CHAPTER **3-5**

The Study of the Management of Groundwater Resources in Sri Lanka

1. Background to the Study Area

1.1 Introduction

This investigation, "The Study of Management of Groundwater Resources in Sri Lanka," is part of the Sustainable Water Management Policy Project, a collaboration between the Institute for Global Environmental Strategies (IGES) in Hayama, Japan and the Department of Civil Engineering of the University of Peradeniya, in Peradeniya, Sri Lanka. The study mainly focuses on groundwater and its alternative water source management in two urban centers in Sri Lanka. In addition, the study briefly discusses groundwater use in agriculture and the impacts of the tsunami on the coastal groundwater reserve.

1.2 Study Area

The two main study areas selected for this analysis are the urban and suburban areas of Colombo and the urban and suburban areas of Kandy (figure 1). Groundwater use in agriculture is discussed through the agro-wells (wells that are used for agricultural purposes) in the northwestern regions, while the impact from the tsunami is discussed through the coastal groundwater resources (figure 1).

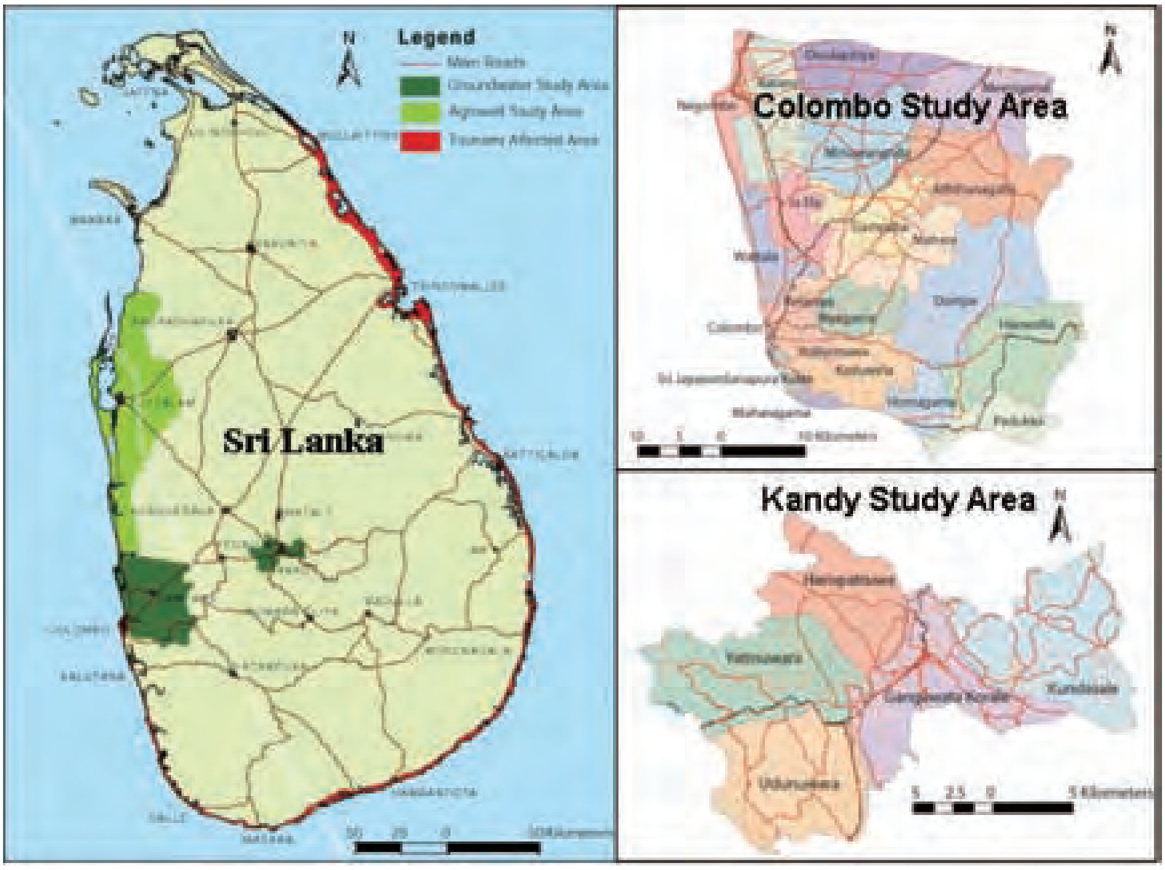


Figure 1. Case Study Areas

(1) Administrative Structure

Sri Lanka has nine provinces, each with its own local government. These provinces are further subdivided into a total of twenty four districts. These are again subdivided into divisional secretariat areas responsible for civil affairs, which in turn are further divided into the smallest administrative divisions, called "*Grama Niladari* Divisions," the village level. The Colombo study area (hereafter called ***Colombo***) includes twenty divisional secretariat divisions covering the **whole districts of Colombo and Gampaha,** while the Kandy study area (hereafter called ***Kandy***) is limited to only five divisional secretariat divisions covering **a portion of the Kandy district.**

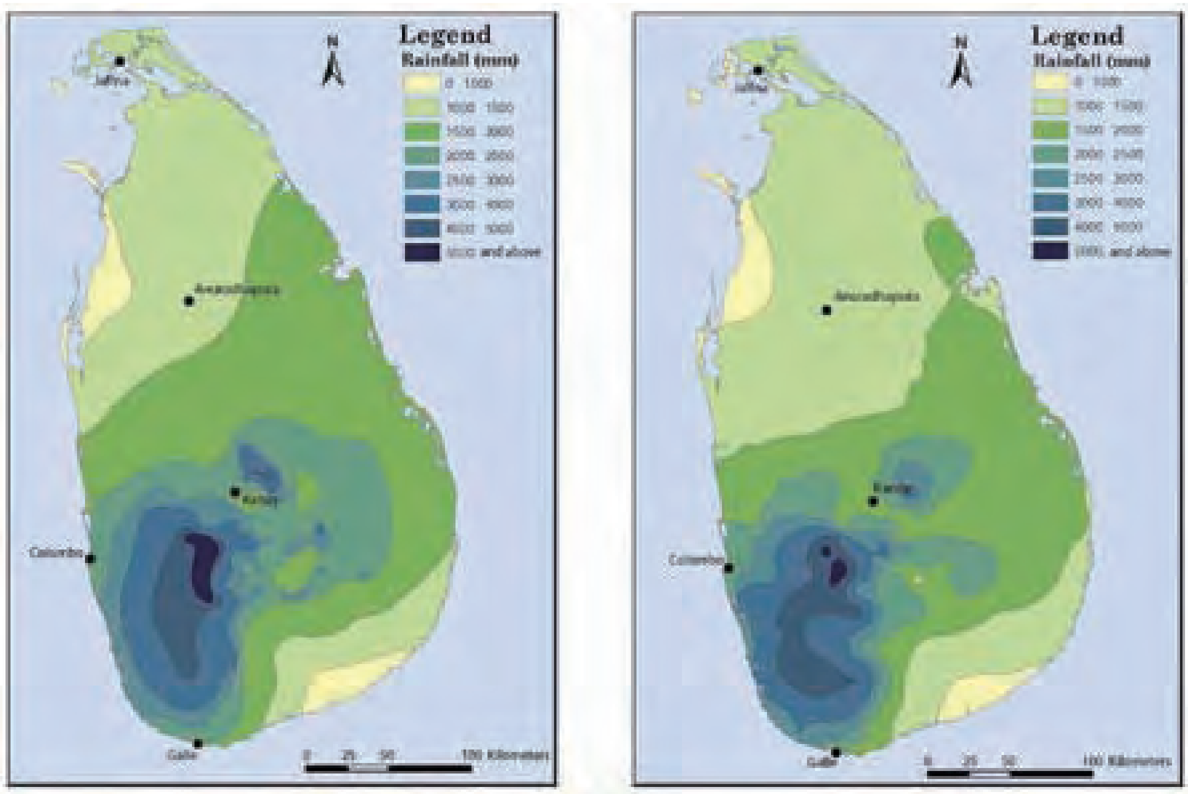
1.3 Topography and Climate

(1) Topography

Sri Lanka has a central mountainous region rising up to about 2,500 m above mean sea level, with the highest elevations covered by virgin forests and grasslands. The surrounding plains, which rise to about 50 to 100 m above sea level, are largely used for agriculture and homesteads, but still have virgin scrubland where the population distribution is lower.

Colombo: Colombo is located in the coastal plains of the western region of the country. The terrain in Colombo consists of gently undulating plains with a high density of drainage paths.

Kandy: Kandy is a plateau in the central mountainous region and lies 500 to 700 m above sea level. The terrain in the Kandy City area does not contain many steep, plunging slopes except in the surrounding mountains. The topography in this plateau consists of undulating plains with hillocks formed by the drainage paths.



1911-1961　　　　1961-1990

Figure 2. Rainfall Changes in Sri Lanka during the Period from 1911 to 1990

Source: Ratnayake and Hearth, 2005

(2) Climate

In terms of the amount and pattern of rainfall received, Sri Lanka can be divided into three different climatic zones. These zones are referred to as the wet zone (usually over 2,000 mm annual rainfall), the intermediate zone and the dry zone (below 1,500 mm rainfall). In general, rainfall in the island mainly occurs during the southwest and northeast monsoons and during the inter-monsoons. Both selected study areas are located in the wet zone, which receive average annual rainfall of about 1,900 mm. With the recent climatic changes happening, however, the average rainfall iso-lines from 1911 to 1940 compared with the average rainfall iso-lines from 1961 to 1990 show that the rainfall has significantly decreased all over the country (figure 2) and especially around Kandy (Ratnayake and Herath 2005). Further it is revealed that the lengths of the dry periods have increased all over the country and the lengths of wet periods have decreased. These changes in rainfall have directly affected groundwater by reducing the recharge time corresponding to the lengths of wet spells and increasing exploitation with increased use during dry spells.

1.4 Geology

Colombo: The geology of Colombo is representative of the geology of the western coast of Sri Lanka and has existed for much of the Quaternary era. Bore holes drilled in central Colombo City show that this area once formed an estuary of the Kelani River and the Kalu Ganga River, the two main rivers that drain into the sea on the western coast. A few kilometers upstream in the inland valleys, there is a high-level gravel formation consisting of quartz pebbles embedded in a matrix of laterite separated with pebble-free layers of laterite. The floodplains along the rivers consist mainly of alluvial deposits. The floodplains of Kelani River also provide thick alluvial profiles for unconfined aquifers, in addition to the productive overburden along tributary banks.

Kandy: The main geological feature of Kandy City and its surrounding area is a band of marble one kilometer thick. This band is classified as coarse crystalline mainly made up of calcite. Calcsilicate gneiss intruded as bands within the host marble including scapolite and spinel as additional minerals. Collectively these two rock types give rise to red-brown overburden latosolic soil that on average ranges in thickness from one to three meters. The major bedrock types available within the Kandy study area are summarized as percentages in figure 3 below. The main rock type identified is Biotite Gneiss, which cover almost half the area. Hornblende biotite gneiss, charnockitic gneiss, garnet biotite gneiss and granitic gneiss are also present in considerable percentages.

