1. INTRODUCTION

1.1. Sri Lanka

Sri Lanka is a tropical island situated just north of the equator, off the southern tip of the Indian sub-continent. It is a developing country, which is facing the numerous challenges common to most developing countries in Asia and the world over.

In the past two decades or so, Sri Lanka has made rapid shifts away from a predominantly agricultural economy, towards a target of achieving 'Newly Industrialized Country (NIC)' status by the year 2010. This has resulted in an increasing urbanization trend and a rural-urban population shift. The rapid growth of urban population has placed increasing pressures on urban infrastructure services such as electricity, water supply, wastewater and solid waste management. Both government and local authorities have, in the past, given higher priority to 'direct-benefit' services such as electricity and water supply at the expense of sanitation.

1.1.1. Relief and drainage

Sri Lanka is situated between latitudes 5^0 55' N and 9^0 50' N and longitudes 79^0 31' E and 79^0 42 E'. The land area is 65,510 square kilometres with 2905 square kilometres of large inland waters (Survey Dept. of Sri Lanka, 1988). The surface configuration comprises three peneplains ascending up to a central highland massif. The lowest is the coastal peneplain, which varies in relief from sea level to about 100 metres, and includes the city of Colombo situated on the southwest coast. The mid peneplain is approximately between 300 - 500 metres above sea level and includes the city of Kandy. The high peneplain is at approximately 1000 – 2000 metres above sea level and includes the resort town of Nuwara Eliya.

Sri Lanka is drained in a radial pattern by 103 river basins radiating from the central mountain massif to the coastal plains. The average length of a river is 135 kilometres with an average catchment size of 575 square kilometres. The longest is the Mahaveli, being 335 kilometres long, with a catchment area of 10448 square kilometres (Perera, 1997). Figure 1-1 shows a relief and drainage map of Sri Lanka and Table 1-1 provides a size classification of river basins.

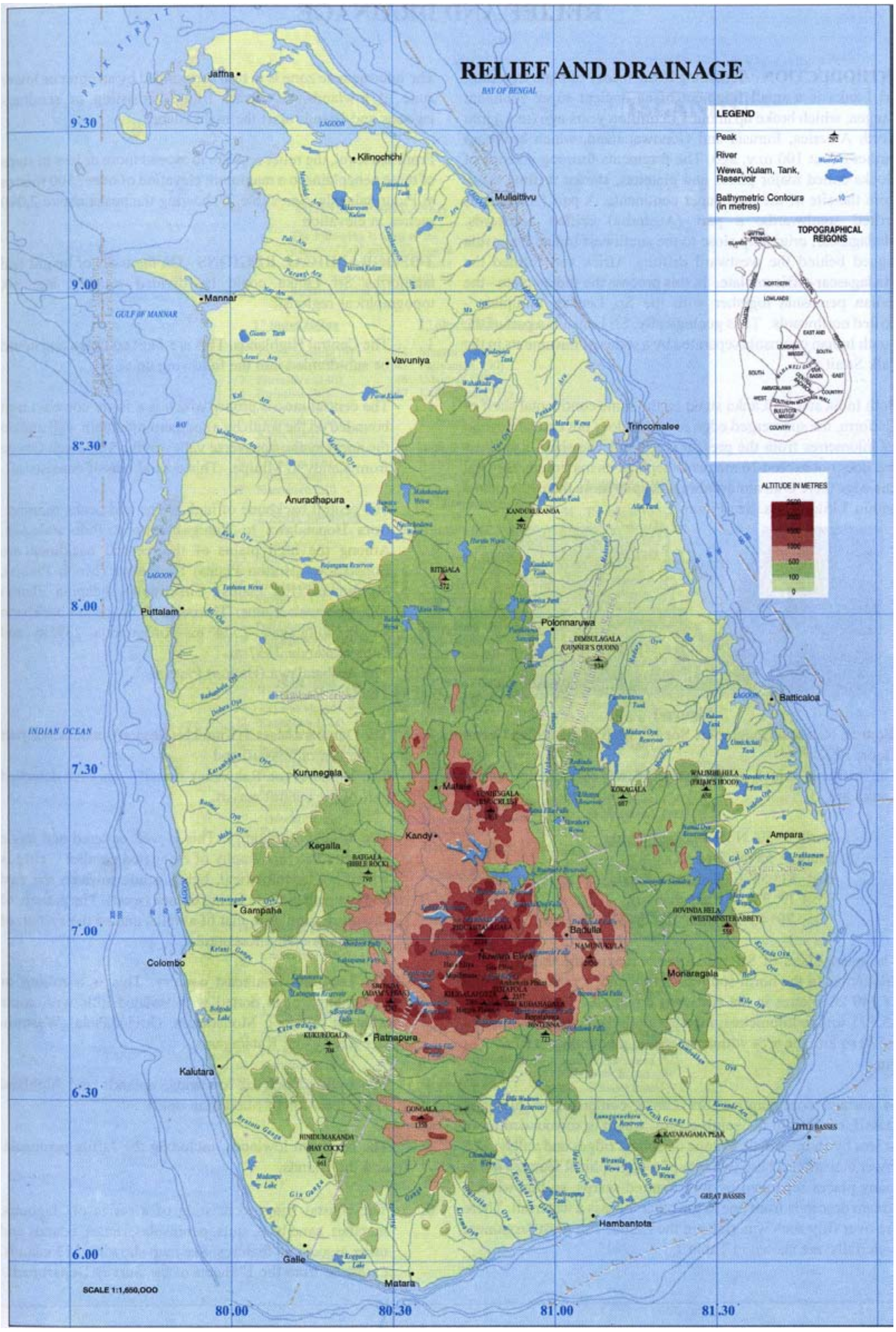

Figure 1-1. Relief and drainage map of Sri Lanka[1]

