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Special Feature on Groundwater Management and Policy

Overview of Groundwater Management, the Agrowell Program, and the Impact of the 2004 Tsunami in Sri Lanka

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The demand for groundwater in Sri Lanka has grown rapidly over the past few decades, mainly as a result of population growth, economic development, and shortages in rainfall. Recent estimates show that over 55 percent of the population now relies on it for their daily needs. As a free, easily tapped commodity groundwater is used in a wide variety of uses such as small-scale irrigation, domestic supply, housing developments, industries and industrial promotion zones, hotels, and aquaculture. Groundwater is being exploited at an unprecedented rate, encouraged in part by subsidies to promote the use of groundwater wells for agriculture (*agrowells*). For example, the number of them has grown over the last two decades from 0 to over 50,000, mostly in the northwest region. Of the 300 urban and rural piped water supply schemes operating across the country, almost one-third of them rely entirely on groundwater. The volume they withdraw exceeds over 16 million cubic meters per year (Mm^3/yr), which includes supply to many industrial zones and urban and rural centers. And the volume of groundwater abstracted by around 11 million individual domestic users (out of the 13 million people with no access to piped water) is estimated at around 400 Mm^3/yr. The increased extraction of groundwater for irrigation, combined with the pollution and damage caused to the coastal groundwater resource by the 2004 tsunami event—which affected more than 60,000 wells throughout the coastal zone, and in some places, almost up to 1.5 km inland—has raised more concerns about the sustainable management of this valuable resource.

Keywords: Agrowell, Dug well, Tube well, Groundwater, Irrigation, Domestic water supply, Sri Lanka, Tsunami.

1. Introduction

Sri Lanka is a tropical island in the Indian Ocean with a total land area of 65,610 square kilometers (km^2), which includes 2,905 km^2 of large inland water bodies. The topography of the island is flat in the coastal areas and mountainous towards its center. The country can be divided into the following three climatic zones based on the amount and pattern of annual rainfall they receive: the wet zone (over 2,500 millimeters per year [mm/yr]), the intermediate zone (1,500–2,500 mm/yr), and the dry zone (less than 1,500 mm/yr).

According to an *EarthTrends* country profile on Sri Lanka (WRI 2003), the amount of renewable water available within the island's freshwater ecosystems is estimated at 49 cubic kilometers (km^3) of surface water, 8 km^3 of groundwater, and an additional 7 km^3 of overlap water (shared between groundwater and surface water). Together these yield 2,592 cubic meter (m^3) of accessible water per

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person (2001 estimate). Sri Lanka receives an average of about 120 km^3 of freshwater annually from rainfall, of which more than 50 percent is lost through evapotranspiration. A further 20 percent infiltrates down to replenish the groundwater, while only 30 percent, or about 35 km^3, is available as surface run-off for stream flow. With the average annual rainfall varying from 1,000 mm/yr to over 5,000 mm/yr, there is considerable variation in time and space in the distribution and volume of the island's surface water, giving rise to frequent water scarcity, which is making groundwater a very important resource in the development of the country.

Both surface water and groundwater are widely used for domestic, commercial, industrial, and irrigation purposes. In 2000, according to a joint report from the World Health Organization (WHO) and UNICEF, 76.1 percent of Sri Lanka's urban population of 5.86 million had piped water supply compared to 11.4 percent of the 13.05 million in rural areas, while the urban and rural population using underground well water was estimated at 22.4 percent and 71.8 percent, respectively (WHO and UNICEF 2004). Also, a growing number of farmers in the dry zone have come to depend extensively on groundwater over the past few decades to supplement their water supply during shortages and for cultivating short-term crops during the dry season because of the recent rainfall changes and the highly diversified nature of agricultural activities. For groundwater extraction, farmers most commonly use either tube wells (borehole wells) or dug wells. The dug wells often have a fairly large diameter (4–6.5 meters [m]), are usually manually excavated and relatively shallow (4.5–12 m), and are sometimes equipped with a motorized pump. The wells that are used for agricultural purposes are commonly known as *agrowells* within the country.

2. Characteristics of accessible groundwater

There are six main types of groundwater aquifers demarcated and identified in Sri Lanka (Panabokke and Perera 2005), as follows:

- Shallow karstic aquifer
- Coastal sand aquifers
- Deep confined aquifers
- Lateritic (*cabook*) aquifer
- Alluvial aquifers
- Shallow regolith aquifer of the hard rock region

Figure 1 shows the distribution of these aquifers across the island. In addition to these major aquifers, a large number of small pockets of groundwater can be found throughout the country. These occur within either isolated patches of soil cover over the bedrock or in the fracture and weathered zones of the underlying metamorphic bedrock formation.