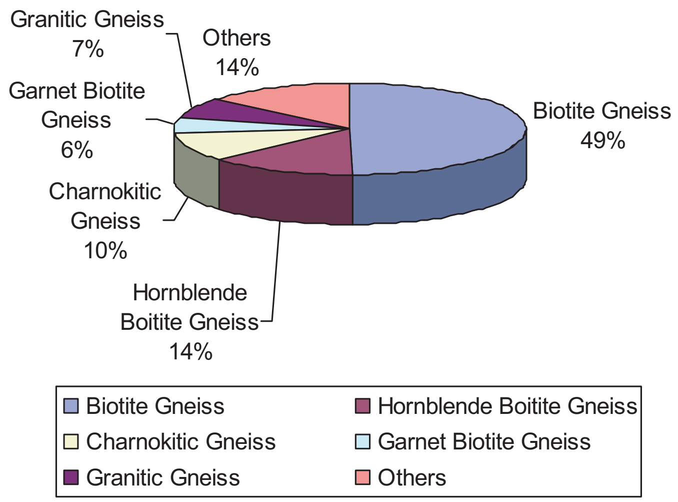


Figure 3. Geological Classification of Bed-Rock Types in Kandy Study Area

1.5 Socio Economic Conditions

Colombo: Regionally, Colombo and its suburbs accommodate the densest population in Sri Lanka. As of 2001 (last official count - Sri Lanka Data Sheet 2004 and Sri Lanka Department of Census and Statistics web page), the total population living in Colombo study area was placed at 4.3 million, with an average annual population growth rate of 1.7%

during the past 20 years. According to the Central Bank of Sri Lanka, the country's per capita GDP was at 473 USD in 1990, and had increased to 1,160 USD by 2005. Of this national GDP, the western province of which Colombo is the capital contributes almost one half (estimated at 48.1% in year 2002). Therefore Colombo, where most of the industrial, commercial and administrative activities taking place, plays a very important role with respect to the overall national economy.

Kandy: The population within the Kandy study area in 2001 was 0.81 million (Sri Lanka Data Sheet 2004 and Sri Lanka Department of Census and Statistics web page). Though Kandy is the second-largest city in the country, in comparison to Colombo its population is very small. The average population growth rate during the past 20 years in the Kandy region is estimated as 1.0%. This value is lower than the country average of 1.2%. As of 2002, the contribution to the national GDP from the Kandy district was only 9.4% (Central Bank of Sri Lanka web page).

1.6 Land Use

Colombo: The total land extent of the Colombo case study area is 1,575.6 km^2. Land use changes during the recent past in Colombo are tabulated in table 1 below. According to the data, the main land use change observed in the Colombo study area is the rapid increase in built-up land, which grew by 933% over the eleven years from 1987 to 1998. This built-up area replaced domestic gardens, water bodies and marshes (a typical domestic garden in Sri Lanka mainly consists of mixed vegetation that surrounds the house). There is also a significant decline in the extent of domestic gardens observed, mainly due to migration to commercial crops.

Kandy: The selected study area in Kandy is only 322 km^2. Compared to Colombo, major land use changes observed in Kandy were in forest cover, built-up area and domestic gardens. Forest cover increased over 100% during the eight years from 1988 to 1996. This increase replaces the domestic gardens and agricultural land. The change in built-up areas was only 48.2%.

However, in both these study areas, a significant reduction was observed with respect to the cropping intensity of paddies, which cover nearly 20% of the total land area. This change is not clearly reflected in the land use maps. Paddy cultivation in the last decade has dropped compared to the late 1970s, and this may substantially restrict the amount of irrigation water in the paddy fields, thereby reducing the sub-surface flow and recharge, which in turn influence the groundwater resources in the area.

Table 1. Land-Use Changes in Colombo

Land-Use Type	1987 (km^2)	1998 (km^2)	% change
Agricultural land	572.5	799.1	39.6
Built-up land	12.7	131.2	933.1
Forests	36.4	30.5	-16.2
Domestic gardens	848.1	560.9	-33.9
Water bodies	53	21.5	-59.4
Mangroves and marshes	52.9	32.4	-38.8

Source: Land use maps, Survey Department of Sri Lanka

Table 2. Land-Use Changes in Kandy

Land-Use Type	1988 (km^2)	1996 (km^2)	% change
Agricultural land	109.1	104.4	-4.3
Built-up land	5.6	8.3	48.2
Forests	22.1	46.5	110.4
Domestic gardens	175.6	149.9	-14.6
Water bodies	9.6	10.4	8.3
Mangroves and marshes	-	-	-

Source: Land use maps, Survey Department of Sri Lanka

2. State of Water Resources

According to the "Earth Trends" country profile on Sri Lanka (2003), the total renewable water resources available in the freshwater ecosystems of Sri Lanka are estimated at 49 km^3 as surface water, 8 km^3 as groundwater, and a further 7 km^3 as overlapping water. The wet zone, which receives over 1,900 mm rainfall annually on average, generates 49% of the total runoff for the entire country. Because of this runoff, the overburden in wet zone is kept moist, which allows considerable subsurface flow through macro pores. These subsurface flows are tapped using shallow wells throughout the study areas, providing water for the majority of the population.

In terms of river basins, the major part of the Colombo study area is located in the lower catchment of the Kelani River, while the entire Kandy study area is located in the middle catchment of the Mahaweli River basin. Therefore both these areas are rich in surface water resources.

2.1 Water Resource

(1) Groundwater Resource

There are six main type of groundwater aquifers demarcated and identified in Sri Lanka. They are shallow karstic aquifers, coastal sand aquifers, deep confined aquifers, lateritic (cabook) aquifers, alluvial aquifers and shallow regolith aquifers in the hard rock region. Figure 4 shows the distribution of these aquifers within the country (Panabokke and Perera 2005). In addition to these main aquifers, a large number of small groundwater pockets can be found throughout the country. These aquifers occur either in isolated patches of soil cover over the bedrock or in the fracture and weathered zones of the underlying metamorphic bedrock.

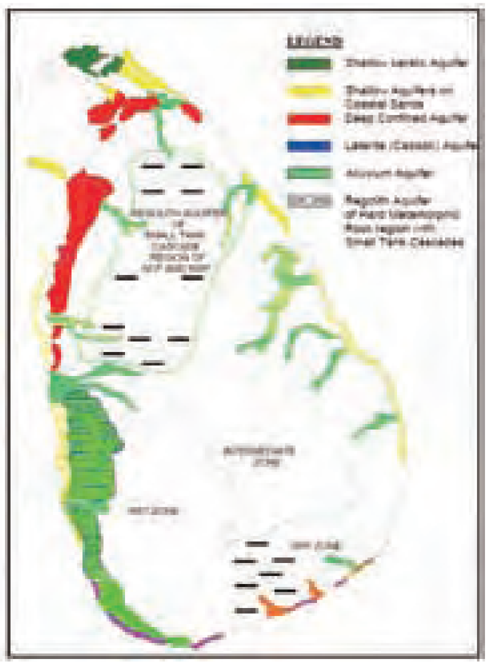


Figure 4. Distribution of the Major Aquifer Types in Sri Lanka

Source: Modified from Panabokke and Perera 2005

a. Groundwater Hydrogeology of study locations

Colombo: The basin hydrology indicates that there is a fair amount of groundwater potential both in the alluvial aquifers and bedrock. The prominent aquifer bedrock types in the basin are quartzite and a few crystalline limestone (marble) bands. The secondary porosity of these formations provides good conditions for deep aquifers. The alluvial sand/gravel aquifers in the basin are recharged by rainfall and seepage from the rivers. High-potential porous residual laterites also contribute to groundwater supplies. During droughts, river water and springs recharge most alluvial aquifers in the basin.

Kandy: Groundwater in Kandy exists mostly in the form of semi-confined aquifers in the first 100 m of the bedrock. This groundwater exits both as small pockets of underground reservoirs and as fissure groundwater. The yields of these aquifers are not very well known and are limited as they recharge very slowly. In addition, there exists high-yielding groundwater resources along the alluvial flood plains of Mahaweli River that are mostly recharged by the river water.

(2) Surface water resources

Since both study areas are located in the wet zone, they are blessed with plenty of rainfall and therefore surface water. However, when the total surface water availability of the areas is considered, depending on the location of demand centres and the location of water resources with respect to the demand centres, it is difficult to find suitable water resources for some demand centres in the study regions. Also, even though the available water resource is good, when one considers the total aggregate water availability, the variations over space and time from the historical perspective demand a proper management strategy.

Colombo: Kelani River, with the third largest watershed in the country, is the main surface water source for the Colombo region. Therefore, the Kelani River water is playing an important role with respect to the Island's overall economy, since it drains the most fertile lands in the wet zone and intercepts the most populated and economically important administrative district of Colombo the capital of Sri Lanka. In the Colombo study area, the principal use of water from the Kelani River is for water supply, including to the Greater Colombo area at Ambatale. The Kelani River

Figure 5. River Basins in Sri Lanka and within Study Areas
Source: Sri Lanka National Water Development Report 2006

is 144 km long and drains an area of 2,292 km^2 originating at levels above 1,500 m on the steep slopes of the western rim of the central highlands. In their descent the main river and its numerous tributaries travel through deep, structurally controlled valleys, generally oriented in many directions at higher and lower elevations. The main river eventually empties into the Indian Ocean on the west coast of Sri Lanka just few kilometers north of Colombo. The Kelani catchment receives an average annual precipitation of 3,718 mm generating a surface runoff volume of about 8,600 million m^3 of which nearly 65% discharges into the Indian Ocean. In addition to the Kelani River, Attanagalu Oya, a non-perennial stream, also flows through the study area but has limited significance with respect to supplying water to the Colombo study area.

Kandy: In addition to rainfall runoff, the only other major surface water source available within the Kandy study area is the Mahaweli River. The Mahaweli River is the longest river in Sri Lanka; originating in the highlands and running in the northeasterly direction through Kandy to Trincomalee to the ocean and draining an area of around 10,300 km^2, nearly 16% of the total land area of the island. As this perennial river flows through the study area, a considerable amount of surface water is available in the study area throughout the year. Furthermore, the tributaries Maha Oya, Pinga Oya, and the Nanu Oya of the Mahaweli River have the potential to supply substantial amounts of water during the rainy seasons to the Kandy study area. However, as the major portion of the Mahaweli River flow through Kandy is regulated at Polgolla and diverted for hydropower and for agriculture towards large irrigation networks in dry zones of Sri Lanka, satisfying these demands together with the Kandy water requirements in the future is of some concern.

2.2 Water Usage Practices

(1) Groundwater

The demand for water in Sri Lanka is steadily increasing, particularly for urban/rural water supplies, irrigated agriculture and in the industrial sector. This rapid increase in demand is exerting considerable pressure on the available groundwater resources. According to the WHO/UNICEF report on "Joint Monitoring Program for Water Supply and Sanitation-2000," only 76.1% of the urban population was supplied with a piped supply compared to 11.4% in rural areas, while the urban and rural populations using underground well-water were estimated at 22.4% and 71.8% respectively (that urban and rural populations in 1999 were 5.86 and 13.05 millions respectively). Also, in recent times use of groundwater is on an increasing trend because of high piped water tariffs and restricted hours for water supply. These two issues have forced the industrial and commercial users and some individual domestic users around the country who are already supplied with piped water to have a supplementary groundwater supply to reduce costs and to ensure a margin of safety in their supply. Of these, most industries today rely heavily on deep wells because groundwater is free, safe, of good quality, and able to be autonomously managed. Presently, there are around 30,000 deep groundwater wells throughout the country registered with the Water Resources Board (WRB). However, this figure does not take into account all groundwater wells in Sri Lanka because wells constructed/developed by the National Water Supply and the Drainage Board (NWS&DB), private drilling organizations and overseas projects have not been included in this registration.

With respect to piped water supply, presently there are 93 urban and rural water supply schemes operating across the country that rely purely on groundwater, accounting for 31% of the total supply. The total amount of annual groundwater abstraction from these 93 schemes is estimated to exceed 16 million m^3. A summary of the groundwater use within the two study areas is tabulated in table 3.