[1] From Vithanage, 1997

Table 1-1. Classification of river basins by catchment area[2]

Size class (km^2)	Number
< 100	43
100-1000	43
1000-2500	10
> 2500	5

1.1.2. Climate

Sri Lanka is divided into two principal climatic zones based on rainfall. The southwest quarter of the island is known as the wet zone and the remaining three quarters is referred to as the dry zone. The annual rainfall varies between 500 – 2000 millimetres in the dry zone and between 2000 – 5000 millimetres in the wet zone. The rainfall is experienced during four distinct periods: two monsoonal periods and two inter-monsoonal periods. The southwest monsoon is experienced from May - September and brings with it the heaviest rainfall over the wet zone. The northeast monsoon is from December to February with lesser rainfall over the dry zone areas. In between these two monsoons are the inter-monsoonal periods, March – April and October-November (de Silva, 1997). Figure 1-2 shows the spatial distribution of rainfall over the island.

The average annual temperature in the lowlands is 28^0 Celsius with a variation of 1.5^0C - 4^0C between the warmest and coldest months of the year. The temperature lapse rate is approximately 2^0C for every 300 metres of altitude. Kandy, at 450 metres above sea level, has an average temperature of 23^0C and Nuwara Eliya, at 1800 metres, an average of 16^0C. Diurnal variations in temperature range from 6^0C in the lowlands to10^0C in the highlands (de Silva, 1997). Figure 1-3 shows the spatial distribution of temperature across the island.

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[2] Adapted from Perera, 1997