- **Shallow karstic aquifer**

This aquifer is found among sedimentary deposits of recent and Pleistocene deposits, Miocene, and older rocks. Its average thickness is around 60 m, but some of the central parts of the aquifer are 100–150 m thick. Water is found in channels and cavities (karsts) of the Miocene-era limestone and is mainly recharged by infiltrated rainfall. The annual volume of recharge to the aquifer is estimated to be around 100–200 million cubic meters (Mm^3/yr), of which only 50 percent is available for use, as the rest usually drains out into the ocean (Balendran et al. 1968). This is the most intensively utilized aquifer in Sri Lanka, as there is no surface water in the region, and most of the groundwater is extracted for domestic and agricultural use from over 100,000 open dug wells in the area.

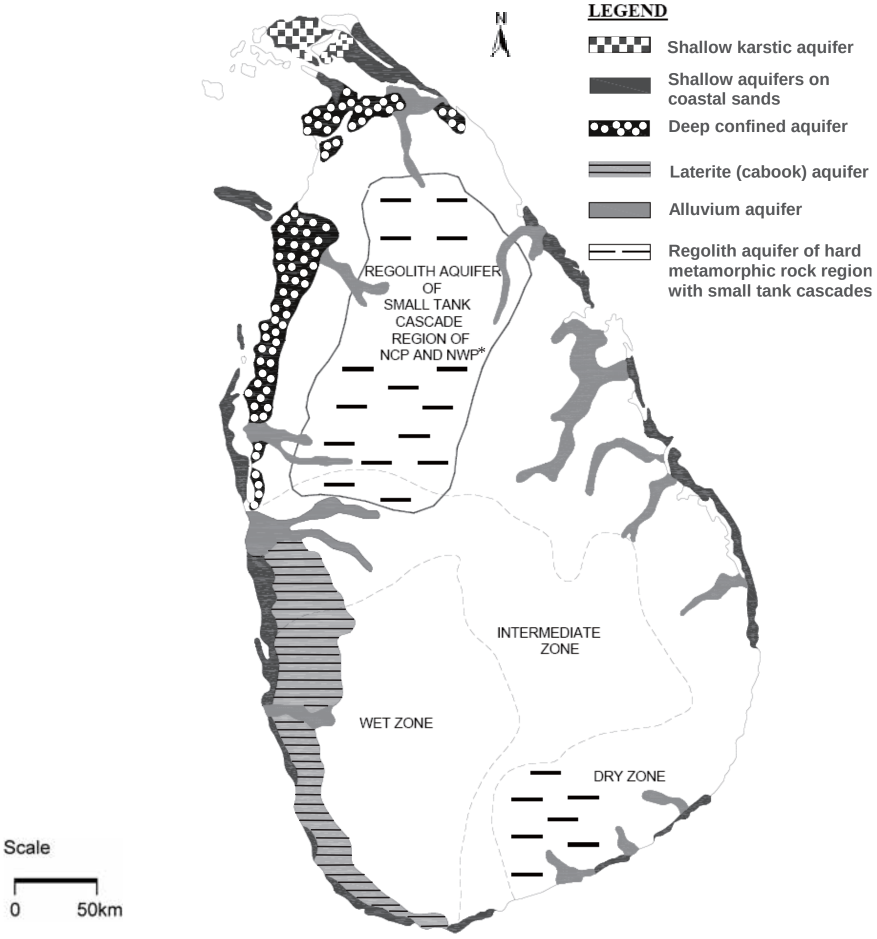

Figure 1. Major types of aquifers in Sri Lanka

*NCP = North Central Province; NWP = North Western Province.

- **Coastal sand aquifers**

Although thin sand aquifers are found in many isolated coastal areas, the two main coastal sand aquifers are located on Sri Lanka’s southeastern and northeastern coasts. Being thin, windblown sand dunes and lagoons (with 12–20 m-thick deposits), these two aquifers yield a limited but very important volume of groundwater. Although their size combined covers only about 125 km^2, they still constitute a very precious renewable groundwater supply that supports intensive human settlement, high-value intensive agriculture, and a flourishing tourist industry (Panabokke and Perera 2005).

