 1	390	87	0.85	24	420	27	50	55
	Treated water pump set 2	390	38	0.85	19.8	250	13	22	62
Ruhunupura Water Supply Scheme : Audit Duration - 9.00 A.M. (04/01/2013) -9.00 A.M.(05/01/2013)									
Raw water pumping	Intake pump set	400	78	0.85	28	375	29	46	63
Treated water pumping	Treated water pump set	400	400	0.85	163	365	162	234	69
Hapugala Water Supply Scheme : Audit Duration - 7.00 A.M. (07/01/2013) - 7.00 A.M.(08/01/2013)									
Raw water pumping	Intake Pumps	406	125	0.79	23	748	47	69	68
Treated water pumping	Pumping set 1	407	168	0.86	93	271	69	101	68
	Pumping set 2	400	245	0.87	128	285	99	147	68
	Pumping set 3	400	72	0.88	94	98	25	38	66
	Pumping set 4	405	278	0.83	100	405	110	161	69
	Pumping set 5	408	214	0.86	118	244	90	129	70

Table C.4: Overall Efficiency of Pump and Motor Systems in Audited Water Supply Schemes (Continued)

Unit Process	**Pump**	**Measured Parameters**					**Water Power (kW)**	**Motor Power (kW)**	**Overall Efficiency of pump & motor system (%)**
		Voltage (V)	**Current (A)**	**Power Factor**	**Head (m)**	**Flow (m^3/h)**			
Malimbada Water Supply Scheme : Audit Duration - 7.00 A.M. (16/01/2013) - 7.00 A.M.(17/01/2013)									
Raw water pumping	Raw water pumps	394	353	0.97	38	1590	165	232	71
Treated water pumping	Pumping set 1	394	620	0.97	127	780	280	408	69
	Pumping set 2	394	159	0.97	96	220	75	105	72
	Pumping set 3	394	342	0.97	91	650	161	225	72
	Pumping set 4	394	113	0.97	56	260	53	74	71
Tangalle Water Supply Scheme : Audit Duration - 09.00 (19/01/2016) - 07.00 (20/01/2016)									
Raw water pumping	Intake pump set 1	400	39	0.75	27	145	11	20	53
	Intake pump set 2	400	45	0.75	29	170	13	23	58
	Intake pump set 3	400	28	0.75	25	128	9	14	63
Treated water pumping	Pump set 1	414	84	0.97	55	220	33	58	62
	Pump set 2	414	64	0.97	64	180	31	55	57
	Pump set 3	414	26	0.97	90	36	9	18	53

Specimen Calculation for Raw water pump set 1 of Hallala WSS

From Equation 2.3 Water power $= \gamma\ Q\ h_p /1000$ = 9.81*1000*(420/3600)*54/1000 =61.80 kWh =62 kWh

From Equation 2.9 Motor power $= \sqrt{3}.\ V.\ I.\ \cos\emptyset$ = 1.732* 390*180*0.85/1000 =103.34 kWh =103 kWh

From Equation 2.4 Overall pump and motor efficiency = Water power / Motor power =62/103*100 = 60%

Table C.5: Percentage Energy Saving and Annual Energy Saving Potential of Improving Overall Efficiency of Pump and Motor Systems in Audited Water Supply Schemes