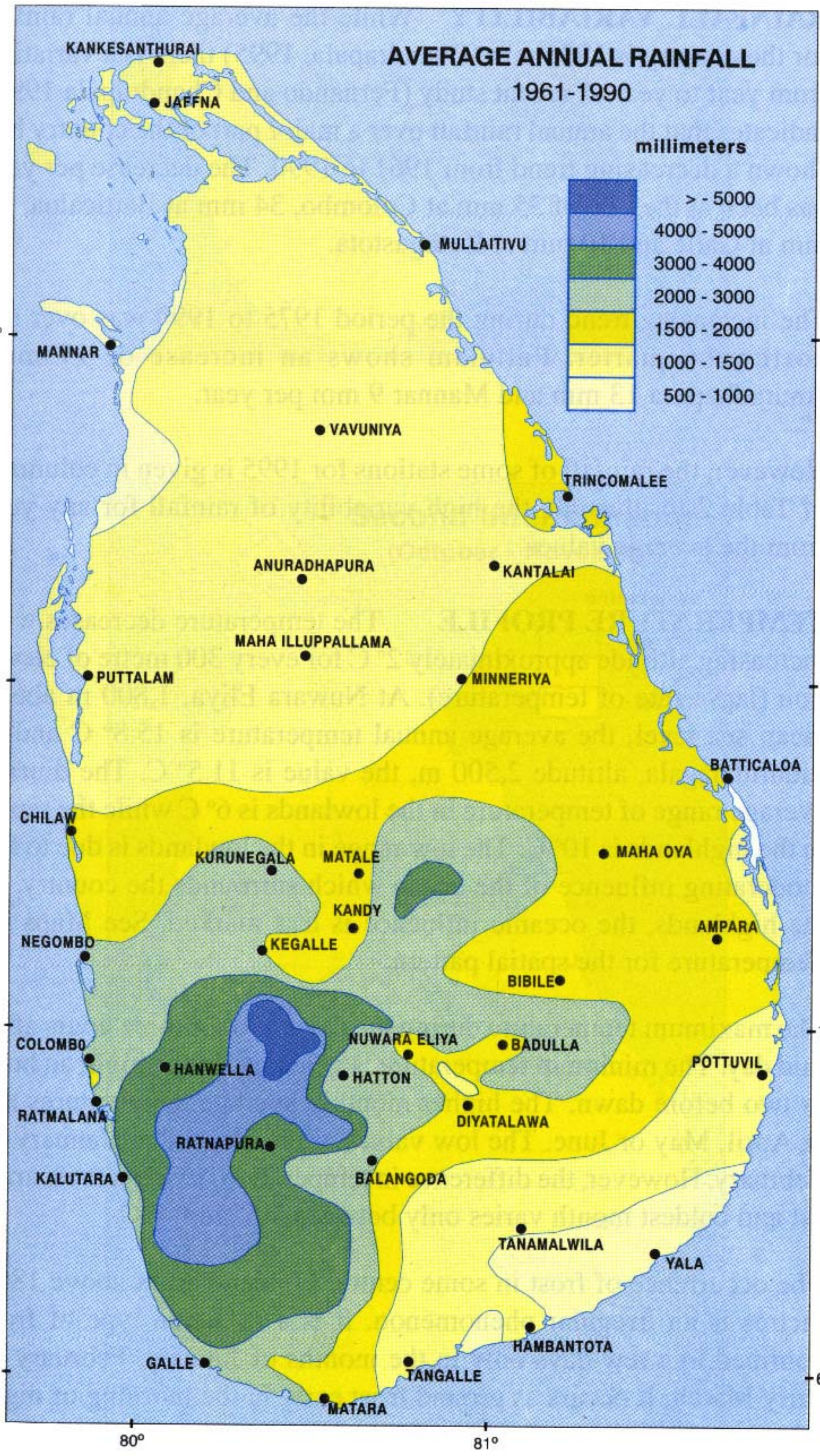

Figure 1-2. Average annual rainfall in Sri Lanka[3]

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[3] From de Silva and Fernando (1997)

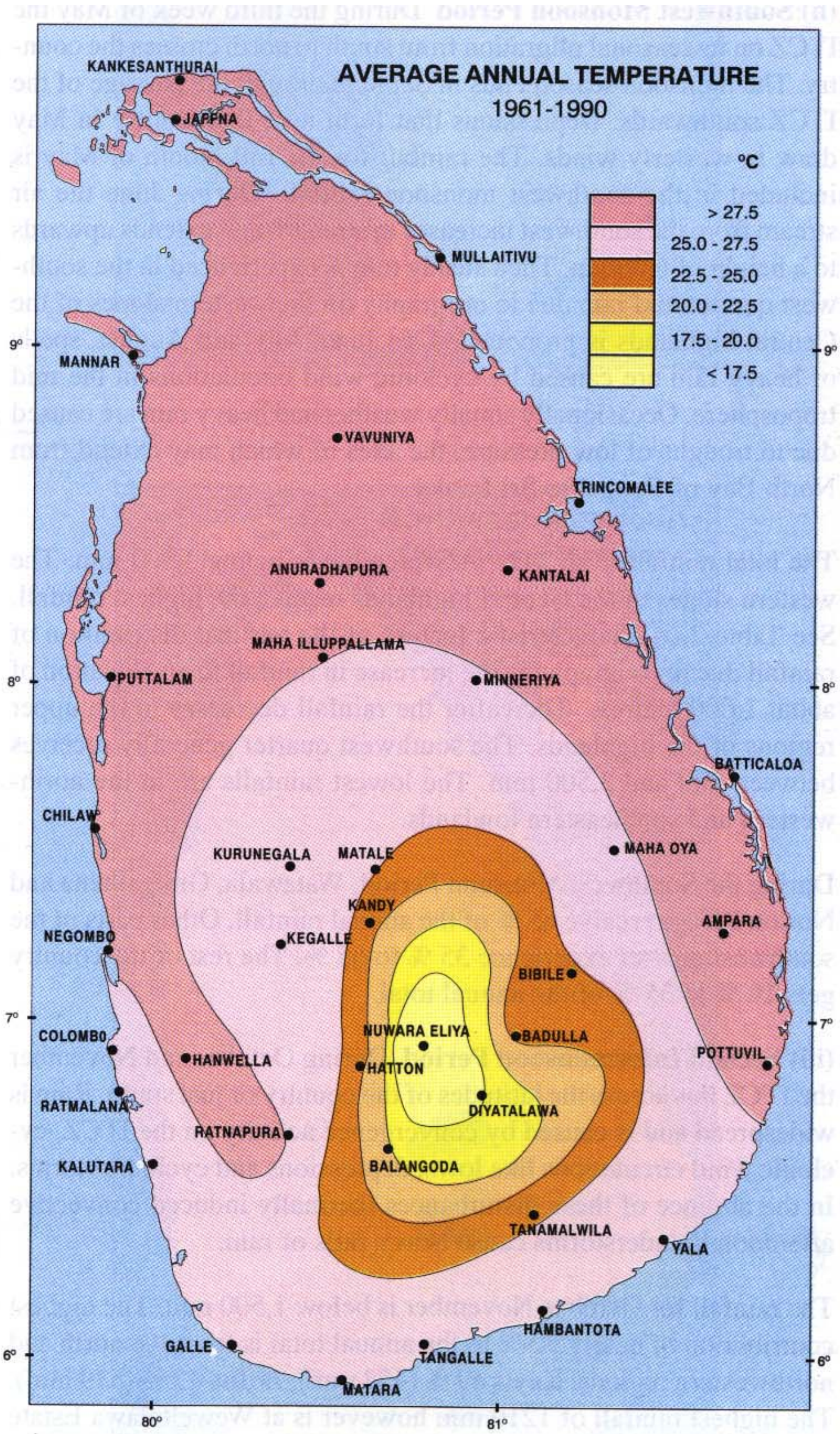

Figure 1-3. Average annual temperatures in Sri Lanka[3]

1.1.3. Population and demography

The population of Sri Lanka was estimated to be 18.3 million in mid 1996, with an average national population density of 292 persons per square kilometre (Dept. of census and statistics, 1997). This would rank Sri Lanka as 20th in the world in population density (Somasekaram, 1997). The population of Sri Lanka has been increasing at a declining rate of growth from 3 percent in the 1950's down to 1.3 percent in the 1990's. According to current trends, the population is expected to grow at a decreasing rate to stabilize around 22 million in the year 2020 (de Silva. 1997).