• Deep confined aquifer

A number of distinct, confined aquifers are found within the sedimentary limestone and sandstone formations of the northwestern and northern coastal plains. Recent drill boreholes in these areas indicate that these aquifers are over 60 m thick, and in the deeper parts the sedimentary succession is over 500 m thick (Panabokke and Perera 2005). These sedimentary limestone formations are highly faulted and separate the aquifers into a series of isolated blocks. So far, seven separate aquifer basins have been identified. Although the “safe” or sustainable yield of all these aquifers is not known, studies on three of them estimate it to be around 3–9 Mm^3/yr each.

• Laterite (cabook) aquifer

Along the southwestern coast, lateritic deposits are found, mostly the result of in situ weathering of the Precambrian rocks. These laterite formations,[1] known as a *cabook formation* in Sri Lanka, have considerable water storage capacity, depending on the depth of formation. A typical profile in this region will show a transition from partly decomposed gneiss (banded or foliated metamorphic rock) through an intermediate zone of kaolin (fine clay) and angular quartz to the typical vesicular and sectile laterite where water can collect. The laterite layer has a honeycomb structure and is of moderate porosity and permeability. The lower kaolinitic layer, which is usually saturated with water, yields it back at a very slow rate. The zone of incipient decomposition immediately above the fresh bedrocks has been found in certain cases to yield water freely. The entire zone of weathering has irregular thickness, the average being about 12–20 m, and gives rise to patches of isolated aquifers. In certain areas, formations of over 35 m in thickness have been encountered. Due to the highly dissected nature of the macro-landscape in this region, the aquifer itself is highly fragmented and is separated within by intervening valley floors (Sirimanne 1957). In the wetern region, these vesicular laterites support relatively shallow aquifers that are easily accessible by dug wells or shallow tube (drilled) wells. High levels of nitrate have been observed in some of the domestic wells around the city of Colombo and its suburbs (Panabokke and Perera 2005).

• Alluvial aquifers

A highly diversified mix of broad and deep alluvial aquifers, with a variety of textures and gravel content, are found in some lower reaches of rivers and river deltas of the island. These alluvial deposits of both fine and coarse depositional in-fill material occur over several different landforms, such as coastal and inland flood plains, dissected and depositional river valleys, buried river channels, small rivulets and stream beds with shallow alluvial deposits, and inland valleys of varying shape. As an example, the estuarine deposits on the flood plain of the Kelani River and its tributaries normally have a profile of clays (lean, stiff, plastic, and organic) and peat. Furthermore, it is believed that a very high

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[1] Laterite is a red residual soil in humid tropical and subtropical regions, which is leached of soluble minerals, aluminum hydroxides, and silica but still contains concentrations of iron oxides and iron hydroxides.

groundwater yield is present in the palaeo-channels of the lower parts of the river alluvium close to Colombo. In general, the thickness of these alluvial deposits varies from 10–15 m and up to 35 m, and may even extend several hundreds of meters on either side of the riverbanks. A highly reliable volume of groundwater can be extracted from these alluvial aquifers throughout the year, but poor quality groundwater exists where beds of organic clays and peat are present. In addition to these large systems, there are many small alluvial water deposits on riverbanks throughout the country that yield a fair volume of groundwater.

- **Regolith aquifer of hard metamorphic rocks**

Many have recognized that the groundwater potential in the hard rock region of Sri Lanka is limited, as these formations have low storage capacity and transmissivity (Sirimanne 1952). It is well known that the available groundwater in hard rock formations is only found in isolated patches within the weathered rock zones (the regolith), or within the deeper fracture zones of the basement rocks. The weathered bedrock zone generally ranges from 2–10 m in thickness, but in some places the fracture zone extends to depths over 30–40 m (Panabokke 2003). Further to this, the Precambrian rocks with isolated patches of soil also cover up to 30 m or more in thickness, forming the minor, localized aquifers found throughout the country. Although the permeability of these isolated soil patches is rather low, the abundant rainfall makes these aquifers perennial in nature. Also, in the valleys (often used for paddy fields, etc.) are found alluvial sediments containing clays, sandy clays, and sometimes pebble beds that carry and yield groundwater. The fissures and joint planes, especially in the limestones and quartzites, carry and transmit water, and low yields may be obtained from them.