Table 3. Groundwater Use in the Study Areas

	Colombo		Kandy
	Colombo district	Gampaha districts	
Ground water for piped supply (m^3/day)	0	5,859	8,567
Groundwater use (individual) (m^3/day)	78,000	156,000	41,000
Population relying on groundwater (%)	34.8	75.4	52.0*
Registered deep borehole well number	342	890	1,754*

*Note; * district values*

Colombo: At present there are no water supply schemes relying on groundwater in the Colombo district. However, the amount of groundwater used in piped water supply schemes in the Gampaha district in the Colombo study area is 5,859 m^3/day (10% of total supply in Gampaha - Panabokke and Perera 2005). As shown in table 3, the total numbers of registered deep groundwater abstraction wells in the Colombo and Gampaha districts are only 342 and 890 respectively making a total of 1,232. In comparison to other cities in the Asian region, this number is very small, but the population relying on shallow groundwater within these two districts is estimated as 34.8% and 75.4% respectively. These high percentages are mainly due to poor pipe water coverage. Individual domestic use in the Colombo study area is estimated to be consuming approximately 85 million cubic meters of groundwater annually. Here, as there is no system of recording the groundwater use, only estimations can be made. Further, it should be noted that this estimation excludes groundwater use by houses that already have a pipe water connection and use groundwater as a supplementary source. Since the percentage of domestic consumers with a piped water supply and using groundwater as a supplementary source, especially in peri-urban areas, is believed to be high and also increasing, the above estimations may be lower than the actual groundwater use.

Kandy: The amount of groundwater use by the piped water supply schemes within the Kandy region is estimated at 8,567 m^3/day (around 12% of the total piped water supply). As shown in table 3, the total numbers of recorded deep groundwater abstraction wells in the Kandy district is 1,754, a much higher value than in the Colombo region. Further, the percentage of the population relying on groundwater in the district is almost 52% and individual domestic groundwater consumers are estimated to be using approximately 15 million m^3 annually.

(2) Surface water

Colombo: In total there are 10 major surface water supply schemes operating within the Colombo study area using surface water. The annual supply from these schemes in 2001 is estimated as 286 million m^3. Except for a small volume taken from the Labugama and Kalatuwawa tanks, all remaining surface water requirements are extracted from the Kelani River. However, as the Colombo water supply intake at Ambatale is only 16 km upstream from the ocean confluence, less than 15 m above mean sea level, it is estimated that unless a salinity barrier across the river is constructed, a minimum of a 33 m^3/s flow is necessary at Ambatale to prevent saltwater intrusion into water intake (Kelani Ganga Basin – 1999). However, our study analyzing the recent salinity problems at Ambatale estimates that a minimum flow of 30 m^3/s is required for salinity control. Additionally there are several other schemes upstream of Colombo that rely on Kelani water for their water supplies.

A summary of potable water use in the 2000-2001 period is given in table 4 below. As given in the table, the non-revenue water (NRW) component is nearly 35-40 % of the total water supply, making it a significant component in both the study areas. These percentages are very high compared to NRW values of the other countries in the region.

Table 4. Domestic and Industrial Water Use within the study areas

	Surface water (m^3/day)		Groundwater (m^3/day)			NRW (m^3/day)
			Deep	Shallow		
	Domestic	Industrial	Domestic	Industrial	Domestic	
Colombo (2001)	380,248	158,445	11,151	6,970	234,000	243,956
Kandy (2000)	36,679	5,972	5,546	804	41,000	22,928

Kandy: In Kandy there are only 7 major surface water supply schemes operating within the study area. These schemes distribute over 25 million m^3/year of water (2001). This entire surface water demand is extracted either from the Mahaweli main river or from its tributaries. Additionally in November 2006, the pipe water distribution to Kandy was further increased by another 19 million m^3/year. This was mainly to upgrade the existing supply in the region and to replace some of the existing problem-prone groundwater supply schemes. With this addition, the current surface water extraction from Mahaweli has increased to 44 million m^3/year. Further, even though the total irrigation requirement in the Kandy district is only 1.6m^3/s (but within the study area is only 0.4 m^3/s), a large amount of surface water from Mahaweli River is diverted at Polgolla to northern parts of Sri Lanka for irrigation purposes. The minimum diversion requirement at Polgolla is estimated at 14 m^3/s in February and March, and the maximum at 36 m^3/s in June. Also, in addition to these requirements, a further 4.2 m^3/s flow is required as environmental flow to satisfy the downstream requirements below the Kandy study area.

2.3 Resource Availability

(1) Groundwater

Colombo: Although there have not been many studies done, in a study under the "Kelani Ganga Basin Study – 1999," the sustainable aquifer yields within different hydrogeological settings of Colombo study area, especially in the Kelani basin have been forecast by the Danish Hydraulic Institute. The estimated yields during this study are shown in table 3 below.

Kandy: In contrast to Colombo, there have been few attempts in Kandy to estimate the groundwater potential in the region. During the 1980-1984 period, one such study was done with foreign assistance through aerial photos and *Landsat*-maps, geological and geophysical studies, topographical map studies, investigational drilling, pump testing, etc. Furthermore, in 1988 another similar investigation has been done in Kandy to determine the suitability of geophysical investigation methods for assessing the aquifer yields in the region. However, the conclusion of both these studies was that none of the methods used were suitable for local conditions in Kandy.

Since there were no reliable estimations for aquifer yields available, an attempt was made during this study to find out the aquifer behavior in three of the divisional secretariat (DS) areas of the Kandy study area, the Harispattuwa, Kundasale and Udunuwara, with the help of available information. In this analysis the borehole logs were studied for construction yield with the yield variation by rock type on which the well was constructed. The obtained comparative results are shown in Table 4 and Table 5 for the borehole yields and borehole success rates respectively. According to this comparison, it was observed that most of the analyzed wells had yields of less than 100 l/min; in fact 81% were less than 100 l/min, 16% between 100-1000 l/min, and only 3% greater than 1000 l/min.

Table 5. Estimations for Annual Sustainable Yields

Aquifer Type	Estimated yields ($\times 10^6$ $m^3/km^2/year$)
Gravel/Pebble	0.91
Vesicular laterite	0.73
Karstic Crystalline Limestone	0.66
Quartzites	0.73
Fractured bedrock	0.55
Clayish sands	0.37

Source: Kelani Ganga Basin Study – 1999

Table 6. Borehole Yield

Yield (l/min)	Udunuwara (%)	Kundasale (%)	Harispattuwa (%)
0-100	80	83.33	46.67
100-1000	18.3	13.6	33.33
>1000	1.7	2.7	20

Source: National Water Supply and Drainage Board, Kandy

Table 7. Borehole Yield and Success with Rock Type

Rock type	No.	Yield (m^3/day)	Success (%)
Biotite Gneiss	135	248	52
Hornblende Biotite Gneiss	37	482	76
Charnockitic Gneiss	28	716	50
Garnet Biotite Gneiss	15	69	53
Granitic Gneiss	19	206	42
Biotite Gneiss with Calcite	4	156	25
Calcite Gneiss	4	122	50
Marble	8	747	37
Charnockite	3	29	33
Charnockitic Biotite Gneiss	5	148	80
Quartz Feldspathic Gneiss	5	-	00

Further the results in table 7 shows that failure rates in construction in Udunuwara and Kundasale DS divisions are over 50%, but comparatively less in Harispattuwa DS division. As shown in figure 3 previously, the main bedrock type in the Kandy study area is biotite gneiss (49%). However, hornblende biotite gneiss, charnockitic gneiss, garnet biotite gneiss and granitic gneiss are present in reasonable percentages as well. Comparing the borehole efficiency (high efficiency means both high yield and high success rates) with bedrock geology, boreholes in hornblende biotite gneiss and in charnockitic biotite gneiss formations give good groundwater. Conversely, poor efficiency is observed in areas with biotite gneiss, charnockitic gneiss, garnet biotite gneiss, granitic gneiss, charnnockite, and marble rock formations. These formations cover over 73% of the total study area in Kandy. Therefore, the ground water potential in the hard rock formations around the Kandy region is highly questionable. Since there is no continuous monitoring data available, substantiating this claim with actual data was not possible.

(2) Surface Water

Colombo: The Kelani River is the major surface water source used in the Colombo. As discussed earlier, the existing water intake to Colombo is located at Ambatale, only 16 km upstream of the ocean outfall. Therefore the Kelani stream flow was investigated just upstream of Ambatale at Hanwella, analyzing the river discharges from 1973 to 2004. The finding from this analysis is summarized in table 8 below. According to this analysis, a minimum average river discharge of 68 million m^3 was observed in February and a maximum of 373 million m^3 in the month of June at Hanwella.

Table 8. Available Surface Water in Study Areas

Monthly Average Flow (million m^3)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mahaweli at Peradeniya	89	47	47	71	129	224	299	224	187	217	234	158
Kelani at Hanwella	94	68	98	162	286	373	275	211	233	345	297	156

Source: Deparment of Irrigation, Sri Lanka

Kandy: The Mahaweli River is the major surface water source for the Kandy study area. Although there are several tributary streams flowing into the main river from Peradeniya to Polgolla, the cumulative discharge from those streams is substantially lower (less than five percent) than the main river. Similar to the Kelani River, an analysis for Mahaweli River flow discharges at Peradeniya Gauging Station between 1964 and 1993 show the highest average monthly discharge of 299 million m^3 in July and lowest of 47 million m^3 in February (table 8).

(3) Rainfall

Colombo: Though a fair amount of rainfall is on record for both the study areas, their seasonal distribution is closely associated with the monsoon pattern. According to historical data, the 40 year average annual rainfall in Colombo is 2,376 mm. Further, the maximum and minimum monthly average rainfall observed in Colombo during this period was 360 mm in May and 78 mm in February respectively.

Kandy: Similarly the 60 year annual average rainfall in the Kandy study area is 1,841 mm. In addition, the maximum and minimum monthly average rainfall observed in Kandy during this period were 278 mm in November and 68 mm in April respectively. Further, a closer look at the rainfall variations in Kandy shows that the annual rainfalls are following a decreasing trend, as shown in figure 6. This trend raises many uncertainties over the future of surface water.

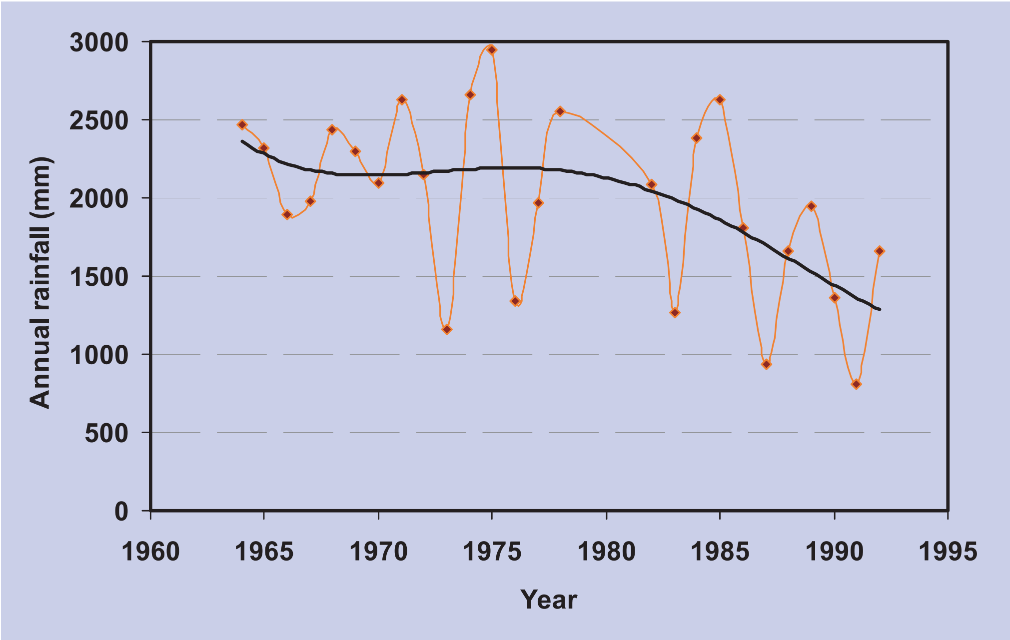


Figure 6. Annual Rainfall Variations in the Kandy Region
Source: Metereological Department of Sri Lanka

Groundwater user trends in Agriculture: As a result of the many subsidy programs intended to diversify agricultural activities, and because of the changes in the rainfall patterns, groundwater use, both as a supplementary source and as a means of cultivating short-term crops during the dry season, has recently become very popular among many farmers in the dry zone of Sri Lanka. For these abstractions, farmers most commonly use either tube-wells (boreholes) or dug wells. Dug wells are fairly large in diameter (4 to 6.5 m), are usually manually excavated, are shallow (4.5 to 12 m), and may or may not be equipped with a motorized pump. These wells, when used for agricultural purposes, are commonly known as agro-wells in the country. With the Government- and NGO-assisted subsidy schemes, the growth in agro-wells is progressing at a rapid pace. At the end of 2000, the total number of agro-wells stood at 50,456, while in 1985, there were only 500 (Kikuchi et al. 2001). This rapid, haphazard expansion of agro-wells without appropriate assessment of factors such as the hydrogeological environment is expected to create many problems. As farmers are used to abstracting groundwater at rates typically ranging between 27 m^3/hour and 45 m^3/hour (Premaratne and Liyanapatabendi, 1994), these high pumping rates are believed to be the most likely potential cause of conflicts because of overexploitation of the groundwater resources either on a local or regional scale.