The distribution of population across the country is very uneven, with the population clustered extremely densely in a few areas in the south-western and central parts of the country and spread out much less densely in most other parts. In 1981, 55 percent of the population was found to be concentrated in just 20 percent of the land area. The smallest administrative district of Colombo, covering just one percent of the land area carried 11 percent of the total population at a district-wide density of over 3100 persons per square kilometre. At the other extreme, a mere 10 percent of the population is spread out over 40 percent of the land, mostly in the north-central and eastern areas of the country. However, even in these districts, the population density ranges between 35 – 100 persons per square kilometre on a district-wide basis (de Silva, 1997). Within districts, the population density is further concentrated in and around towns, thinning out away from the main roads, in the typical pattern of 'strip-development' in developing countries. The variation of population density by administrative district is shown in Figure 1-4.

The literacy rate of the total population in 1994 was 90.1 percent for both sexes, with 92.5 percent for males and 87.9 percent for females (Dept of Census and Statistics, 1997). The unemployment rate was 12.7 percent in 1995 (Central Bank of Sri Lanka, 1995)

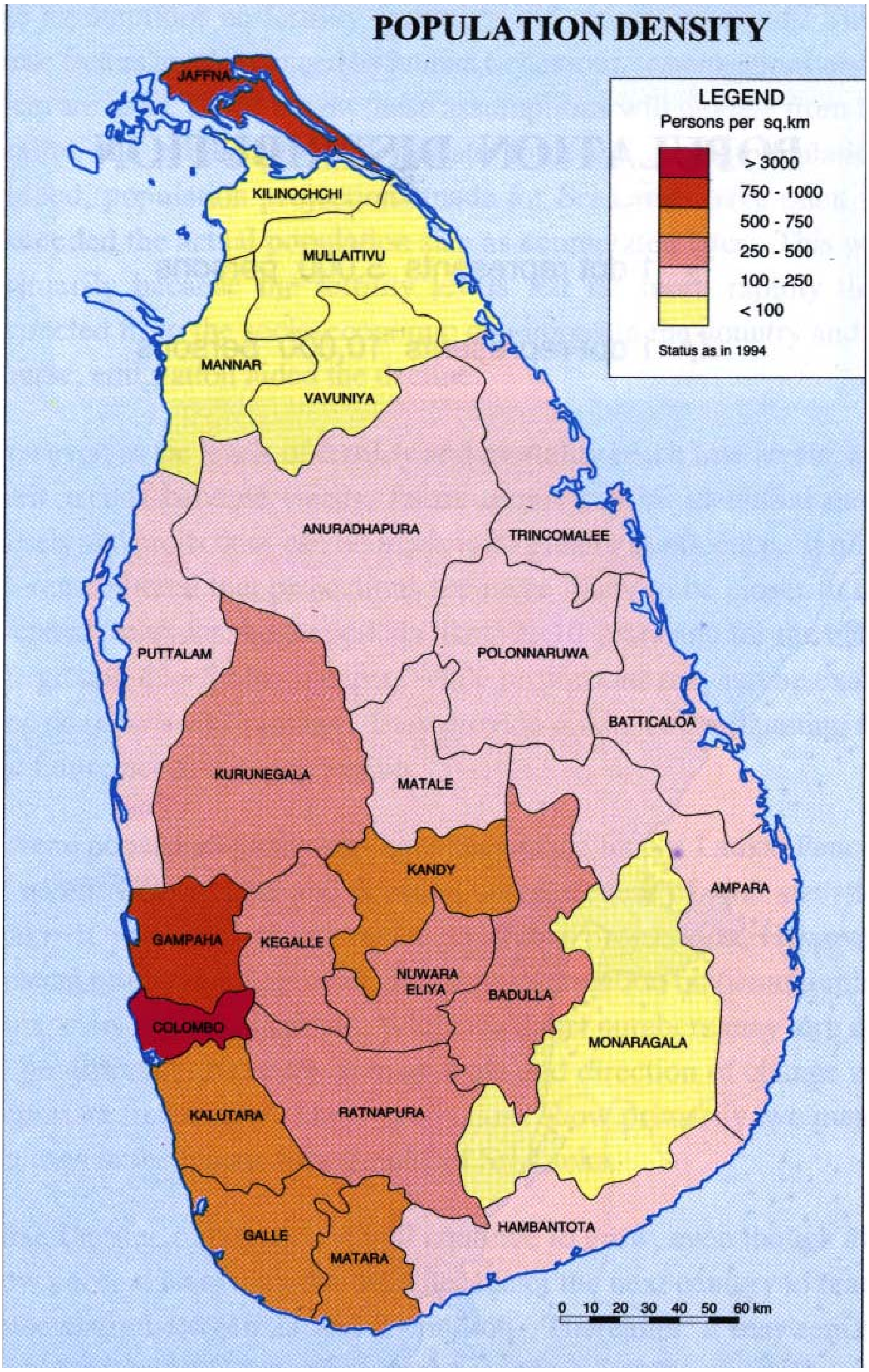

Figure 1-4. Population density by administrative districts in Sri Lanka[4]