Unit Process	Pump	SEC of Pump & Motor System (kWh/m^3)	SEC of Pump & Motor System at 70% Efficiency (kWh/m^3)	Specific Energy Saving (kWh/m^3)	Total Specific Energy Saving (kWh/m^3)	Percentage Energy Saving (%)	Annual Energy Saving (kWh)
Hallala Water Supply Scheme : Audit Duration - 9.00 A.M. (15/12/2013) - 9.00 A.M.(16/12 2012**)**							
Raw water pumping	Raw water pump set 1	0.2569	0.2206	0.0363			
	Raw water pump set 2	0.0098	0.0077	0.0021			
Treated water pumping	Treated water pump set 1	0.1112	0.0878	0.0234			
	Treated water pump set 2	0.0056	0.0050	0.0006	0.0624	15.7	219894
Ruhunupura Water Supply Scheme : Audit Duration - 9.00 A.M. (04/01/2013) -9.00 A.M.(05/01/2013)							
Raw water pumping	Intake pump set	0.1283	0.1148	0.0135			
Treated water pumping	Treated water pump set	0.6577	0.6501	0.0076	0.0212	2.5	62054
Hapugala Water Supply Scheme : Audit Duration - 7.00 A.M. (07/01/2013) - 7.00 A.M.(08/01/2013)							
Raw water pumping	Intake Pumps	0.0946	0.0917	0.0029			
Treated water pumping	Pump set 1	0.0869	0.0841	0.0028			
	Pump set 2	0.153	0.1479	0.0051			
	Pump set 3	0.0191	0.0180	0.0011			
	Pump set 4	0.1327	0.1299	0.0028			
	Pump set 5	_	_	_	0.0146	1.9	94480

Table C.6: Percentage Energy Saving and Annual Energy Saving Potential of Improving Overall Efficiency of Pump and Motor Systems in Audited Water Supply Schemes (Continued)

Unit Process	Pump	SEC of Pump & Motor System (kWh/m^3)	SEC of Pump & Motor System at 70% Efficiency (kWh/m^3)	Specific Energy Saving (kWh/m^3)	Total Specific Energy Saving (kWh/m^3)	Percentage Energy Saving (%)	Annual Energy Saving (kWh)
Malimbada Water Supply Scheme : Audit Duration - 7.00 A.M. (16/01/2013) - 7.00 A.M.(17/01/2013)							
Raw water pumping	Raw water pumps	-	-	-	-	-	-
Treated water pumping	Pump set 1	0.2304	0.2258	0.0047			
	Pump set 2	-	-	-			
	Pump set 3	-	-	-			
	Pump set 4	-	-	-	0.0047	0.8	61327
Tangalle Water Supply Scheme : Audit Duration - 9.00 A.M. (19/01/2013) - 7.00 A.M.(20/01/2013)							
Raw water pumping	Intake pump set 1	0.0465	0.0352	0.0113			
	Intake pump set 2	0.0536	0.0442	0.0094			
	Intake pump set 3	0.0334	0.0287	0.0047			
Treated water pumping	pump set 1	0.134	0.1086	0.0254			
	pump set 2	0.1021	0.0832	0.0189			
	Pump set 3	0.0415	0.0291	0.0124	0.0820	17.1	313301

Table C.7: Reasons for Water Losses and the Average NRW of Audited Water Supply Schemes

NRW component	**Quantity (number)**			
	Ruhunupura WSS	**Hapugala WSS**	**Malimbada WSS**	**Tangalle WSS**
Physical losses				
Pipe breakdowns (major)	2	6	8	4
Pipe breakdowns (minor)	13	50	70	20
Reservoir overflow	Automatic reservoir level monitoring systems available (no overflows)			
Apparent losses				
Free water	All water services are measured and revenue generated			
Defective meters	426	756	2000	920
Illegal connections	50	90	150	100
Average production (m^3/day)	7388	19255	42236	10458
NRW (%)	35	26	26	33

Table C.8: Components of Non-Revenue Water in Audited Water Supply Schemes

NRW component	Volome of Non-Revenue Water (m^3/day)			
	Ruhunupura WSS	**Hapugala WSS**	**Malimbada WSS**	**Tangalle WSS**
Physical losses				
Pipe breakdowns	920	2200	3000	1200
Leakage House connection leakage	1376	2364	7011	1693
Reservoir overflows	0	0	0	0
Total Physical losses	2296	4564	10011	2893
Apparent losses				
Defective meters	170	302	800	368
Illegal connections	120	140	170	190
Free water	0	0	0	0
Total losses	2586	5006	10981	3451