2.4 Piped Water Coverage

(1) Present Supply Coverage

The present (2005) safe drinking water coverage of the country is estimated at 69%. The Government of Sri Lanka expects to increase its investment in water supply to achieve a safe water coverage target of 87% by the year 2015 and nearly 100% coverage in 2025. A number of new projects have been launched with local and foreign funding to achieve this target. Total pipe water production in Sri Lanka in the year 2005 was estimated as 383 million m^3. In Sri Lanka, access to safe drinking water is interpreted as having a source or water supply satisfying the Sri Lankan standards for drinking water, which are more stringent than the WHO standards. Therefore "safe drinking water" in this section implies that the water is within the minimum required standards for drinking.Poor monitoring, however, especially in community wells and individual groundwater extractions, raises many doubts on the actual safety of this water.

Colombo: According to National Water Supply and Drainage Board (NWS&DB) information, figure 7 below shows the percentage of people using different water sources for their drinking water needs within the two study areas. The Sri Lankan Government established NWS&DB in 1974 for providing safe drinking water to the population. According to these data, 62% of the population in Colombo study area is served with piped water and of the rest, 36% use protected groundwater and the other 4% unsafe water sources, such as streams and unprotected wells.

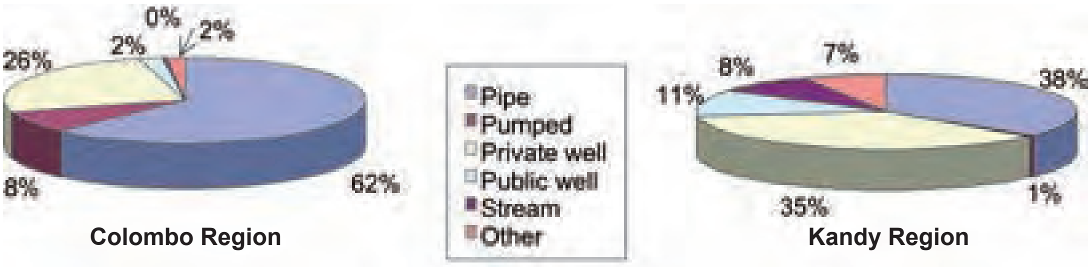


Figure 7. Sources for Drinking Water in the Study Areas in the Year 2000 (NWS&DB data)
Source: Statistical Abstract 2005, Department of Census, Sri Lanka

Kandy: As shown in Figure 7, only 38% of the population in the Kandy study area is served with piped water, and of the rest 47% use groundwater and 15% others unsafe water sources, such as streams and unprotected wells.

(2) Future Water Supply Demands

Colombo: At present in Colombo, the surface water is mainly used for drinking/recreational purposes. Using the population growth trends in the past, industrialization trends and the NWS&DB 1991 Master-Plan documents, future water demand for various sectors within the Colombo study area was estimated. The obtained water demands are shown in Table 8a below. According to this estimate, even in the year 2020, the major water requirement will be for satisfying the domestic demand. The forecasted industrial demand in 2020 will only be around 40% of the 2020 domestic demand.

Table 9. Water Supply Requirements in Colombo according to Sector and Source

Usage (m^3/day)	2001		2010		2020	
	Surface	Ground	Surface	Ground	Surface	Ground
Domestic supply	380,248	105,621	441,971	115,328	506,325	118,684
Industrial supply	158,445	6,970	181,508	7,129	198,898	9,465
Other	33,280	976	46,098	1,810	58,913	2,803
NRW	243,956		206,138		200,051	

Kandy: Surface water in the Kandy study area too is mainly used for a) drinking/recreational purposes, b) diversion/transfer requirement at Polgolla for hydropower generation and irrigation and c) to maintain minimum flow requirement in the downstream. With the population in the Kandy study area expected to reach 1.04 million by the year 2025, the

Table 10. Water Supply Requirement in Kandy According to Sectors and Sources

Usage (m^3/d)	2000		2015		2025	
	Surface	Ground	Surface	Ground	Surface	Ground
Domestic supply	36,679	31,300	61,029	98,415	86,336	107,207
Industrial supply	5,972	804	15,157	1,684	16,690	1,451
NRW	22,928		28,068		18,141	

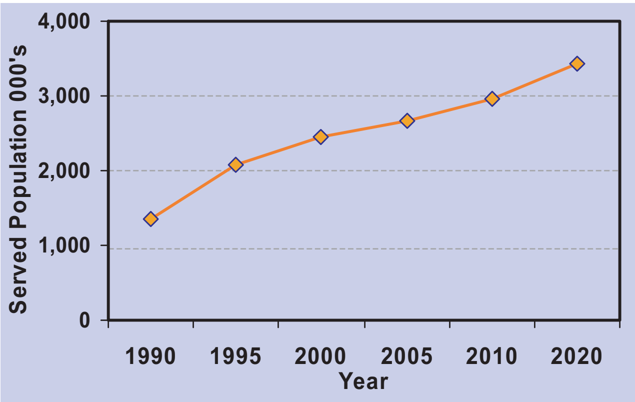
estimated future potable water demand in Kandy is tabulated in table 10 below. In addition to these requirements, the Kandy Water Supply Master Plan document proposes diverting surface water from Mahaweli River to the adjoining Kurunegala District for drinking purposes.

(3) Future Water Supply Developments

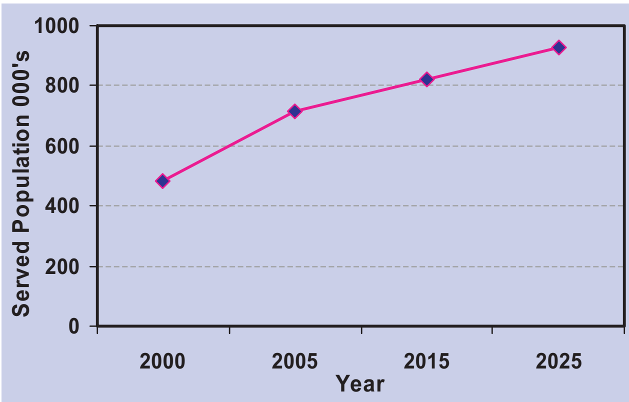
Colombo: Master Plan documents of the NWS&DB details the proposed future pipe water supply coverage plans within the two study areas. The planned supply coverage by year 2025 proposed in the Colombo report is shown in Figure 8. According to the proposals, piped water coverage will increase from the present 2.67 million people to 3.47 million people by 2020 in this study area.

Kandy: According to figure 8, which was based on the Kandy water supply Master Plan Document of 2001, pipe water coverage within the Kandy study area will increase from the present 0.31 million people to 0.395 million people by the year 2025.

In addition, the safe drinking water coverage augmentations planned during the next 20 years within the Kandy district is given in table 11. According to these data, the highest coverage increase of 19% is expected from pipe water augmentations. By the year 2025, 10 new piped water schemes are foreseen to be constructed. Already two large surface water treatment schemes are under construction there: the North of Kandy Town Project to cover the central and northern parts of the region, and the South of Kandy Town Project to cover the western and southern parts of the regions. However the expansion in groundwater use forecasted for the future is small as the expected increases in tube wells and protected dug wells supply is estimated only at 1.0%-3.5% respectively.



Colombo



Kandy

Figure 8. Future Water Supply Coverage in Colombo and Kandy

Source: National Water Supply and Drainage Board, Water Supply Master Plans for Colombo 1991 and Kandy 2001

Table 11. Mode of Safe Drinking Water Coverage in Urban and Rural Areas of Kandy District

Mode of supply	Drinking Water Coverage(%)			
	2000	2005	2015	2025
Pipe borne	38.0	54.0	55.8	57.0
Tube Well	15.0	15.5	15.8	16.0
Protected Dug Well	15.5	17.0	18.0	19.0
Other	0.5	1.0	1.5	2.0
Total	**69.0**	**87.5**	**91.0**	**94.0**

Source: National Water Supply and Drainage Board, Water Supply Master Plan for Kandy 2001

3. Issues of Groundwater Management

Over the past 30 to 50 years, there have been three main state agencies involved in groundwater development in Sri Lanka. They are the Water Resources Board (WRB), National Water Supply and Drainage Board (NWS&DB) and the Agriculture Development Authority (ADA). In addition, a few private drilling companies and donor-funded projects have also been engaged in the investigation and development of this resource. In terms of monitoring and data collection, these organizations collect data primarily for their own use, although some is shared with other agencies and some is released to the public. However, this collected data is mostly limited to deep wells. In most cases, the recorded information is restricted to the drill log, the initial water levels, and the initial water quality. There is no information available on wells constructed by private drilling companies. Because of this, there is no continuous groundwater-related monitoring data available, and hence there is no means of controlling the adverse impacts from the developments taking place in recharge areas.

The history of well construction in Sri Lanka itself is indicative of the success rate. The NWS&DB is responsible for the rural and urban water supply for domestic use and is currently the largest organization that develops groundwater in the country. According to the well construction unit of NWS&DB, production wells that yield less than 20 l/min and hand-operated tube wells that yield less than 4 l/min are classified as failures. According to this classification, the success rate of wells during the construction stage is currently about 80%. Some wells go dry in short time while others have a smaller reduction in yield and continue at a lesser yield. Usually a well will achieve a steady state after about five to eight years. If a well fails to continue to function at the rates mentioned above, it will be classified as a failed well. Usually the average success rate achieved at this stage for the whole country is about 65%. This rate is slightly higher for dry-zone wells maintained by the community, which stay at about 70%. The lower success rate achieved in wells maintained by the local governments is attributed to poor maintenance and over-abstraction. Addition to this data, our investigations showed that in the Kandy area, the success rate was only around 50%, much lower than the national average, even as early as at the drilling stage for deep boreholes. Further, the yield at drilling in majority of these borehole wells in Kandy is below 144 m^3/day, thus making them suitable only for small-scale water supply systems.

The general opinion among many officials involved in groundwater development in Sri Lanka is that the exact reasons for most of the borehole failures are not commonly known because one would require a borehole camera to investigate, and this facility is not available in the country. Further, though there are various other opinions concerning the country' s groundwater issues, lack of data and the wide range of abstraction across many different aquifer environments make the problem analysis very complicated. Hence in this section, the quantity and quality-related issues experienced in the study areas are discussed in a more generalized form.