3. Types of groundwater use

The demand for groundwater in Sri Lanka is steadily increasing—especially for urban and rural water supplies—and for irrigated agriculture, industrial estates, aquaculture, small and medium enterprises, and urban housing developments. The rapid increase in these demands is exerting considerable pressure on the available groundwater resource.

3.1. Domestic use

In Sri Lanka, about 70 percent of rural and 25 percent of urban households satisfy their daily water requirements with groundwater by means of dug wells or tube wells (borehole wells). This percentage is increasing, however, because the piped water supply is getting costlier and is not always reliable. In this context, many industrial and commercial users (and some individual households) throughout the country that have piped water supply also have a supplementary groundwater system to save money and to have a margin of safety to ensure their supply. Out of these, most industries now depend heavily on deep wells because the groundwater is good quality and can be self-managed.

There are presently over 300 urban and rural piped water supply schemes operating across the country, with almost one-third of them relying entirely on groundwater. Figure 2 shows the location of the 93 that extract water exclusively from shallow and deep groundwater sources for their supply (Panabokke and Perera 2005). The total amount of groundwater they withdraw exceeds over 16 Mm^3/yr, which includes supply to many industrial zones and urban and rural centers. The volume of groundwater abstracted by around 11 million individual domestic users (out of the 13 million people with no access to piped water) can be estimated at around 400 Mm^3/yr. Note that this estimate does not include households with a piped water supply that use groundwater as their supplementary water source.

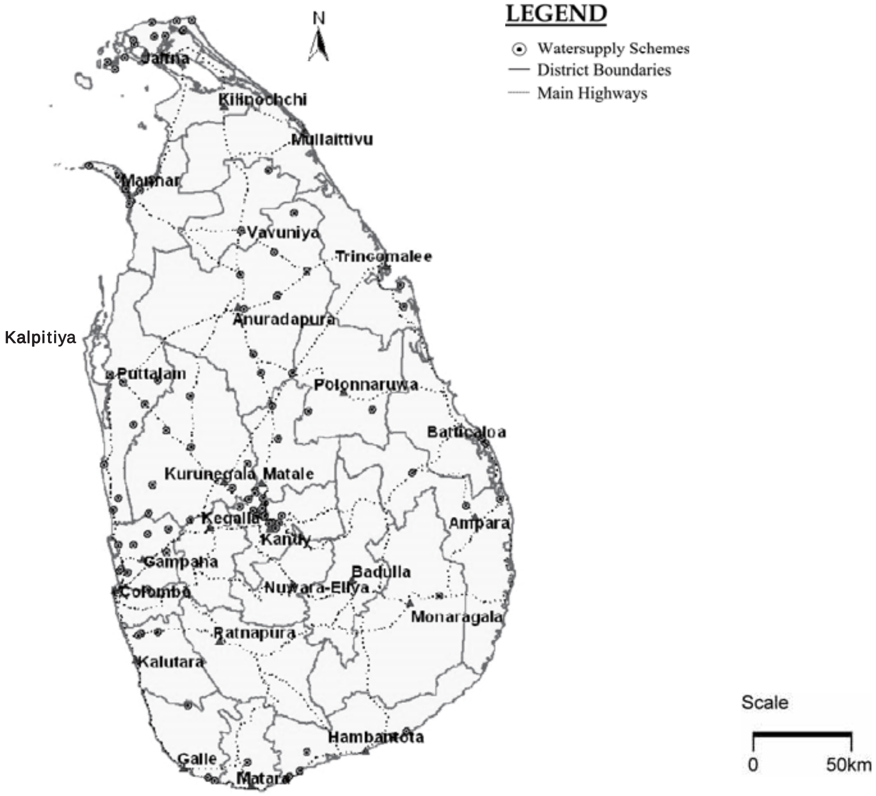

Figure 2. Distribution of urban, rural, and industrial water supply schemes that rely entirely on groundwater

The above data shows that the shallow, open dug wells distributed across the country provide the basic drinking and domestic water supplies to most of the population. But with the rapid increase in population that has taken place over the past two to three decades, increasing water stress is being seen in both declining quantity and quality of water. In fact, the long-term sustainability of this valuable resource is very uncertain, and overuse could lead to acute drinking water shortages in the future for the following reasons: (1) no proper guidelines or guidance exist for safe and sustainable development of the groundwater resource, (2) there is no system for monitoring or recording the use of groundwater and changing characteristics of the aquifers, (3) there is no proper authority overseeing the overall management of the groundwater resource, and (4) there is no easy access to groundwater data, etc.