Note: Link between Table C.5 and C.6

Minor leak (for 63-110 mm pipe diameters) : 40 m^3/minor leak

Major leak (for 150 mm and above pipe diameters) : 200 m^3/major leak

Defective meters : 0.4 m^3/day/defective meter

Illegal Connections : Commercial (10% of the suspected number) -0.5 m^3/day/connection

: Domestic (90% of the suspected number) -10 m^3/day/connection

Table C.9: Energy Conservation Potential of Reducing Physical Losses in Audited Water Supply Schemes

Description	Unit	Water Supply Scheme			
		Ruhunupura WSS	Hapugala WSS	Malimbada WSS	Tangalle WSS
Number of Connections (Nc)	Number	10647	25200	51800	18375
Lowest elevation (MSL)	m	116	477	437	196
Highest elevation (MSL)	m	250	640	570	300
Average operating pressure (P)	m	67	80	66	52
Economic Level of Leakage	L/connection/day	155	155	155	155
Economic Level of Leakage	m^3/day	1650	3906	8029	2848
Total physical losses	m^3/day	2296	4564	10011	2893
Possible reduction of physical losses	m^3/day	646	658	1982	45
Specific energy consumption of water supply	kwh/m^3	0.851	0.765	0.622	0.48
Energy conservation potential of reducing physical water losses	kWh/day	550	503	1233	22
Energy conservation potential of reducing physical water losses	kWh/Year	200750	183596	766962	8030
Average production per day	m^3/day	7388	19255	42236	10458
% of Economic Level of Leakage	%	22	20	19	27
% of physical losses	%	31	24	24	28
% Energy saving per unit volume of treated water	%	9	4	5	1

Table C.10: Energy Conservation Potential of Reducing Commercial Losses and Total Potential of Energy Conservation Through Reducing Non-Revenue Water in Audited Water Supply Schemes

Description	**Unit**	**Water Supply Scheme**			
		Ruhunupura WSS	**Hapugala WSS**	**Malimbada WSS**	**Tangalle WSS**
Possible reduction of losses by reducing defective meters down to 1%					
Number of defective meters at 1%	Number	106	252	518	184
Reduction of defective meters	Number	320	504	1452	736
Reduction of water losses by reducing defective meters	m^3/day	128	202	581	294
Possible reduction of losses by reducing illegal connections down to by 0.1%					
Number of illegal connections at 0.1%	Number	11	25	52	18
Reduction of illegal connections	Number	39	65	98	82
Reduction of water losses by reducing illegal connections	m^3/day	58	128	125	108
Total reduction of commercial losses					
% of commercial losses	%	3.9	2.3	2.3	5.3
Possible reduction of commercial losses	m^3/day	186	330	706	402
Specific energy consumption of water supply	kwh/m^3	0.851	0.765	0.622	0.480
Energy conservation potential of reducing commercial losses	kWh/day	158	252	439	193
	kWh/Year	57774	92033	160238	70500
% Energy saving per unit volume of treated water	%	2.5	1.7	1.7	3.8
Total energy conservation potential					
Total energy conservation potential of NRW reduction	kWh/Year	258524	275629	927200	78530
% Energy saving per unit volume of treated water	%	12	6	7	5

Table C.11: Active Power Consumption and Total Electricity Cost of Ruhunupura Water Supply Scheme

Month	**Active Power Consumption (kWh)**			**Total Cost (LKR x 10^6)**
	Peak	**Day**	**Off Peak**	
Ruhunupura Water Treatment Plant				
Jan-12	12,811	75,325	43,672	1.5
Feb-12	22,667	77,188	45,654	1.7
Mar-12	15,346	67,580	39,862	1.6
Apr-12	21,612	76,168	43,825	1.8
May-12	21,757	80,119	45,856	1.9
Jun-12	22,706	84,616	46,074	2
Jul-12	20,362	68,770	36,942	1.7
Aug-12	24,819	75,522	45,312	1.9
Sep-12	21,933	82,279	43,581	1.9
Oct-12	23,982	79,100	45,079	2
Nov-12	20,324	78,432	41,276	1.9
Dec-12	23,515	76,387	43,279	1.9
Average	**20,986**	**76,791**	**43,368**	**1.8**
Ruhunupura Intake Pump House				
Jan-12	2,445	10,461	5,991	0.2
Feb-12	4,343	16,198	9,042	0.3
Mar-12	3,626	14,862	8,540	0.4
Apr-12	4,191	15,691	8,811	0.4
May-12	4,698	16,827	9,375	0.4