3.1 Quantity-related Issues

Colombo: Most of the quantity problems experienced in this study area occur in the coastal aquifers, vesicular laterite aquifers or in semi-confined rock aquifers. In addition, there is a significant amount of groundwater abstraction using very productive alluvial aquifers along the river and tributary banks. In the coastal regions of Colombo, over-exploitation is seen as a major threat to the sustainable use of its coastal sand aquifers (e.g., water supply system in Ragama). These thin, freshwater lens aquifers that float on saline water are often contaminated with saline water due to excessive abstraction, especially during prolonged droughts. In regions of vesicular laterite aquifers, some are highly productive, and therefore they are commonly used for medium-scale piped water supply schemes. The excessive abstraction that mostly occurs in these laterites located away from the flood plain results in the lowering of the water table (industrial zone in Ekala). When these aquifers are used excessively, the aquifers themselves are subjected to localized groundwater table depletions affecting the groundwater wells in the surrounding areas. These coastal aquifers and laterite aquifers are only available in the Colombo study area and not in the Kandy study area.

The other major groundwater extractions are coming from semi-confined bedrock aquifers. These semi-confined rock aquifers are used in high-volume requirements such as industrial activities, and by water-supply schemes. According to the NWS&DB, most of these deep, hard rock abstraction wells have experienced either a rapid lowering of their water levels or decreased yields or both. Since there is no continuous monitoring being done, the only information available on these boreholes is the initial drill log, initial water quality, and test pump results. Hence the actual causes for these failures are largely unknown. In such failures, the usual practice adopted by the authorities is to drill another new borehole in the vicinity, and in some cases, only a few meters away from the existing well, to replace the problematic borehole. This has been possible since the groundwater resources in hard rock formations are highly variable even within a very close proximity. Many officials involved in groundwater abstraction suggest that a poor understanding of the resources and poor preliminary investigations, inadequate monitoring, and poor maintenance are the main causes for these failures.

Kandy: Most of the quantity problems experienced in this study area occur in the semi-confined bedrock aquifers. In this region too, the current problems associated with these rock aquifers are very much localized. In addition, there is a significant amount of groundwater abstraction using very productive alluvial aquifers along the river and tributary banks. Personal communication shows that there are a number of groundwater schemes in the Kandy study area such as the Kondadeniya scheme, Gohagoda scheme, Kulugammana scheme, Hedeniya scheme, Yatihalagala scheme, etc., that have been abandoned due to water depletions. Furthermore, a number of schemes such as Ampitiya, Galhinna, Bokkawala, Ankumbura, Akurana-Welekade, Alawathugoda and Rajapihilla schemes are suffering from lower yields. All of these schemes were initiated in the early 1980s and, at present, almost all schemes operating using hard rock deep aquifers are failures and the water supply is restricted to few hours a day on a few days per week. In the Kandy region, unlike in Colombo, the success of drilling new bores in the vicinity as a solution had only limited success, as, in most cases, water had to be taken from places far away from the existing intake boreholes, making the supply very expensive. Even these new borehole locations also had run into many problems as they were in hard rock formations. Consequently, a massive surface water facility to replace the groundwater schemes was constructed in November 2006, and now some of the schemes closer to the Mahaweli River—Kondadeniya, Kulugammana, Yatihalagala, Gohagoda, Rajapihilla—that previously operated using groundwater have been replaced by the water from this new surface water scheme.

Using the limited data available, monthly minimum and maximum extractions from one of the borehole stations in Harispattuwa DS division at Owissa was analyzed. The obtained plot is shown in figure 9. According to the available data, the maximum pumping rate is around 500 to 600 m^3/day, which is also using two borehole wells. At the test pumping, the recommended yield for this borehole field was in excess of 1,500 m^3/day.

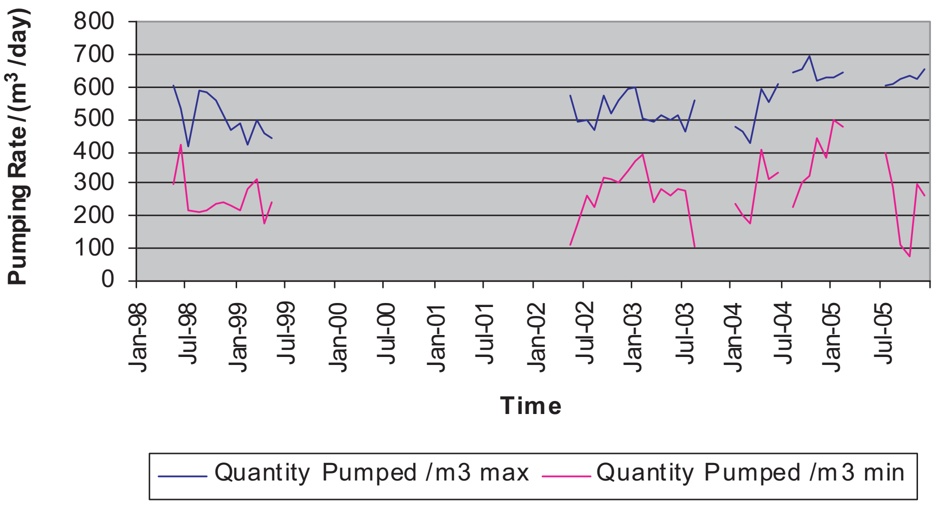


Figure 9. Groundwater Pumping Rates in Owissa (Kandy study area)
Source: National Water Supply and Drainage Board, Kandy

Considering all the above information, the most common failure modes in the boreholes constructed on hard rock formations can be listed as:

i. Clogging the fracture zone/path of borehole wells, thus failing to recover even after flushing. Past experience in Sri Lanka shows that not all wells recovered even after repeated flushing.
ii. As the storage in a hard rock aquifer is limited, this type of aquifer will exhibit higher yield at construction but gradually deplete due to over-exploitation. It is very difficult to determine a so-called "safe yield." In a situation such as a test pumping, the storage can exhibit a higher yield than the actual yield.
iii. Slow recharging potential in hard-rock/crevice aquifers.
iv. In some aquifers, siphon action within the fracture zone can bring substantial water volumes, and its failure caused by excessive pumping can drop the water levels considerably making the yield drop drastically.
v. Lack of information to take timely and adequate measures.

3.2 Quality-related Issues

Colombo: Though legal provisions are available with the Water Resources Board of Sri Lanka (WRB) to control groundwater pollution, there is no mechanism available with the WRB to monitor the groundwater quality continuously. Random or quality data is limited to the initial measurements done during developing the resource and that quality monitoring is not mandatory either. However, the NWS&DB monitor groundwater quality in water supply schemes under them. Based on the random quality measurements available, table 12 below summarizes the general groundwater quality in the Colombo study area. The available quality data does not raise many concerns in deep groundwater, except for high iron content in some locations. However, since there are many small- and medium-scale industries specially located in the suburban parts of Colombo that have no proper wastewater disposal systems, many shallow water contamination problem complaints arise there. In one such case, an investigation for heavy metal concentrations in shallow groundwater was done by Gunawardhana et al. in 2002. This study found that many in southern parts of Colombo have abandoned their drinking wells mainly due to problems of odor and taste. It also reveled that, as expected, most of the industries in this area tend to discharge untreated or partially treated effluent into nearby drains, polluting the groundwater. The heavy metal concentrations measured during this study shows that the area groundwater is high in Fe, Mn, Ag, Ni and Al concentrations. The summarized average and maximum concentration of heavy metals in well waters detected during this study is tabulated in table 13 below.

Table 12. Groundwater Quality in Colombo

Parameter	EC (μC/cm)	Chlorides (mg/l)	pH	T-Iron (mg/l)	Free NH_4 (mg/l)	Nitrate (mg/l)	P (mg/l)	Sulphate (mg/l)
Max.	1170	800	8	13	2	4	0.16	208
Min.	77	12	7	0	0	0	0	0

Table 13. Concentrations of Heavy Metals in the Groundwater in Southern Colombo

Metal	Fe	Mn	Ag	Ni	Al	Cr	Cu	Pb	Cd	Co
Max. (mg/l)	9.27	0.92	0.58	0.21	5.62	0.13	0.03	0.04	0.00	0.02
Ave. (mg/l)	1.1	0.09	0.05	0.1	0.37	0.03	0.01	0.01	0.00	0.01

Source: Gunawardhana et al. in 2002

Kandy: Similar to Colombo area, there is almost no continuous groundwater quality monitoring done in Kandy either. But, as there are many borehole wells constructed in the suburban areas in Kandy, based on the quality measurements taken in these locations during construction, table 14 below summarizes the groundwater quality in the suburban areas. According this data, hardness, iron and nitrite are of concern in some locations in southern, western and eastern regions. Hardness as high as 1,125 mg/l is observed. Further, total iron concentration of 18 mg/l, nitrites 128 mg/l and sulphates of 500 mg/l is observed. A notable point with these results is that the groundwater quality in the northern areas is found to be very good.

In addition to the above water quality measurements, there have been a few quality measurements taken for shallow groundwater wells over the last few years. Although they have not been tested at regular intervals or at regular locations, some trends can be observed with these measurements. Generally, most of these quality tests are made on request and for some of the boreholes used for community piped water supply schemes. This monitoring shows that the main quality concern in the shallow groundwater is contamination due to coliform.

Table 14. Groundwater Quality in Kandy (Maximum Observed Values)

Parameter	EC (Mhos/cm)	pH	T-Iron (mg/l)	Sulphate (mg/l)	Hardness (mg/l)	Nitrite (mg/l)	Mn (mg/l)	F (mg/l)	P (mg/l)
East	2,190	4.6 - 7.9	15.2	500	1,096	128	1.5	0.9	-
North	790	5.8 - 7.5	4.8	50	197	3.5	0.5	0.65	0.2
South	705	5.6 - 8.5	18	0.5	1,125	48	4.4	-	-

Source: National Water Supply and Drainage Board, Kandy

3.3 Future Groundwater User Trends in Colombo Study Area

The piped water tariff in Sri Lanka has increased over tenfold during the past twenty year period. Presently the cost of a unit of water (1 m^3) ranges from a low of 0.011 USD for the first 10 units to a high of 0.7 USD a unit for units consumed above 40. As such tariff increases surely reduce the piped water consumption, consumers may tend to use more groundwater, which is freely available. Therefore, to ascertain consumers' perception a questionnaire survey was conducted in the peri-urban areas north of Colombo with the primary objective of studying the effect of the recent tariff increase on water consumption and on groundwater use. In addition, water use pattern, opinion on groundwater, sanitary conditions, and groundwater use were also questioned. In total over 375 samples were collected.

The obtained results show that a majority of consumers with pipe connections trust the pipe-borne water, especially for drinking and in-house use. However, a substantial percentage of respondents are using groundwater as an alternative source. In addition to this, many consumers' feeling is that groundwater is safer than the piped water supply. Further to this, an effort was made to ascertain the future trends in groundwater use by allocating different weights (both negative and positive weights with average 0) for key questions asked in the questionnaire based on their importance. According to this analysis, a net value of +1505 was obtained. Therefore it can be predicted that there will be an increasing trend in groundwater use in the future, although this may depend on the water tariff.