3.2. Agricultural irrigation

Water scarcity is one of the major challenges for agricultural activities in the intermediate and dry zones of Sri Lanka. The average annual rainfall in the dry zone is about 1,200 mm/yr, and usually occurs during the two distinct rainy seasons, traditionally called the *Yala* and the *Maha*. The Yala season begins in April and ends in July, while the Maha season begins in October and ends in late December. Most of the annual rainfall (over 80 percent) in this dry region occurs during the Maha season. Due to various changes occurring with the rainfall pattern, however, water shortages (even during the Maha season) have become a common occurrence over the past 25 years (Wickramaratne and Dharmagunawardhane 1998).

In addition, agricultural activities in these areas have become so diversified during the past few decades that farmers, in addition to their regular paddy cultivation, often grow other crops during the rest of the year (dry period) using alternate sources of water for irrigation—either water diverted from the wet zone or groundwater. As the water from the wet zone is available only from major irrigation networks and only at specific times, farmers with smaller irrigation schemes, often clustered around small water tanks (reservoirs), mostly depend on stored rainwater to irrigate their off-season crops during the dry periods. Since the storage capacity of these is not adequate to support diversified agricultural needs throughout the year, however, it has become common among farmers to use groundwater—historically used mostly for domestic purposes.

Wells constructed specifically for irrigation are typically shallow and one of the following three types: lined dug well, unlined dug well, or tube well.[2] A ring-wall, usually measuring one-half to one meter high, protects the mouth of the lined dug well, while the unlined dug well is usually left unprotected, walled simply by exposed gravel or rock. Tube wells are constructed by first drilling down to the water table at 5–18 m deep and then inserting a PVC pipe (50–150 mm diameter) to access the groundwater below.

According to a report published by the International Water Management Institute (IWMI) on the trend and present status of agrowells in Sri Lanka (Kikuchi et al. 2003), there is no uniform pattern in agrowell use and distribution in the dry zone or among large and small irrigation schemes. This has made it more difficult to understand the rapid growth of the number of agrowells on the island over the last two decades (from 0 to over 50,000). As most farmers use low-capacity pumps to draw water from wells, a typical agrowell with a small pump can irrigate 0.2–0.8 hectares (ha) of cropland (Kikuchi et al. 2003). They use these wells mostly to irrigate non-paddy crops in the dry seasons. In some instances, however, agrowells are also used to irrigate paddy fields, especially towards the latter part of the cultivation period, due to lack of rainfall or access to other sources of water, or for a third short term of paddy cultivation.[3]

With the introduction and diffusion of agrowells, the cropping patterns in the dry zone have changed from cultivating low-value, drought-resistant crops to the intensive cultivation of high-value crops such

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[2] Regardless of the size and type, a well is defined in this section as an *agrowell* as long as the water from it is used at least partly for irrigation.

[3] General and recommended practice is to have only two paddy cultivation periods in the Yala and Maha seasons.

as onions, chilies, and bananas. This has increased the cropping intensity during the low rainfall (dry) season from 20–80 percent within the major irrigation schemes and in minor schemes in the highlands (Kikuchi et al. 2003).

a. Growth in the number of agrowells

According to some studies of historical data, the rapid diffusion of agrowells began in the early 1980s, while the expansion of lined dug wells accelerated in the early 1990s. The use of pumps to move water and irrigate crops preceded the use of agrowells by about a decade (Kikuchi et al. 2003). Due to a growing interest in agrowells among farmers, the government along, with many non-governmental organizations, initiated financial support schemes (subsidies in terms of monitory assistance for well construction) to encourage agrowell use.

In general, including both major and minor irrigation schemes, 55 percent of farmers in the dry zone use groundwater and 45 percent use surface water to cultivate off-season crops, compared to the water use of those in the south, where it is 10 percent and 90 percent, respectively (Kikuchi et al. 2003). This variation from north to south is well understood, as the availability of groundwater is generally better in the northwest than in the south. Data on the estimated growth of agrowells in the dry zone during the past 30 years are provided in table 1, which shows that the number of agrowells had grown from none in 1980 to 50,456 by the end of 2000, out of which 40,746 were in the northwest region (Kikuchi et al. 2003).