Month	Active Power Consumption (kWh)			Total Cost (LKR x 10^6)
	Peak	Day	Off Peak	
Jun-12	6,376	21,356	11,865	0.5
Jul-12	3,522	10,534	5,517	0.3
Aug-12	5,442	15,985	9,653	0.4
Sep-12	5,920	20,416	10,776	0.5
Oct-12	4,477	13,699	7,827	0.4
Nov-12	4,436	15,814	8,641	0.4
Dec-12	5,191	15,768	8,988	0.4
Average	**4,556**	**15,634**	**8,752**	**0.4**

Table C.12: Active Power Consumption and Total Electricity Cost of Hapugala and Malimbada Water Supply Schemes

Month	**Active Power Consumption (kWh)**			**Total Cost (LKR x 10^6)**
	Peak	**Day**	**Off Peak**	
Hapugala Water Treatment Plant and Intake Pump House				
Jan-12	45,103	203,023	67,183	3.7
Feb-12	48,052	210,412	75,671	4
Mar-12	38,121	215,761	81,582	4
Apr-12	40,657	225,472	92,272	4.1
May-12	37,434	233,072	86,285	4.2
Jun-12	47,054	243,460	89,602	4.4
Jul-12	38,674	226,801	79,422	4.1
Aug-12	44,983	231,360	83,162	4.2
Sep-12	49,762	219,855	73,712	4.1
Oct-12	47,760	246,948	75,492	4.4
Nov-12	41,177	245,167	82,154	4.3
Dec-12	43,783	236,101	70,413	4.2
Average	**43,547**	**228,119**	**79,746**	**4.2**
Malimbada Water Treatment Plant				
Jan-12	30,005	286,310	76,390	6
Feb-12	31,657	275,980	78,780	5.9
Mar-12	32,550	264,886	80,830	5.9
Apr-12	35,919	291,090	88,100	6.4
May-12	32,442	290,270	87,850	6.3
Jun-12	33,455	296,160	90,620	6.6

Month	Active Power Consumption (kWh)			Total Cost (LKR x 10^6)
	Peak	Day	Off Peak	
Jul-12	31,578	287,700	79,810	6.2
Aug-12	33,217	298,750	79,390	6.3
Sep-12	31,470	269,980	91,820	6.1
Oct-12	33,083	202,030	83,430	5.3
Nov-12	32,945	293,720	76,750	6.2
Dec-12	31,554	280,770	65,730	5.8
Average	**32,490**	**278,137**	**81,625**	**6.1**
Malimbada Intake Pump House				
Jan-12	16,181	68,612	30,005	1.7
Feb-12	18,098	69,081	31,657	1.8
Mar-12	18,968	65,442	32,550	1.7
Apr-12	19,836	70,583	35,919	1.9
May-12	20,613	70,271	32,442	1.8
Jun-12	20,837	73,302	33,455	1.9
Jul-12	18,896	72,604	31,578	1.9
Aug-12	20,437	76,302	33,217	2
Sep-12	22,110	68,246	31,470	1.8
Oct-12	21,005	81,278	33,083	2
Nov-12	20,176	79,846	32,945	2
Dec-12	17,786	77,673	31,554	1.9
Average	**19,579**	**72,770**	**32,490**	**1.8**

Table C.13: Active Power Consumption and Total Electricity Cost of Tangalle Water Supply Scheme