3.4 Effects of the Tsunami on Coastal Groundwater

Sri Lanka has a coastline of approximately 1,660 kilometers. This coastal zone is very diverse, and contains lagoons and estuaries, fringing and offshore reefs, mangrove swamps, sea-grass beds, salt marshes, beaches, sandy spits, rocky shores and dune systems. Shallow groundwater wells have traditionally provided the main domestic water source for the settlements throughout the entire coastal areas. The Asian tsunami on December 26, 2004, hit the Sri Lankan coastline with various degrees of impact, but the eastern, northern and southern coastlines in particular were devastated (ADB, 2005; UNEP, 2005). In Sri Lanka alone, over 40,000 people were killed or went missing, and many thousands were displaced by the flood waves and the extensive property damage. In addition, most of the natural ecosystem along the coast was destroyed and complete infrastructure facilities in this coastal belt were totally devastated. Immediately after the tsunami, it was estimated that over 60,000 groundwater wells (mostly dug wells) throughout the affected coastal zone, and in some places almost up to 1.5 kilometers inland, had been damaged or destroyed. Many of them were left unable to provide water that was fit for human consumption or even for bathing or washing (ADB et al., 2005; UNEP, 2005). The damage to the wells ranged from filling them with debris, sewage and saltwater to salt water intrusion from the stagnant saline water collected in local depressions. Many water supply schemes catering to domestic needs were also affected due to breaches in the water distribution pipelines and the filling of wells with debris and saltwater. In addition, the characteristics and quality of soil and water resources in the coastal areas were changed by the flow of seawater over the soil surface, the stagnation of saline and possibly polluted water in local depressions, and the disruption and loss of the coastline. According to a study by Jayaweera et al., 2005, a few days after the tsunami, the contaminated wells had COD levels of 128 mg/l, total and fecal coliform levels exceeding 30 and 7 CFU/100 ml, and conductivity levels of over 3,000 µS/cm.

The two most common methods adopted to clean up wells soon after the tsunami was to empty the contaminated water either by means of pumping or by manual cleaning and disinfection using bleaching powder (hypochlorite). These restoration efforts encountered a range of problems, as most of the people involved lacked specialized knowledge. Most of the cleaned wells were reported to remain saline, even after repeated cleaning and emptying. In addition, wells collapsed during the cleaning process, and the presence of contaminants from other sources of pollution caused potential health hazards that previously did not present a significant problem (Jayaweera et al., 2005; Villholth et al., 2005). These experiences made very clear the necessity of a well-coordinated, integrated plan to restore the groundwater after the effects of the tsunami and to implement relief measures. In this regard, the IWMI, through some monitoring (Villholth et al., 2005) has suggested a set of possible guidelines to follow with respect to the cleaning of wells after a tsunami. The guidelines include short-term as well as long-term measures.

4. Issues relating to Alternative Water Resources to Groundwater

As explained, both the study areas of Kandy and Colombo are blessed with plenty of rainfall and surface water. But, when one considers their variations over space and time, further analysis is required to ensure sustainability. Hence, during this study rainfall and surface runoff data in the two study areas were closely investigated to identify the surface water issues and the possibility of rainwater harvesting as an alternative water source for domestic use.

4.1 Surface Runoff Issues

Since there are many concerns with the existing groundwater sources, assuming the entire future water supply requirement in the two study areas is to be satisfied with surface water, the required minimum river runoff volumes to fulfill a) the full development water supply demand level (water provided to entire population) and b) planned water supply demand (what is planned in the water supply Master Plan Documents) for year 2025 was estimated.

Colombo: The estimated river flow requirements to satisfy the full development water supply demand and planned water supply demand in Colombo study area is tabulated in table 15 below. Though there are previous study data available on salinity control at Ambatale (river water intake), our investigation shows that the minimum river flow (environmental flow) requirement for salinity control downstream of Ambatale is estimated at 30 m^3/s. Analyzing the available Kelani flow data given in table 8 with the required minimum demands in table 15, it is obvious that satisfying demands, especially during dry weather low flow periods, can create salinity problems at the Ambatale water treatment plant. During recent years on a few occasions, the Ambatale water treatment plant had to be closed due to high salinity levels. Knowing this, a salinity barrier (barrage) across the river has been proposed. However the estimations in table 15 have not taken into consideration any salinity controls in existence. Therefore, if a salinity barrier is constructed, the minimum environmental flow requirement downstream of Ambatale will be less than that considered here.

Considering the past 40 year Kelani River discharges at Ambatale, an analysis was done to determine the reliability of daily available average flows in the river to satisfy the future expected demand in the Colombo study area. The obtained reliability percentages for this case are tabulated in table 16 below. The reliability values show that Kelani River flow can satisfy the Colombo study area year 2025 full development demand 79.7% of the time and planned supply demand in year 2020 by 90.8% of the time.

Table 15. Minimum Surface Water Requirements to Satisfy Future Demand in Colombo

Full Development Demand	Water demand/(million m^3/month)			
	2001	**2005**	**2015**	**2025**
Water demand	46.4	50.3	61.3	74.7
Environmental flow to salinity control	77.7	77.7	77.7	77.7
Total required flow	124.2	128.03	139.04	152.46

Planned supply demand	Water demand/(million m^3/month)		
	2001	**2010**	**2020**
Water demand	24.5	26.3	28.9
Environmental flow to salinity control	77.7	77.7	77.7
Total required flow	102.2	104	106.6

Table 16. Percentage Reliability of Kelani River to Satisfy the Future Water Demands in Colombo

Demand	2001(%)	2005(%)	2015(%)	2025(%)
Full Development Demand	85.8	84.9	82.4	79.7
	2000(%)	2010(%)	2020(%)	
Planned Supply Demand	91.8	91.1	90.8	

Kandy: The estimated river flow requirements to satisfy the full development water supply demand and planned water supply demand in Kandy are tabulated in Table 17 below. Here the irrigation requirement at Polgolla is a variable depending on the demands in the command areas. According to the NWS&DB "Kandy District Water Supply Development Program" of 2002 (Master Plan Document), the minimum recharge requirement (Environmental Flow) through the Polgolla dam is 4.2 m^3/s and the minimum diversion requirement through the Polgolla tunnel is 14 m^3/s, in February and March and the maximum diversion requirement through the Polgolla dam in June is 36 m^3/s.

Table 17. Minimum Surface Water Requirements to Satisfy Future Demand in Kandy

Full Development Demand	Water demand/(million m^3/month)			
	2001	2005	2015	2025
Water demand	5.2	5.4	6.0	6.7
Diversion water at Polgolla maximum	93.3	93.3	93.3	93.3
minimum	36.3	36.3	36.3	36.3
Environmental flow	10.9	10.9	10.9	10.9
Total required flow maximum	**109.4**	**109.6**	**110.2**	**110.9**
minimum	**52.4**	**52.6**	**53.2**	**53.9**

Planned supply demand	Water demand/(million m^3/month)		
	2000	2015	2025
Water demand	2.0	3.1	3.6
Diversion water at Polgolla maximum	93.3	93.3	93.3
minimum	36.3	36.3	36.3
Environmental flow	10.9	10.9	10.9
Total required flow maximum	**106.2**	**107.1**	**107.8**
minimum	**49.2**	**50.1**	**50.8**

Analyzing the available Mahaweli discharges given in table 8 with the required minimum demands in table 17, it is obvious that satisfying the demands, especially during dry weather low-flow periods, can be a major issue at present and also in the future. Hence, considering the past 40 years of Mahaweli River discharges at Peradeniya, an analysis was done to determine the reliability of daily available average flows in the river to satisfying the future expected demand at Kandy. The obtained reliability as a percentage for this case is tabulated in table 18 below. The reliability values show that Mahaweli River flow can only satisfy the diversion demand at Polgolla and the Kandy study area year 2025 full development demand 68.8% of the time and planned supply demand 70.6% of the time. Further, the same analysis based on average monthly discharge gives the lowest reliability of 32% during February and maximum of 100% in November. Therefore it is vital to use the existing reservoirs at both upstream (Kotmale) and downstream (Polgolla) to control the flow to meet the future demands.

Table 18. Percentage Reliability in Mahaweli River to Satisfy the Future Water Demands in Kandy

River	2001(%)	2005(%)	2015(%)	2025(%)
Full Development Demand	69.8	69.7	69.3	68.8
Planned Supply Demand	72*	-	71.1	70.6

** Year 2000 demand*

4.2 Surface Water Quality Issues

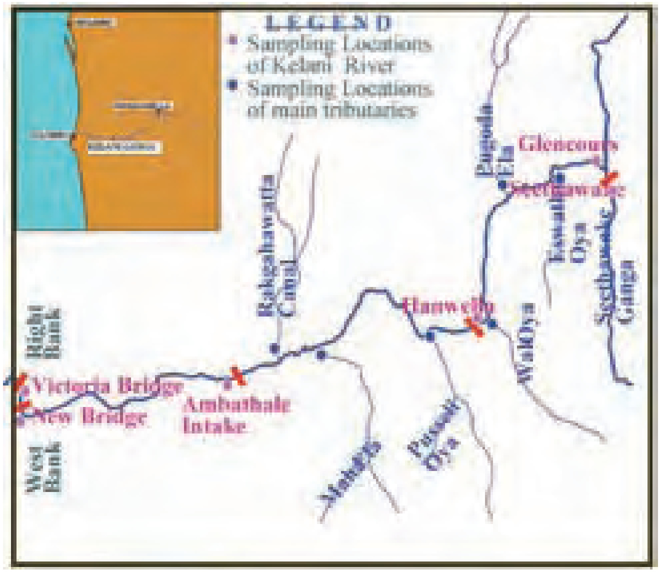


Figure 10. Water Quality Monitoring Points in Kelani River Colombo

Source: Hearth and Amerasekara, 2004

Colombo: The other major setback using the surface water sources in the two study areas comes from pollution issues. The water quality variation of the Kelani River was analyzed at several locations both upstream and downstream of Ambatale, as indicated in figure 10. The rapid development occurring in this region during the last two decades is contributing a substantial pollution load to the Kelani River. The upstream area of the Ambatale intake is congested with urban centres, industries and agricultural lands. According to the Danish Hydraulic Institutes' estimations in 1999, the urban pollutant load during dry season ranges from 150 – 650 kg/day of BOD. The urban load and per capita waste generation is much higher in the downstream of the Ambatale river intake. The total load is estimated to be about 4,000 kg/day of BOD below the water intake. The major wastewater generating industries upstream of the river intake include raw rubber factories, textile industries, beverage factories, rubber latex factories, milk food industries, steel manufacturing factories, plywood factories, fertilizer manufacturing factories and industries within the Biyagama Export Promotion Zone. These industries are estimated to discharge about 1,000 kg/day of BOD into the Kelani River. The petroleum refinery, chemical industries (soap, detergents, and pharmaceuticals) and Lindel industrial estate downstream of the Ambatale intake discharge about 2,000 kg/day of BOD (Danish Hydraulic Institute, 1999). Referring to the land usage in the basin, it is expected that the run-off of fertilizer, from tea lands in the upper catchment and from rubber and paddy lands in the mid-catchment, is the principal source of nutrients into the river. The current application of Nitrogen and PO_4 as fertilizer is estimated to be about 6,900 million tons and 1,920 million tons/year, of which 4,000 million tons and 845 million tons are applied to tea, 2,000 million tons and 370 million tons to paddy and 500 and 650 million tons to rubber, respectively (Danish Hydraulic Institute, 1999).

Recent water quality in the river is tabulated in Table 16. The data show heavy pollution. The dissolved oxygen (DO), 5-day biochemical oxidation demand (BOD_5) and chemical oxidation demand (COD) levels at Ambatale and downstream of Ambatale were often in excess of the Sri Lankan inland surface water standard required for bathing or for drinking with complete treatment (current standards are 5 mg/l for DO, 4 mg/l for BOD_5, and 20 mg/l for COD respectively). Further, in most tributaries and the lower river estuary very low DO values (occasionally below 1 mg/l) and low BOD_5/COD indicate high industrial waste disposal. Further, the observed levels of dissolved Cr and dissolved Pb too indicate extensive industrial pollution, especially in the estuary area. However, the nutrient levels observed in the river are smaller than anticipated considering the loads of applied fertilizer in the catchment. Nonetheless the available nutrient concentrations are far more adequate for eutrophication to occur (Muller, 1999) and periodic algal blooms were observed in the shallower areas, especially in stagnant waters during low-flow periods. Also, the observed high coliform counts well over 15,000 CFU/100 ml in almost all monitoring stations show the high degree of urban sewage discharge, too.