Table 1. Number of agrowells in the dry zone

Year	Lined dug wells	Unlined dug wells	Tube wells	Total
1975	0	0	0	0
1980	0	0	0	0
1985	400	0	100	500
1990	4,800	100	500	5,400
1995	13,900	2,100	3,200	19,200
2000	32,465	8,236	9,755	50,456

Source: Kikuchi et al. 2003.

b. Implications of the agrowell program for the groundwater resource

Although the original objective of supporting the agrowell program financially was to assist farmers to cultivate crops close to their homesteads and in highland areas where cultivation depends on rainwater, it is now seen, however, that farmers have often established agrowells to support paddy cultivation in areas where it is felt that the amount of water provided by gravity-fed irrigation from tanks needs to be supplemented. This change in irrigation pattern and the haphazard rapid expansion of agrowells without proper hydrogeological assessments is expected to create many problems in various parts of the dry zone (Wijesinghe and Kodithuwakku 1990). In general, the groundwater level varies annually between 1.9–5.0 m below ground level in the northwestern region, with the average at about 3.5 m below ground. Farmers used to extract groundwater at rates typically ranging between 27 cubic meters per hour (m^3/h) and 45 m^3/h (Premanath and Liyanapatabendi 1994). In some parts, these high pumping rates have lowered the groundwater table, causing wells to run dry and affecting natural rivers, streams, and wells, including those used for drinking. If this situation gets worse, it could become severe, especially during the more frequent extended dry spells being experienced, possibly due to climate change (Ratnayake and Herath 2004).

A study done in the highland areas by the National Water Supply and Drainage Board found that for each acre (0.404 ha) irrigated using groundwater, a recharge area of 34 acres (13.736 ha) is required in order to have a sustainable use/supply situation. The corresponding figure for lowland areas is 17 acres (6.868 ha) per acre cultivated (Kikuchi et al. 2003). According to the IWMI report (Kikuchi et al. 2003), agrowell distribution and density differ considerably across regions and between individual schemes. Within the major schemes in the northwest, however, the density is as high as 27 wells per 100 ha (an average of only 3.7 ha, or 9.1 acres, of recharge area per well) and 22 wells per 100 ha (average of 3 ha, or 7.4 acres, per well). There are also several other mid-sized irrigation schemes within the region with over 10 wells per 100 ha in their densest area.

The target beneficiaries of the financially supported agrowell program are, to a large extent, the poor peasants who used to only cultivate a single season with rainwater and abandoned cultivation during the dry season due to an inadequate supply of water. In most situations, even rainy-season crops were subjected to severe water shortage towards the end of the cropping season. With the introduction of the agrowell program, these farmers today are benefiting from full cultivation seasons and, in a few cases, even a short third one between the two major seasons. Also, in most cases, cultivation is comprised of cash crops such as chilies, Bombay onions, red onions, and vegetables, which have increased people’s incomes substantially, in some cases up to ten times. As a result, the peasants who often had to migrate as laborers are now employed full-time in their cultivation areas, earning in the range of 20,000–40,000 Sri Lanka rupees (SLR) per season per acre.[4]

This program has so far had only a very few cases of adverse effects especially attributed to the haphazard diffusion of wells. There were no cases reported of wells abandoned, overt depletion of groundwater, or an adverse impact on water quality due to the pumping of water from agrowells. In one exception though, farmers complained of groundwater and surface water shortages caused by heavy groundwater pumping in the upper reaches. In this case, there were many abandoned wells, lined dug wells in particular, in the paddy fields and highlands of this particular irrigation scheme. The major reason the wells were abandoned, however, was the poor groundwater conditions and low profitability—not the depletion of groundwater due to pumping (Kikuchi et al. 2003). Most experts believe, however, that this low number of negative incidences involving agrowell schemes is due to the relatively short history of use. Therefore, a proper policy framework should be put in place to achieve the long-term sustainability of the agrowell program.

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[4] Conversion: US$1 = ~100 SLR (August 2005).

c. Agrowells in Kalpitiya

The main reason for considering the agrowells in the Kalpitiya area separately is due to the fact that it is a sand dune beach formation with a high-yielding groundwater aquifer. The area is famous for its productive vegetable farming, which is based on the intensive use of dug wells and tube wells, and the vegetable farmers here depend almost entirely on groundwater for irrigation (~100 percent). The Kalpitiya Peninsula is a narrow corridor of coastal land measuring 1,800 ha (figure 2), where about 1,500 farmers grow vegetables and other crops, such as red onion, chili, string bean, sweet potato, and tobacco, using groundwater from agrowells (Kikuchi et al. 2003).