[4] From de Silva (1997)

1.1.4. Urban settlements

Settlements in Sri Lanka cover the whole range from isolated farmsteads to hamlets, villages, towns, cities and metropolitan regions, and are categorized as urban and rural. In Sri Lanka, urban settlements are defined as those settlements administered by municipal and urban councils, while all remaining settlements are classified as rural. This is not a very satisfactory categorization as it results in many settlements with urban characteristics being classified as 'rural' and results in the actual degree of urbanization being under-reported in most instances. These urban settlements are distributed unevenly across the country and are concentrated in three major areas along the south-western and southern coastline, in the hill country, and in the Jaffna peninsula. Figure 1-5 shows the distribution of urban settlements according to the current classification.

Recent trends in urban growth include the expansion of the City of Colombo into a vast functional urban region known as the Colombo Metropolitan Region (CMR), the expansion of Kandy and Galle into metropolitan regions, and the linking of towns by urban sprawl. The proportion of people living in urban settlements is expected to increase to between 42 and 50 percent in the year 2010 from its present level of around 20 percent (Wanasinghe, 1997). However, this does not include the people living in 'urban pockets' of settlements currently classified as 'rural'.

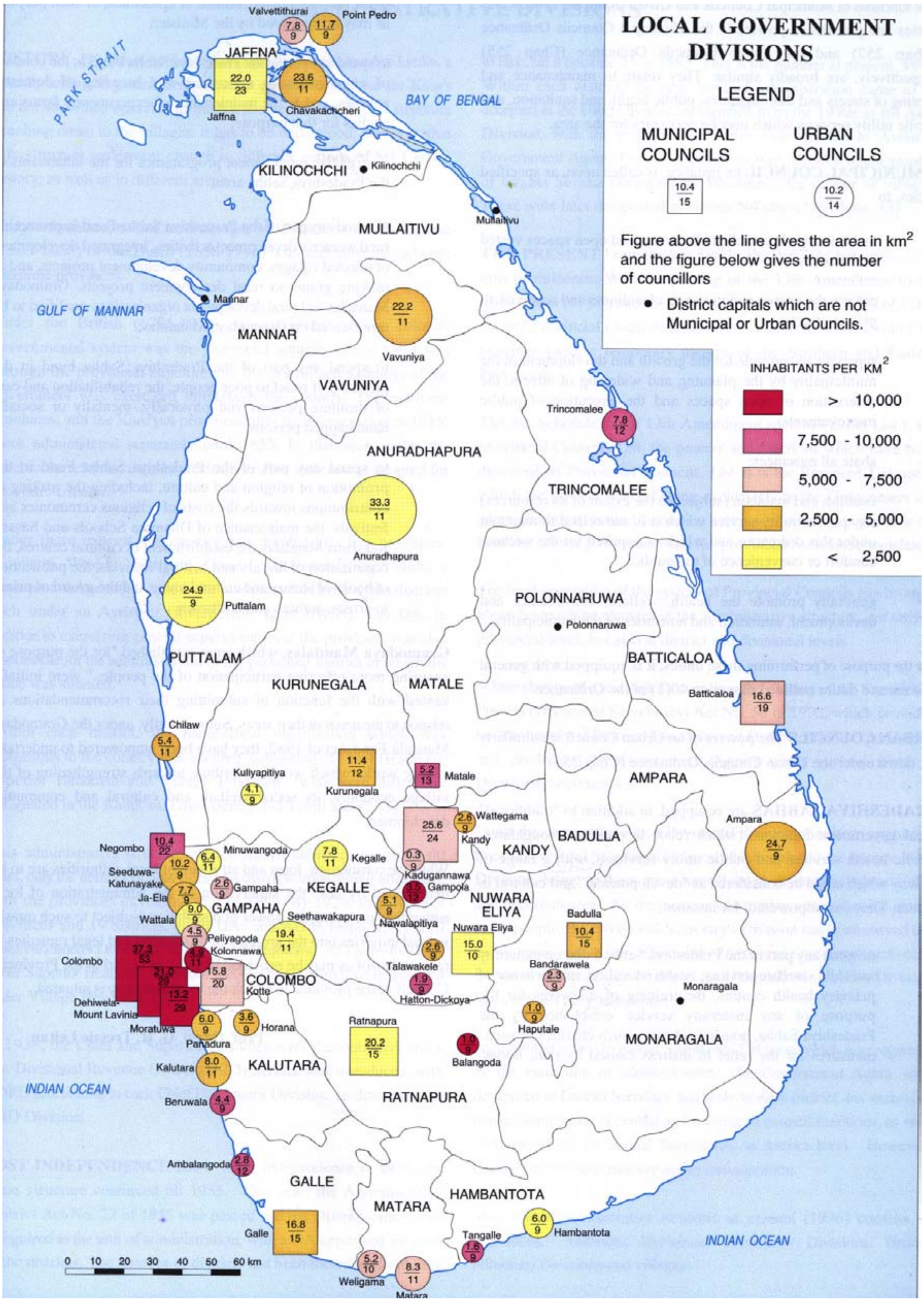

Figure 1-5. Distribution of settlements in Sri Lanka which are currently classified as 'urban'[5]