The chloride content shows high variations, especially in the lower reaches. The main reason is seawater intrusions as a result of low river flows and sand mining. Occasionally this saline water even reaches the Ambatale water supply intake during prolonged droughts and, as mentioned, interrupts the water supply to the Colombo area. Therefore, this saline-water intrusion can be a major problem in the future as many recent studies have shown that rainfall, compared to few decades back, has significantly reduced, with the lengths of the dry periods having increased and the lengths of wet periods having decreased all over the country (Ratnayake and Herath, 2005).

Given the current and future importance of the Ambatale intake, the construction of a salinity barrier appears to be a priority to protect the water supply during prolonged dry periods. The flow at intake is currently protected from large industrial effluent discharges by a government policy not to site such industries above Ambatale. However, the river water quality should be monitored and modelled so as to extend the sustainability.

Table 19. Water Quality Data along the Kelani River

Location		BOD (mg/l)	COD (mg/l)	NO_3^- (mg/l)	DO (mg/l)	PO_4^{3-} (mg/l)	E-Coli (cfu/100ml)
Sri Lankan Standard	Maximum Permissible	4	10 – 20	-	5	-	0
Hanwella	Average	2.26	20.1	0.24	6.75	0.03	5,083
	Range	0.4 – 7.2	10 – 52	0.01 – 0.91	2.6 – 8.7	0.01 – 0.1	230 – 16,000
Kaduwela	Average	1.87	16.4	0.25	-	0.11	-
	Range	0.4 – 5.8	4.0 – 46	0.01 – 0.67	-	0.01 – 1.09	-
Ambatale	Average	3.2	20.8	0.26	6.63	0.03	3,702
	Range	0.4 – 9.2	10 – 50	0.01 – 0.86	4.9 – 8.3	0.01 – 0.25	400 – 16,000
Victoria bridge	Average	3.06	111	0.22	5.53	0.02	11132
	Range	0.6 – 6.4	7.5 – 359	0.01 – 0.72	0.8 – 7.5	0.01 – 0.13	800 – 16,000

Source: Hearth and Amerasekara, 2004

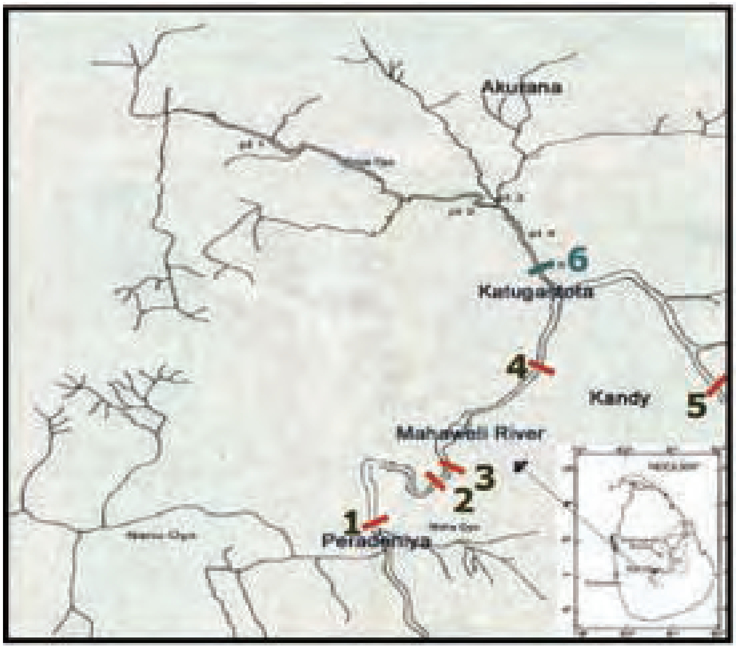


Figure 11. Water Quality Monitoring Points in Mahaweli River Kandy
Source: Herath, 2003

Kandy: Since Maheweli River is the only source of surface water available in the Kandy study area, water quality variations in this river were analyzed during this study (Figure 11). Land cover in the upstream catchment of Mahaweli River is mainly of forestland, tea cultivation and human settlements. Therefore urban wastewater and agricultural runoff are the main sources of pollution from the upstream area. However, most pollution to Mahaweli River comes not from upstream but from the surrounding areas of Kandy. The tributaries from Peradeniya to Polgolla bring this wastewater into the main river. Of these, the "Meda Ela"—having a catchment area of 19.31 km^2—is adding most of the pollutants into the Mahaweli River. This urbanized sub-catchment that covers a substantial part of Kandy City, mainly consists of commercial and industrial activities, hospitals and urban clusters that have direct sewerage outlets to the stream. The other considerable pollution comes from the largest tributary, "Pinga Oya." Its catchment too is fairly urbanized. The following table, table 20, shows a summary of the past 15 years' water quality data for Mahaweli River and its tributaries.

At Peradeniya (before entering the Kandy City limits) the main stream of Mahaweli River has relatively good water quality, yet the tributary confluence from Peradeniya to Polgolla has higher pollutant strengths. Higher amounts of coliform and nutrients are signs of human waste contamination. Among the three tributaries shown in the table; the Pinga Oya and Meda Ela brings the most polluted water into the Mahaweli River. Apart from the sewerage disposal, direct solid waste dumping also takes place in the tributary catchment areas and muddy soil, with a great deal of polyethylene waste is observed at the Pinga Oya confluence. The polythene deposits on the riverbed reduce the infiltration and increase the surface water runoff, which will cause flash floods and dry periods. The water quality at Polgolla shows the impact of the Kandy City region on the quality of water in Mahaweli River. Fortunately the most polluted stream confluence is located downstream of the water supply intakes.

CHAPTER 1 CHAPTER 2 CHAPTER 3

Table 20. Average Water Quality Data of Mahaweli River, Meda Ela and Pinga Ela

Location		BOD (mg/l)	DO (mg/l)	E-Coli (CFU/100ml)	NO_3- (mg/l)	PO_4^{3}- (mg/l)
Sri Lankan Standard	Maximum Permissible	4	5	0	10.0	2.0
Mahaweli River (At Peradeniya)	Average	3.2	6.4	50	1.42	0.20
	Range	3.0 – 4.2	5.3 – 7.5	10 – 120	0.17 – 4.2	0.01 – 1.5
Maha Oya (A tributary)	Average	3.06	5.2	450	0.65	0.06
	Range	0.6 – 6.4	4.3 – 6.2	50 – 850	0.08 – 1.3	0.01 – 0.43
Meda Ela (A tributary)	Average	8.4	2.4	3500	2.24	0.22
	Range	3.2 – 15.8	1.0 – 4.6	900 – 9000	0.94 – 6.02	0.02 – 2.59
Pinga Oya (A tributary)	Average	5.2	3.87	1400	0.95	0.18
	Range	3.4 – 9.2	1.5 – 6.2	9 – 7500	0.08 – 4.4	0.01 – 2.85
Mahaweli River (At Polgolla)	Average	4.6	3.4	420	2.36	0.03
	Range	3.2 – 6.4	1.0 – 4.9	160 – 960	1.32 – 4.97	0.01 – 0.1

Source: Herath, 2003

4.3 Rainfall Issues

Since there is adequate rainfall available in the two study areas, rainwater harvesting (RWH) can be an attractive alternative to surface/ground water. However, issues such as rainfall reliability, its storage and quality, consumer acceptance, etc., are very important for the future success of rainwater harvesting. Therefore, during this study the necessity for rainwater harvesting, rainfall variations, quality of rainwater comparison with drinking quality standards and the required infrastructure requirements were studied. Further, the future success of the proposed "Rainwater Harvesting Policy and Strategies" was investigated using a questionnaire survey in the Kandy study area.

Assuming an average family size of 5 and a minimum water requirement of 40 l/person/day for basic needs, the required tank capacity and the necessary roof area for rainwater harvesting were calculated, taking into account the past 40 years' rainfall data in Kandy. The study obtained the minimum tank capacity as 6,000 l and roof area of 134 m^2. It was estimated that this storage facility using low cost materials such as ferro cement would cost around 200-250 USD. With the help of these findings, a questionnaire survey was conducted in two urban areas (a total of 22 samples) and four peri-urban areas (51 samples). The results showed that the preference for RWH potential in urban areas is very low but most people in peri-urban areas are keen on RWH. Also, most people preferred rainwater only for secondary purposes such as washing, gardening, etc. Although 80% of people with a piped water supply were not keen to harvest rainwater for basic needs, over 80% of people who do not have a piped water supply were very keen to harvest RW. However one major problem identified during this survey is the extent of available roof area, where over 60% roofs were below 133 m^2. Also awareness and knowledge on rainwater harvesting were very poor among the respondents. Therefore a program should be implemented to popularize rainwater harvesting within the society.

5. Policy Responses and Future Challenges

Despite the fact that Sri Lanka is blessed with a good water resource, when one considers its variations over space and time, a proper management strategy for its sustainability is needed. Additionally, there have been a number of recent warning signals pointing to heightening water resource issues in Sri Lanka. Competition and water shortages are increasing as a result of the highly variable rainfall and growing demand for water. Watersheds are being degraded resulting in soil erosion, the sedimentation of reservoirs, landslides and more serious floods and droughts. Water pollution from domestic, agricultural and industrial sources is contaminating the surface water and groundwater and affecting the environment and public health. Excessive groundwater abstraction is occurring in some areas, affecting long term sustainability. Therefore, in this section, the available policy instruments and the existing institutional arrangements are analyzed from the perspective of how they could respond to the immediate challenges posed to the water resources of the country in realizing their ultimate sustainability.

5.1 Available Policy Framework and the Institutional Arrangement

As mentioned, at present the Water Resources Board (WRB), National Water Supply and Drainage Board (NWS&DB) and the Agriculture Development Authority (ADA) are all engaged in investigations into and development of groundwater resources in Sri Lanka. Of these the WRB and the NWD&DB are playing a much more active role in the water sector today compared to the ADA. Further, the Central Environmental Authority, (CEA) though not directly involved, is related to water conservation in the country as it has the mandate to prevent the pollution of the environment, including water environment. The main functions of these water-related institutions could be listed as follows:

Water Resources Board: The WRB was established in 1964 by an Act of Parliament to control, regulate and develop—including the conservation and utilization of—water resources of Sri Lanka. Further, it was tasked with the promotion, construction, operation and maintenance of water-related schemes (e.g. irrigation, drainage, flood control and hydraulic power, etc.) and the prevention of the pollution of rivers, streams, and other watercourses. The WRB also was given the authority to formulate national policies relating to the control and use of water resources of the country with the objectives of:

i. Multi-purpose development and use of water resources;
ii. Short-term and long-term provision of water resources;
iii. Disposal of sewage and industrial wastes;
iv. Preparation of the comprehensive and integrated plans for the conservation, utilization, control and development of the water resources;
v. Coordination of the activities related to surveys of basic data and other investigations relating to river-basin and trance-river-basin development projects, soil classification, and the hydrological, geological and other similar aspects of the use of lands; and
vi. Any other suitable measures to be taken by the Government for the proper control and economic use of water.

National Water Supply and Drainage Board: In 1974, the NWS&DB was established and given the responsibility to develop, maintain and provide a proper, safe water supply for public, domestic and industrial purposes and to establish, develop, operate and maintain the necessary wastewater disposal systems in the country. With this Act, the NWS&DB was given freedom to: buy and sell water; develop, operate, and investigate; collect necessary data and document the information related to water supply and wastewater disposal; owning or leasing tangible and intangible property; conducting research related to the supply of piped water and wastewater services, its developments and information related to the operation and maintenance of such projects, etc.