In the past among farmers in this area, an open dug well design with a 2.4-m diameter and 3-m depth was most popular. Since the mid-1990s, however, tube wells using 50–150 mm diameter pipes have become very popular, which extract water at a depth of 6–10.7 m using electric motors (1.5–2 horsepower) to pump out the groundwater. Their use has grown so rapidly that, by the end of 2000, about 40 percent of farmers in the area were using tube wells, many installed with an underground network of pipes (5 mm diameter) to distribute water to their fields. A typical dug well or tube well in Kalpitiya is able to irrigate about 1.2 ha. The pervasiveness of agrowells and pumps in the Kalpitiya Peninsula is reflected in their high density: 82 dug wells and 33 tube wells per 100 ha in the upland area (Kikuchi et al. 2003). Groundwater conditions in the area allow year-round irrigation with maximum flexibility for farmers, making it possible for them to practice many combinations and rotations of a wide variety of crops at one time as well as over a period of time.

4. Impact of the 2004 tsunami on water resources

Sri Lanka has a coastline of approximately 1,660 km. This coastal zone is very diverse and contains lagoons and estuaries, fringing and offshore reefs, mangrove swamps, sea-grass beds, salt marshes, beaches, sand spits, rocky shores, and dune systems. The events near the island of Sumatra, Indonesia, many kilometers away, on December 26, 2004 (6:58:23 a.m. Sri Lankan time to be precise), hit Sri Lanka’s coasts with varying impacts; the eastern, northern, and southern coasts were especially devastated (ADB et al. 2005; UNEP 2005). When the tsunami waves struck the coastal belt, almost two-thirds of the coastline areas were destroyed, although there were patches in between where no impact occurred at all.

Over 40,000 lives were lost in Sri Lanka alone, and many thousands more were displaced due to flood waves and extensive property damage. In addition, most of the natural coastal ecosystem was destroyed and infrastructure and facilities were totally devastated. Eleven sectors were identified as having been affected by the destruction caused by the tsunami. There was widespread damage done especially to the water sector, including drinking water supply schemes and distribution systems, wastewater treatment plants and collection systems, on-site individual wastewater treatment systems, groundwater wells, and hot water springs.

Shallow groundwater wells have traditionally provided the main domestic water source in many coastal areas. The majority of rural and semi-urban people, especially on the eastern coast, rely heavily on groundwater from sandy aquifers for domestic and agricultural activities. In urban areas, however, these sources have been supplemented with piped and tapped surface or groundwater (Panabokke and Perera 2005). Immediately after the tsunami, it was estimated that considerably more than 60,000 groundwater wells (mostly dug wells) were affected throughout the coastal zone, and in some places, almost up to 1.5 km inland, they were totally destroyed or partially damaged. Many were left unfit for human consumption, even for bathing and washing purposes (ADB et al. 2005; UNEP 2005). The damage caused to these wells ranged from filling with debris, sewage, and saltwater to saltwater intrusion from the stagnant saline water collected in local depressions. Furthermore, the disruption and changes to the coastline also altered the properties and quality of soil and, subsequently, the water in the coastal aquifers. Figure 3 depicts the situation before the tsunami hit, and figure 4 shows the saline water intrusion into the coastal freshwater aquifer and then into the dug well system that occurred after. A few days after the tsunami event, a study conducted by Jayaweera et al. (2005) found a chemical oxygen demand (COD) level of 128 milligrams per liter (mg/L), total and fecal coliform levels exceeding 30 and 7 pfu/100 mL, and conductivity levels over 3,000 μS/cm in some contaminated wells.[5]

The two most common methods used to clean up wells soon after the tsunami was either emptying the contaminated water by pumping, or manual cleaning and disinfection using bleaching powder (sodium hypochloride). These restoration efforts encountered various problems, however, as most of the people involved often lacked specialized knowledge. Most of the cleaned wells were reported to remain saline, even after repeated cleaning and emptying. Furthermore, wells sometimes collapsed during the cleaning process and the presence of contaminants from other sources of pollution posed potential health hazards that were not a significant problem previously (Jayaweera et al. 2005; Villholth et al. 2005). These experiences made very clear the necessity of a well-coordinated and integrated plan for the restoration of the impacts of the tsunami on groundwater resources and the implementation of relief measures. In this regard, the IWMI, after some monitoring, suggested a set of possible guidelines to follow with respect to cleaning up wells after a tsunami event, which includes short-term as well as long-term measures (Villholth et al. 2005).