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5 From Tressie Leitan, 1997.

1.1.5. Housing

According to the demographic survey of 1994, there were close upon 3.3 million households living in 3.2 million housing units in seven of the nine provinces of Sri Lanka[6]. The average household size ranged between 4.2 and 4.9 on a district-wide basis. Close upon 87 percent of all housing units were single houses and 79 percent were owner-occupied. Urban household size averaged at 5.9 persons per housing unit in 1981 (Dept. of Census and statistics, 1997). The average floor area of houses is around 50 square metres. Colombo, Gampaha and Kandy districts have over 25 percent of houses with floor areas greater than 100 square metres (Wanasinghe, 1997). The percentage of houses with floor areas less than 25 square metres was less than 30 percent in most districts. Table 1-2 gives a comparison of selected housing statistics for 1981 and 1994.

Table 1-2. Selected housing statistics for 1981 and 1994[7]

	1981	1994
Number of houses	2,514,499	3,180,035
Average household size	5.2	4.5
Permanent houses	89.6%	93.2%
Temporary houses	7.9%	4.3%
Water from wells	72.9%	61%
Pipe borne water		33%
Toilets for exclusive use	52.8%	76%
Flush toilets	26.9%	63.4%
Electricity available	14.6%	44.0%

[6] The survey was not conducted in the war-torn northern and eastern provinces.

[7] From Wanasingha, 1997.

1.1.6. Government and Authorities

The National government of Sri Lanka has certain powers devolved to Provincial councils representing the nine administrative provinces of the country. For administrative purposes, the provinces are further sub-divided into a total of 25 districts, which in turn are subdivided into a total of 280 divisions. Each district is administered by a district secretary, and each division by a divisional secretary.

Local authorities, comprising Municipal Councils, Urban Councils and 'Pradeshiya Sabha's (village councils), exercise separate authority at the local level. They are also charged with maintaining streets and thoroughfares, public health and sanitation, and public utility services, These councils are established and empowered by relevant Ordinances and are often independent of national authorities.

In addition to the local authorities, certain national authorities exercise simultaneous regulatory powers in specific areas. The Central Environmental Authority (CEA) is one such national authority exercising widespread powers to safeguard the environment. In addition to the CEA, certain provinces have their own Environmental Authorities. The Urban Development Authority (UDA) is another national authority, which exercises authority over urban areas defined as areas coming under Municipal or Urban Councils. The National Water Supply and Drainage Board (NWSDB) is another national authority charged with supplying water and sewerage services to the country. The Coast Conservation department exercises authority over areas within the 'coastal zone'. Consequently, developers often have to go through a series of permit processes from different authorities, with often confusing, and sometimes contradictory, regulatory requirements. More recently established authorities such as the CEA have detailed regulations and standards, which are specific and reasonably precise. Municipal and Urban councils, on the other hand have powers to 'abate all nuisances', which can be, and often are, interpreted loosely and inconsistently.

1.2. Sewage disposal in Sri Lanka

1.2.1. Existing situation

Almost the entire urban and suburban population of Sri Lanka is dependent on on-site systems for sewage disposal, mainly septic tank-soakage pit systems. Only a part of the commercial capital, Colombo, has a sewer network. Even here, the coverage remains poor and is limited to the core areas of the city with service being available to less than 20% of the population of Greater Colombo. In 1992, an estimated 1.7 million people in the Greater Colombo Metropolitan area (approximately 80 percent of its population) were dependent on on-site systems (Fernando, 1994). None of the other major cities or towns have any type of central sewer network, and their populations are dependent, almost entirely, on on-site systems.

With increasing urban congestion as well as high groundwater table and unfavourable soil conditions in many areas, soakage systems have begun to fail. Partially treated effluents from septic tanks are often diverted into open storm drains, ditches and canals (Engineering-Science, Inc., 1993).

1.2.2. Regulatory trends

The enactment of the National Environmental Act in 1980 and its subsequent amendment in 1988 has given rise to a plethora of Environment related regulatory activity in Sri Lanka. Effluent discharge standards have been established for a variety of commercial and industrial activities and are being increasingly enforced by the Central Environmental Authority (CEA) and its allied bodies. All permit applications have to go through an environmental licensing procedure for compliance with the relevant waste discharge standards. The Environmental Protection License (EPL) is renewable annually and, consequently, requires a review of waste discharge practices at least once a year. The relevant regulation passed under the act in February 1990 specifies effluent discharge standards for three categories, namely; discharge into inland surface waters, discharge into marine coastal areas and discharge on land for irrigation (Wickramanayake, 1999).