Central Environmental Authority: In 1980, the Central Environmental Authority (CEA) was established by an Act of Parliament for the protection of any portion of the environment against waste discharges. Further, this Authority was entrusted to conduct surveys, to conduct, promote and coordinate research on any aspect of environmental degradation, develop criteria and specify standards for environmental protection and powers to undertake investigations and inspections to ensure the regulations related. Again, this Act was amended in 1990 such that many specified large-scale projects need necessary approval from the CEA for their construction and operations. This included groundwater-based water extractions but limited only for projects that exceed daily extractions above 500,000 m^3.

5.2 Proposed National Water Policy

The origins of Sri Lanka's recent water policy development may be traced back to the recommendations given by the Presidential Land Commission of 1985, who perceived their role not only as a 'land commission' but also to some extent as a 'water commission.' This commission stressed the need for developing a 'National Water Master Plan' as they have identified many problems with the existing institutional arrangement available for managing the water resources of the country. Therefore, on these recommendations, the Government of Sri Lanka with technical assistance from the Asian Development Bank formulated the draft proposal 'National Water Resources Policy' through the Water Resources

Secretariat (WRS), which is a new institution set up especially for this purpose. The prime objective of this policy was to strengthen the capacity of the Sri Lankan Government to manage water resources in a sustainable, participatory and transparent manner. In these new proposals, some major deficiencies in the present water, as well as groundwater management setup, were identified. The major problems in groundwater management identified in this water policy can be listed as (National Water Policy – Draft, 2000):

i. Ownership, and therefore management responsibility, of the groundwater is not clearly defined in legislation.
ii. Responsibility for investigation into and development and regulation of groundwater is not formally assigned to any agency.
iii. There is neither a coordinated groundwater information program nor a proper groundwater planning system.
iv. Even when a considerable body of information on seasonal behavior and quality is available, there is no institutional authority for control or regulation of the resource.
v. There is no legal basis for groundwater allocation.
vi. There is no public information or awareness program regarding groundwater.

However, with the change of government in 2001, the proposed water policy had to go through significant changes and, in 2002, a major revision was made to the policy formulated in 2000. This policy is still in the draft stages, as the government changed again in 2004.

5.3 Stakeholders' Meeting

During this study a stakeholders' meeting on "Sustainable Water Management Policy: Ground and Surface Water Resources" was organized in February 2007 to discuss and identify the following:

i. The water development and management practices in the past, and their adverse impacts;
ii. The tools and policies available for the mitigation of the adverse impacts;
iii. The important technical inputs and policy issues that need to be addressed to improve management of water resources; and
iv. To develop guidelines and strategies for improved policies for sustainable water resources management.

The meeting was well attended, with over 30 participants from various water-related agencies. At the end of the meeting many suggestions were put forward for achieving the ultimate objective of sustainable water management in the country. Based on the discussions held during the meeting, a list of recommendations was formulated. The main recommendations made in this meeting can be summarized as:

i. Available policy is adequate, but proper implementation is necessary to overcome the present ground and surface water problems.
ii. Crevice groundwater should not be recommended for large-scale abstractions.
iii. Need to raise awareness among the public on water related issues.
iv. Proper ground and surface water monitoring is necessary.
v. Dialogue on the proposed water policy should be started immediately.

5.4 Policy Gaps Identified during this Study

In this study, several issues were identified as urgent challenges to be immediately addressed. Among those, the most important issue is the establishment of a single authority responsible for overseeing management of the water and the groundwater resource. In the present set up, as there are several agencies involved in groundwater development; even though the WRB is responsible for managing the overall water resources, due to confusion in deciding who should manage the groundwater resources, policies are been implemented poorly with nobody taking responsibility for managing the groundwater resources. Often this can be one of the main reasons for many of the present groundwater problems. Furthermore, a lack of adequate financial and trained human resources within these agencies has also seriously affected the present groundwater management.

As described in a previous section, data from the construction stage of deep groundwater wells in the Kandy study area shows that only few hard rock crevice aquifers have reasonable yields. Further, many water supply schemes in Kandy (as well as in Colombo) that were based on successful boreholes drilled in the hard bedrock have run into several problems due to a lowering of both the water levels and the yields. Hence, past experiences in Kandy and Colombo clearly show that the amount of groundwater available in this type of hard rock aquifer is very limited and hence may be suitable only for rural, small-scale water supply projects and not for large, urban water supply schemes. Therefore it is the correct time for the Authorities to formulate proper policy guidelines in this regard and should be made available very soon. The NWS&DB is already in the process of replacing the problem-prone groundwater scheme with surface water schemes.

Incidents of this nature, together with the other groundwater problems experienced in the recent past, suggest that groundwater development in urban areas has now reached a stage where it is useless to speak of sustainable development of the country's groundwater resources without a supporting research effort to diagnose and troubleshoot both existing and emerging problems, and without properly managing and guiding the ongoing groundwater activities in the country. Therefore, another prime need at the present stage is the establishment of an appropriate research plan to promote both short- and long-term research and investigation programs. Funding for this may come by establishing a fund through levying a groundwater charge for heavy use. Further, as there are no present programs available for monitoring either the changes in the quality or quantity of groundwater, the actual state of groundwater in the country is very uncertain. Therefore, in the absence of these information sources, establishing a proper monitoring network and using it as a comprehensive and reliable information system is essential. Without this initiative, the groundwater resources of a country are often poorly understood and over-exploited by both the decision-makers and the users of the groundwater.

Further, at present, information about groundwater resources in this country is not readily accessible. There is no coordinated groundwater information program, although some studies have been undertaken in the past. This data has not been consolidated and, even in its scattered form, it is not used to any significant extent in management decisions. Therefore, through publications that may periodically be issued, the presently available information on the different aquifers and the management issues need to be taken to the general user and managers at the district level in a readily understandable manner. The information should be easy to understand to increase awareness and to obtain support in managing the resources. Also, guidelines for the safe and sustainable use of groundwater should also be framed for all types of aquifers in this country. The guidelines should be widely disseminated to both the local and district provincial agencies and other end-users.

5.5 Policy Recommendations

Based on the findings of this study, the following list of policy recommendations can be suggested to overcome the issues related to the water resources of Colombo and Kandy study areas:

(1) Proper Management of the groundwater resource

a. Main issues

i. Current Groundwater ownership is with the individuals, but changing ownership is a critical and sensitive issue. This was one of the main reasons for the failure of the proposed water policy.

ii. Poor Groundwater management/governance due to multiplicity of institutions
WRB Act – empowered the WRB by law to control, regulate and develop, including the conservation and utilization of water resources of Sri Lanka (not practiced however, as available legal provisions are confusing) but, on the other hand the NWS&DB Act has given a mandate to the NWS&DB for the development of water supply schemes. Complexities such as these have resulted in nobody taking the responsibility of managing the groundwater resource.

iii. Limitations in the existing groundwater resources
It is vital to limit the hard-rock groundwater resource to be used in limited applications and should base extraction limits through proper scientific investigations

b. Recommendations

Identify and demarcate groundwater sensitive areas in each administrative division

Regulation only in sensitive areas with the following proposed priority scheme

i. Top priority for domestic purposes with an upper per capita limit

ii. Regulate other uses with a pre-determined priority basis (case by case)
iii. Non-sensitive areas – no regulation necessary but identify/keep records on heavy uses

Limit hard rock groundwater use only to small scale/individual water supply.
Encourage surface water use and rain water harvesting, especially in sensitive areas.
Establish principals for groundwater management by issuing proper guidelines for proper constriction, the safe and sustainable exploitation and use of groundwater for all types of aquifers.

(2) Need for Regular Monitoring and Investigation Programs

a. Main Issues

At present there are no reliable, continuous or ongoing monitoring data available on groundwater. This has made it difficult to determine causes for groundwater failures in the study areas and also to identify groundwater behavior trends in aquifers, making it a major setback in managing the resource (e.g., groundwater problems in Kandy).

b. Recommendations

Establish a system for collecting groundwater-related data
Make WRB responsible for this task (already empowered by an Act of Parliament)

(3) Need for a Well-coordinated and Reliable Information System

a. Main Issues

Although some groundwater studies have been undertaken in the past, even this data is scattered or misplaced. Also, different organizations collect and keep data essentially only for their own use. Hence, a proper database is necessary to collect these scattered data, to manage them and to make them readily accessible for all.

b. Recommendations

Establish a centralized information system with data readily available to any interested party.
Demand-driven research, assessment and monitoring programs need to be undertaken both on a widespread, reconnaissance basis and more intensively, in priority aquifers and in areas of declared water management and areas sensitive to groundwater.

(4) Conflicting in Water Allocation Rights

a. Main Issues

According the present policy set up:

i. WRB - Has the right to Control Regulation and Development of all water resources of Sri Lanka
ii. NWS&DB – Not clearly state their rights but use water for water supply schemes without the permission from WRB
iii. Mahaweli and Irrigation Departments – Play both the roles of the regulator and user for irrigation in some important river basins, including the Mahaweli River
iv. Ceylon Electricity Board – Permission is granted (and high priority given) by an Act of Parliament to use water for hydropower generation. These types of priority listings have led to many confusions and conflicts in the past over who has the priority/right over whom to use water (e.g. Salinity intrusion into the Colombo water treatment facility as water in the Kelani River is regulated at upstream reservoirs for hydropower generation)

b. Recommendations

Establish a clear priority policy for water allocation
Establish a proper mechanism to manage water use between different sectors
A proper compensation scheme for the lost opportunity (e.g., if irrigation water rights are lost due to water taken for drinking water supply, proper compensation for farmers, etc.)

(5) Pollution Prevention

a. Main Issues

At present, almost all surface water sources in urban areas are highly polluted. Further, the shallow groundwater resources in urban areas are often contaminated with coliform and nutrients. One major reason for these failures is shortcomings in the present management structure. As explained earlier, the Central Environmental Authority (CEA) was established for the protection of any portion of the environment against waste discharges, but also the WRB has provisions from its Act for prevention of the pollution of rivers, streams and other watercourses. Even though there are two agencies available to prevent water pollution, due to the following reasons, prevention has not being effective so far:

i. lack of stringent legal instruments to punish polluters
ii. lack of standards for coliform, nutrients, etc., discharges
iii. failure to implement the laws especially for GW contamination (WRB)
iv. influence from local politicians (local government)
v. no coordination between the two organizations

b. Recommendations

Strict enforcement of the present law with enhanced legal provisions
Introduction of new discharge standards covering all pollutants

(6) Other Issues and Recommendations

In addition to the above five main recommendations, this study identifies the following, also, as important recommendations for sustainable water resources both in Colombo and Kandy:

i. Proper definition for safe drinking water and a proper monitoring mechanism is necessary, as at present there is no clear definition for safe drinking water in Sri Lanka and, further, no proper guidelines for maintenance of such supply or sources.
ii. Reduction of non-revenue water, which are very high in both study areas: 40% in Colombo and 36% in Kandy.
iii. Awareness raising and stakeholder (especially public) participation in decision making
iv. An integrated approach should be taken in the management of surface and groundwater. This may involve education and other means of encouraging water users to use surface water or rainwater harvesting when it is available and to save groundwater for use during periods when there is deficient surface/rain water.
v. Initially, a registration program should be started for heavy groundwater users. Thereafter, establish a well-licensing program to track groundwater development.
vi. One main reason for the failure of the proposed water policy in Sri Lanka in 2000 was the poor level of consultation with the stakeholders. It is therefore necessary to have strong participation from the community and water users, and to promote awareness to facilitate the planning and management of groundwater resources.
vii. In most cases, the exploitation of shallow groundwater is through small-scale domestic and agricultural wells. While each of these wells use only a small amount of water, their cumulative impact can be considerable. As it is considered impractical to regulate these small wells through water entitlements, steps must be taken to somehow control the over-use of shallow aquifers and thus to safeguard the water supplies of existing users of shallow wells.

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