Month	Active Power Consumption (kWh)			Total Cost
	Peak	Day	Off Peak	(LKR x 10^6)
Tangalle Water Treatment Plant				
Jan-12	15,297	53,144	25,779	1.1
Feb-12	17,101	56,075	27,563	1.2
Mar-12	17,437	55,055	28,903	1.3
Apr-12	17,299	55,295	29,531	1.4
May-12	17,988	55,786	30,185	1.4
Jun-12	18,757	59,899	32,584	2
Jul-12	17,657	54,140	29,428	1.3
Aug-12	19,716	58,474	33,999	1.5
Sep-12	21,908	63,099	37,263	1.6
Oct-12	18,605	58,372	32,445	1.5
Nov-12	15,762	52,623	28,244	1.3
Dec-12	17,358	52,759	26,702	1.3
Average	**17,907**	**56,227**	**30,219**	**1.4**
Tangalle Intake Pump House				
Jan-12	6,982	24,499	12,244	0.5
Feb-12	7,170	23,844	12,095	0.5
Mar-12	6,910	22,849	11,689	0.6
Apr-12	7,429	24,639	13,138	0.6

Month	**Active Power Consumption (kWh)**			**Total Cost**
	Peak	**Day**	**Off Peak**	**(LKR x 10^6)**
May-12	8,072	25,546	14,057	0.6
Jun-12	7,931	25,991	13,943	0.6
Jul-12	6,801	21,216	11,457	0.5
Aug-12	7,153	22,324	12,578	0.6
Sep-12	7,815	23,055	13,603	0.6
Oct-12	7,095	22,825	12,318	0.6
Nov-12	6,293	21,634	11,207	0.5
Dec-12	6,668	20,943	10,655	0.5
Average	**7,193**	**23,280**	**12,415**	**0.6**

Table C.14: Analysis of Potential Energy Saving From Shifting Consumption from Peak Time to Off Peak time of Electricity Tariff Structure

Component	**Peak**	**Day**	**Off Peak**	**Off Peak Spared Consumption (kWh)**	**No of Peak Hours compensated**	**Cost Saving (LKR/day)**	**Cost Saving (LKR/Year) x 10^6**	**Total Cost Saving (LKR/Year) x 10^6**
	Consumption per Hour (kWh/h)	**Consumption per Hour (kWh/h)**	**Consumption per Hour (kWh/h)**					
Ruhunupura Water Supply Scheme								
WTP	172	210	178	256	1.5	1600	0.58	
Intake	37	43	36	55	1.5	343	0.13	0.71
Hapugala Water Supply Scheme								
WTP & Intake	358	625	328	2,378	3	6711	2.45	2.45
Malimbada Water Supply Scheme								
WTP	267	762	335	3,413	3	5007	1.82	
Intake	161	199	134	527	3	3017	1.1	2.92
Tangalle Water Treatment Plant								
WTP	147	154	124	239	1.5	1380	0.5	
Intake	59	64	51	102	1.5	554	0.2	0.7

Table C.15: Analysis of Total Energy Conservation Potentials of Audited Water Supply Schemes

Description	**Hallala**	**Ruhunupura**	**Hapugala**	**Malimbada**	**Tangalle**
Average daily production (m^3/day)	9,223	7,388	19,255	42,236	10,458
Annual production (m^3/Year x 10^6)	3.4	2.7	7	15.4	3.8
Specific energy saving potential (kWh/m^3)	0.0687	0.1762	0.1072	0.1	0.16
Annual energy saving potential (kWh/Year x 10^6)	0.23	0.48	0.75	1.54	0.61
Average electricity charge including surcharges (LKR/ kWh)	-	11.44	11.44	11.44	11.44
Annual cost saving potential from reducing consumption (LKR/Year x10^6)	-	5.5	8.6	17.6	7
Annual cost saving potential from shifting consumption (LKR/Year x10^6)	-	0.7	2.4	2.9	0.7
Regional annual energy cost (LKR/Year x10^6)	-	91	94	201	91
% Cost saving from regional annual energy cost	-	7.9	11	10.2	8.5