Compliance with these standards and regulations are monitored by the CEA, municipal and urban councils, and the Sri Lanka Tourist Board (in the case of tourist hotels) as well as numerous Non-governmental Environmental watchdog organizations at the local and national level. However, most regulatory staff lack sufficient training and understanding to effectively assess the performance and compliance of the systems they inspect and to properly interpret sample analysis results.

Municipal and urban councils as well as ‘Pradeshiya Sabha’s’ (village councils) require a sewage disposal system to be located on the building plans of all new building permit applications. In the case of small to medium scale buildings, this is usually a ‘type design’ of a septic tank – soakage pit system with which the council is familiar. However, no regulations or guidelines are stipulated for the design of these systems. Percolation tests are not required prior to siting, designing, or approval of the soakage systems.

1.2.3. Public sector trends

With a view towards resolving the problems of the Greater Colombo Metropolitan area, the National Water Supply and Drainage Board, together with UNDP assistance commissioned a study to come up with a comprehensive master plan for wastewater and sanitation for the Greater Colombo area. The main objective of the study was to ‘formulate a comprehensive wastewater and sanitation master plan for the area with a planning horizon to the year 2020’. This led to the implementation of a ‘Greater Colombo Sewerage Project’ at an estimated capital cost of 2.5 billion SLR[8]. The project comprises a rehabilitation component to restore the deteriorated parts of the existing sewerage system, an extension component to extend sewers to selected areas close to the existing network, and a sanitation component aimed at improving sanitation for the low-income population groups in the area. The project is expected to increase the total population connected to the sewer network from 550,000 in 1992 to 1.2 million in 2020. However, it is significant to note that after the conclusion of the project, there would still be 72 percent of the population of Greater Colombo

[8] 1992 values (60 SLR’s = 1 USD).

dependent on on-site systems, with the total numbers increasing from 1.7 million in 1992 to 3.2 million in 2020. In fact, one of the key issues, which emerged from the Master Plan study, was that "on-site disposal will remain the predominant method of disposal for the entire project period" (Engineering-Science, Inc, 1993).

Similar studies have been commissioned, or are currently in progress, for other cities such as Kandy, Nuwara Eliya, Hikkaduwa etc. However, it is unlikely that the outcome of such studies and their resultant projects would alter the unalienable fact that most of the urban and suburban population of Sri Lanka would be dependent on on-site systems for sewage disposal for at least the next half century and beyond. At best, it could be reasonably expected that no more than 20 percent of Sri Lanka's urban population would be provided with sewer connections within the next fifty years. This would leave the balance 80 per cent, or a projected 8.8 million people in urban settlements, dependent on on-site systems for sewage disposal[9].

1.2.4. Private sector trends

In the light of the increasingly stringent regulatory requirements and the lack of an adequate response from the public sector service providers, private sector developers are often caught in between, and have been responding to the situation in a variety of manners according to their resources. Private housing developers of housing estates often pay 'lip service' to the legal requirements by installing the minimum requirement of a small septic tank and soakage pit irrespective of the soil conditions and water table. In time, with increasing complaints from customers, due to systems failing within a year or less, they often install 'overflow lines' which directly divert the septic tank effluent to nearby drains, canals and other water bodies.

With the advent of the new regulations, tourist hotels and other medium to large-scale commercial establishments began to purchase and install 'package' treatment plants – mainly Activated Sludge plants and Rotating Biological Contactors (RBC's). The package plants are sold by local sales agents of foreign manufacturers, who

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[9] Based on a projected stabilization of population at 22 million by the year 2020 (de Silva, 1997), of which 50 percent would be in urban settlements (Wanasinghe, 1997).

often lack basic understanding of the systems they sell, and their applicability to specific situations. This, coupled with the lack of technical understanding of the client, often results in the plants not functioning at all, or ceasing to function within a short period of time. Most spares are not available locally and neither is proper technical assistance. Often the ‘agents’ cease operations within a few years leaving the customer stranded, unable to maintain or operate the system. The system soon becomes obsolete, and with no other option available to the user, either partially treated, or raw sewage is surreptitiously diverted to drains, canals etc. The plant itself is preserved for ‘display’ purposes for the benefit of regulatory inspectors who often lack the basic understanding to determine whether the plant is functioning properly, or in fact, at all. Many cases are reported of Hotels and industries storing their effluent and releasing them either at night or during periods of high flow in the receiving water bodies (Wickramanayake, 1999).

Several Government and Private sector programs exist to provide financial and so-called technical assistance to developers and existing institutions to upgrade their waste discharge practices to comply with current regulatory standards. However, what is lacking appears to be proper technical advice, which is sensitive to the ground conditions of the particular situation, and the availability of appropriate technologies, which are within the capability of the user to operate and maintain in the medium to long-term.

