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WATER QUALITY OF SRI LANKA

a review on twelve water bodies

Department of Environmental Sciences
Institute of Fundamental Studies

E.I.L. Silva

1996

USAID FUNDED IFS-NAREPP/IRG PROJECT ON QUALITY ASSESSMENT OF SURFACE WATER

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Many national institutions namely the Central Environmental Authority (CEA), National Aquatic Resources Agency (NARA), National Building Research Organization (NBRO), National Water Supply and Drainage Board (NWSDB) and Ceylon Institute of Scientific and Industrial Research (CISIR) which are actively involved in water related research shared their unpublished data and made useful suggestions. The members of the NAREPP/IRG, in particular Mr. Edward Scott, Mr. Vasantha Siriwardena and Mr. Ariyaratne Hewage also extended their support throughout this work. Finally, I am grateful to Prof. Kirthi Tennakone, the Acting Director of Institute of Fundamental Studies, who encouraged me to finalize this work which was delayed due to unavoidable circumstances.

FOREWORD

Accurate and precise analysis of water quality (i.e. physico-chemical characteristics and bacteriological properties) and monitoring programmes are undeniably important in interpretation of data and subsequent implementation of conservation and management strategies. It has been estimated that about 21.5% of Sri Lanka's population live in urban areas and their association with surface water for a variety of purposes is inevitable. Further, agro-communities are considered to be threatened by contamination of aquatic resources with pesticides which are generally used in excess. Serious problems of water pollution are therefore, often caused by haphazard waste disposal and indiscriminate effluent discharge in these densely populated areas, with the excess use of pesticides in agricultural watersheds.

There is a scarcity of scientific studies aimed at monitoring water quality of our water bodies on a regular basis. With a view to filling in this long standing lacunae, the Natural Resources and Environmental Policy Project/International Resources Group (NAREPP/IRG) proposed that the Institute of Fundamental Studies (IFS) carry out a comprehensive study on quality assessment of surface water in Sri Lanka. The IFS scientists who are actively involved in water research identified four important components including, identification of hot-spots in the country, introduction of user-friendly methodologies, training water analysts and carrying out a monitoring programme as a model study.

The proposed study certainly fulfills a long felt national need for a thorough and comprehensive investigation on the status of some of our important aquatic systems. The first component of this study, identification of hot-spots in Sri Lanka and compilation of already available data, has disclosed a cohesive base for the other activities. Pre-selected study sites cover different climatic and geographic regions with varying anthropogenic influences. Further, the spectrum of the study sites includes almost all types of inland waters and a variety of potential anthropogenic impacts which could change the nature of these aquatic systems.

Dr. E.I.L. Silva, of the Department of Environmental Sciences of the Institute of Fundamental Studies, who prepared this review has made a significant effort to demonstrate the status of water quality and trends in pollution of twelve aquatic systems which are considered as hot-spots in Sri Lanka. This review would be invaluable to research organizations and individuals dealing with water research in Sri Lanka.

Professor Kirthi Tennakone
Acting Director, IFS

MESSAGE

Observers of Sri Lanka's development process can scarcely ignore the fundamental contribution of water to the development process. Whether as a source of energy, an input to the production process, a medium for recreational activity or, in its most essential form, a source of life, water must be maintained in sufficient quality and quantity.

Because water is so important, society must monitor its use closely. The deterioration of water's quality and quantity - as evidenced through sickness in the population, contamination of ground water tables, or shortages in energy, for example- may have important social, economic and political repercussions.

Recognizing the importance of water quality monitoring, and the relative inaccessibility of timely and accurate water monitoring information, USAID and International Resources Group agreed in 1993to give financial support to the Institute of Fundamental Studies to carry out a project on Quality Assessment of Surface Water in Sri Lanka. The work was to support, among other things, the production of a training manual on water analysis and assessment of the water quality of twelve selected water bodies in Sri Lanka. These two documents have now been completed.

NAREPP/IRG sees the production of these two documents as important steps in the longer process of improving water monitoring in Sri Lanka. The challenges remains significant, not least in beginning the actual monitoring of quality in the twelve identified water bodies. Additional challenges include clarification of the roles of the diverse institutions involved in water monitoring. It is our hope that the documents produced by the IFS may serve as input for those who aim, ultimately, to establish coordinated water quality monitoring systems and to support the institutions which can sustain them in the long run.

The Natural Resources and Environmental Policy Project (NAREPP/IRG)
International Resources Group, Prime Contractor
Colombo, 1996

PREFACE

Quantitative information on the quality of natural resources available at any level is a national asset. In many countries, especially in developed nations, state institutions operate in a coordinated manner to acquire this information and store them in commonly known data banks. These data banks disseminate available information as the need arises. Established data banks make it convenient for scientists to accomplish quick literature surveys and avoid repetition of work unless it is extremely important. In addition, in the present context already available data is used for Initial Environmental Examination (IEE) and Environmental Impact Assessment (EIA) when development projects are planned to be undertaken. Such information can also be used for trend analysis in pollution or to quantify the rate of deterioration of environmental quality.