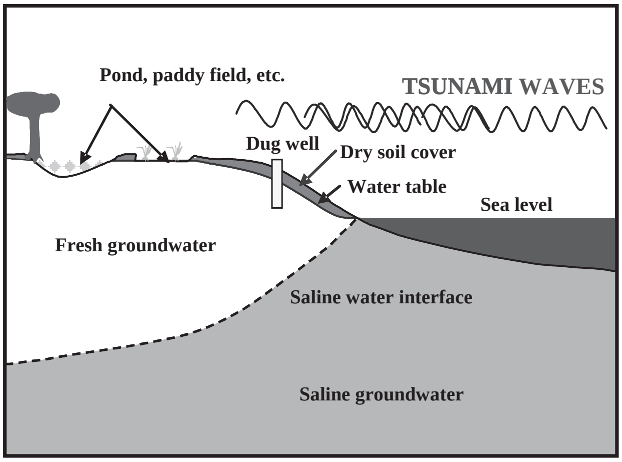

Figure 3. The coastal area ecosystem just before the tsunami event

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[5] pfu = plaque-forming units; μS = microSeimen.

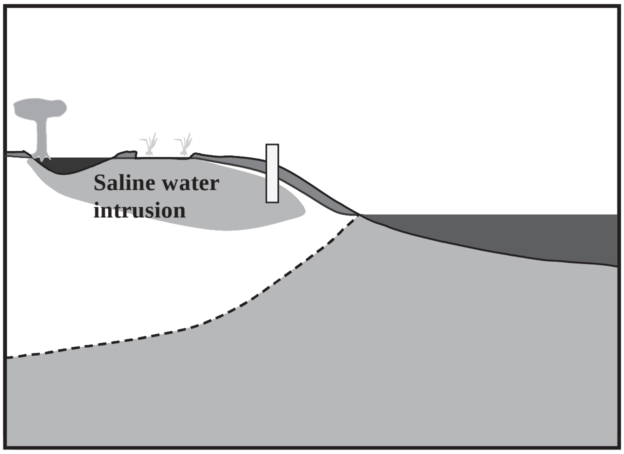

Figure 4. The coastal area ecosystem a few days after the tsunami event

5. Conclusion

Water shortages have become a common occurrence in Sri Lanka over the past 25 years—even during the rainy season in some places—because of a combination of less rainfall and demands from a growing population, industry, and irrigated agriculture. A large change has occurred in irrigation patterns, and the haphazard rapid expansion of agrowells without proper hydrogeological assessments is expected to create many problems in various parts of the dry zone. With the rapid increase in population that has taken place over recent decades, especially, increasing water stress is being seen in both declining quantity and quality of water.

In some parts of the country, high pumping rates have lowered the groundwater table, causing wells to run dry and affecting natural rivers, streams, and wells, including those used for drinking. If this situation gets worse, it could become severe, especially during the more frequent extended dry spells being experienced, possibly due to climate change. In fact, the long-term sustainability of this valuable resource is very uncertain, and overuse could lead to acute drinking water shortages in the future.

Since the government, along with many non-governmental organizations, initiated financial support schemes (subsidies) to encourage the use of agrowells, the number of wells used for agriculture in the dry zone has increased from none in 1980 to 50,456 in 2000, raising many concerns about overuse. While many have benefited from the agrowell program, further planning and implementation should be done in an integrated manner based on the actual supply/demand situation.

The latest damage to groundwater resources was the 2004 tsunami event, which demolished almost two-thirds of Sri Lanka's coastline areas and totally destroyed or partially damaged more than 60,000 groundwater wells (mostly dug wells), in some places almost up to 1.5 km inland. Many were left unfit for human consumption, even for bathing and washing purposes, placing even more pressure on available water resources.

Based on the data in this paper, the following recommendations are offered in order help move towards sustainably managing groundwater resources in Sri Lanka:

1. Proper guidelines and guidance should be created for safe and sustainable development of groundwater resources.
2. A system should be put in place to monitor and record groundwater use and the changing characteristics of the aquifers.
3. A main authority should be established to oversee the overall management of groundwater resources.
4. There needs to be easier access to groundwater data.
5. A proper policy framework should be put in place to achieve the long-term sustainability of the agrowell program.
6. A well-coordinated and integrated plan is needed for the restoration of the impacts of the tsunami on groundwater resources and the implementation of relief measures and long-term initiatives.

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