1.3. Aims and objectives

The main aim of this study was to select, implement and evaluate appropriate, cost-effective technologies, in the field, with a view to developing practical selection and design guidelines for appropriate on-site wastewater management systems in urban and suburban Sri Lanka.

1.3.1. Identification of appropriate technologies

In order for a particular technology to be deemed 'appropriate' it should satisfy the following requirements.

Affordability

The technology should be affordable to the user or service provider in terms of both capital and operating cost without compromising the financial viability of the original development.

Low maintenance

The technology should be within the maintenance capability of the user or service provider as well as compatible with his maintenance 'culture'. That is, all normal operation and maintenance activity should be of a level and frequency within what could reasonably be expected of the user or service provider, in comparison with his other regular operational activities. Also, consumables, spares and replacement parts should be locally available and the supply consistent.

Non land-intensive

In the urban and suburban context, all land is high-value and precious. Therefore, the technology should not exclusively occupy a disproportionate area of land in relation to the principal facilities.

Minimal energy requirement

In Sri Lanka, energy is particularly expensive, and reliability of supply, particularly electricity, is poor with frequent power failures. Therefore, for overall reliability of service, energy dependence should be minimal and, preferably, non-continuous.

Ability to meet the required treatment objectives

The technology should be able to consistently meet the required treatment objectives of the users as well as the regulatory authorities. These are often not necessarily the same in Sri Lanka. In many instances, the users are not satisfied with basic regulatory compliance, and sometimes *vice versa.* Users are usually most concerned with aesthetic and health aspects (mainly odour, colour, turbidity and pathogens), while regulators tend to stress parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Suspended Solids, etc.

Locally implementable

The technology should be implementable locally by the individual user, community or developer, and materials and skills for fabrication and implementation should be locally available.

1.3.2. Implementation

The main objective in implementation was to subject the identified technologies to real field conditions in order to observe and evaluate them from a practical standpoint. The systems would be implemented at full scale under real operating conditions of the various field scenarios. They would be designed and commissioned under actual field conditions and operated and maintained by the actual parties who would normally be expected to do so.

1.3.3. Evaluation and monitoring

The systems would be evaluated and monitored for performance and reliability with an emphasis on the user perspective as well as mere regulatory compliance.

1.3.4. Cost analysis

The implementation costs of the different technologies would be analysed and evaluated principally from the users, or developers, perspective and compared against each other.

Economic costing vs. financial costing

The basic idea behind economic costing as relevant to sanitation technologies is to assess the opportunity cost of implementing a particular technology to the national economy. In this case, all costs to the economy are included with the appropriate discounting, or 'shadow pricing' of labour, land, water and other inputs, as well as the opportunity cost of capital. The principal use of economic costing of sanitation technologies is to provide a meaningful basis for policy-makers and planners in decision-making at the national level, to assess the least-cost option to the national economy as regards provision of sanitation services (Kalbermatten et al, 1982).

Financial costing, conversely, focuses on the consumer, as opposed to the national economy, and assesses the direct cost to the consumer and how it would be spread over time. The financial costs of a technology could be very different from the economic cost, depending on prevailing government policies such as subsidies, taxation, minimum wage policies etc. The financial costs of a system are directly related to prevailing market prices and interest rates. In assessing financial costs of a technology or system, the 'base financial cost', or the financial cost assuming no financial subsidies, incentives etc., is often used as the basis for comparison. Once the base financial cost is known, various different sets of financial costs based on different scenarios of municipal and national government subsidies etc., could be computed for purposes of comparison. For on-site systems, with short construction periods and little requirement for municipal maintenance, the simple construction cost of the system (in market prices), is simply annuitized over the life of the system at the prevailing interest rate.

The purpose of the costing exercise in this study, was to provide a good understanding of the financial costs of implementation, to the user or developer, of the different alternative technologies under consideration. This would serve as a basis for assessing the base financial costs of similar systems in the future.

1.4. Scope

The scope of the study was limited to sewage disposal, both black and grey water, from mainly domestic and commercial establishments in an urban or suburban context. It did not include wastewater from industrial processes or sanitation for low-income communities.

The main categories under consideration in this study were the 'mid' categories which are often neglected by the larger projects, which typically focus on either the 'high-end' or the 'low-income' categories. The middle-income categories are often left to fend for themselves, be they individuals or commercial establishments[10].

Consequently, the individual categories considered included individual houses, housing schemes, small to medium-scale hotels and restaurants, school, camps, and residential halls, and day-time occupancy buildings such as banks, offices, shops etc.

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[10] A typical case in point would be the Greater Colombo Wastewater and Sanitation Master Plan which recommended a total capital expenditure of over SLR 2.5 billion over an eight year period. SLR 2 billion to be spent on upgrading and extending the sewer service for less than 20 percent of the population of Greater Colombo (mainly high income groups) and the balance sum to be spent on providing basic sanitation to low-income groups accounting for another 10 percent of the population. The balance 70 percent of the population, an estimated 2.6 million people with on-site facilities, did not receive any kind of benefit other than "to have their facilities checked and rehabilitated to ensure satisfactory operation at the owners expense" (Engineering-Science, Inc., 1993)