The generally accepted opinion is that a majority of surface water resources in Sri Lanka have already deteriorated to varying degrees of magnitude due to human activities such as irrigative agriculture, crop cultivation, waste disposal, effluent discharge, and mining activities etc. However, the magnitude of pollution and the rate of deterioration of aquatic resources due to pollution are not quantified as yet. It has been proposed during several instances to establish national monitoring programmes for both water and air quality. Implementation has been hindered due to several reasons. At present, we are in the process of establishing mechanisms to launch monitoring programmes on water and air quality. It is important to note that there is some information collected either by state organizations or interested individuals on water and air quality. A fair amount of information on water quality is already available compared to that of air quality in Sri Lanka. But some of this scattered information is neither published nor stored in data banks.

It is unfortunate that in our country, unlike in most developed nations, acquisition, documentation and dissemination of information related to water quality have been ignored to a great extent. At least, as a preliminary step to satisfying this requirement it was proposed to compile the available information on water quality of twelve pre-selected water bodies as an activity component of the proposed study on quality assessment of surface water in Sri Lanka (under the sponsorship of USAID-NAREPP/IRG). In this review an attempt is made to compile already available data on water quality of selected water bodies in a systematic manner and diagnose them individually and collectively to identify the status of water quality and trends in pollution.

E.I.L. Silva
July, 1996

INTRODUCTION

The current global awareness of human impacts on the earth's environment and its gradual deterioration with indiscriminate and increasing development activities has resulted in the quest for environment-friendly technologies, industries and strategies which will lead to sustainable development. The earth's environment comprises the land, atmosphere and biosphere which are interconnected together by the hydrosphere. The understanding of interconnecting processes and cycles is essential to derive models and predict what the future consequences are likely to be. Quantification of the impact of human activities on environment on a local basis will in turn permit the assessment of trends on a global scale. Therefore a scientific information base at the national level will be needed for policy makers and national leaders to formulate national plans for appropriate development and thus enable them to participate meaningfully in the global endeavour to protect our common heritage.

Sri Lanka: In Sri Lanka, we have had many ambitious development programmes during the forty eight years, since independence. A majority of development programmes, had been in relation to watershed management or stream flow regulation. However, only a little attention has been paid to water related environmental problems which could be aggravated by human activities.

National Concern: In 1980, the National Environmental Act was enacted by the Parliament, of Sri Lanka and the Central Environmental Authority (CEA) was established in 1987 under that Act. The Environmental Council and District Environmental Agencies were established in 1982 and 1984 respectively. The National Environmental Act was amended in 1988, and the National Environmental (Protection and Quality) Regulations were adopted in 1990. In addition, in 1990, the setting up of a Ministry of Cabinet rank to be in charge of the subject of the environment, is an important land mark in the progress towards legislative and institutional development in the field of Environment.

Water Resources: Sri Lanka's highland massif, located in the south central part of the island is the most important geographic determinant of inland water resources. The radial drainage pattern carries surface water dividing the entire island into 103 river basins. There are also 94 small coastal basins which contribute a little to the surface water course. The quantity and quality of ground water in Sri Lanka have been to a large extent determined by its geological formation.

Being a non-industrialized nation, Sri Lanka has given priority to water use for irrigative agriculture since ancient time. New development programmes were also launched to tap running water for generation of hydroelectricity. Quantities of water used for industries and domestic purposes are not that significant compared to the amount of water used for irrigation and hydroelectric power generation. Nevertheless, the amount of water required for industrial and domestic use will significantly increase as demand arises. Therefore water resources development and utilization require rehabilitation and improvement of watershed management.

Trends in Water Quality: It has now been understood that there has been a steady depletion in the quantity of water available, a progressive deterioration in its quality and emergence of water related health problems. We are not certain whether the available water resources are threatened by pollution or already polluted or chronically contaminated. However, when problems relating to depletion of water quality or to watershed management are highlighted, management strategies are merely forwarded and shelved. Several project-oriented studies have also revealed that the quality of water in some important sources has deteriorated due to chemical residues, fertilizer leachates and siltation. All these are linked to poor watershed management. There is no systematic programme to monitor the status of water quality and its effects on biodiversity and human health.

Further, already available scattered data through various project-oriented studies are not systematized enough for policy makers to implement necessary actions. Therefore, here, we propose a systematic water quality assessment module using a set of selected water bodies which require urgent assessment of their present water quality. The methodology developed in this module may be utilized in environmental impact assessment (EIA) exercises and for implementation of mitigation measures in other tropical countries as well.

Scattered data on water quality of several surface water bodies in Sri Lanka has been documented since the early fifties. However, spatial and temporal patterns of water quality parameters and the degree of present deterioration of surface water bodies are poorly known. It is also apparent that the quality of surface water in certain sites has completely deteriorated and recovery back to the natural state may be uncertain. In addition, several water bodies in the country are already endangered and their direct or indirect effects on human health are becoming increasingly chronic. On the other hand, available data on water quality cannot be used as baseline information even in the case of impact assessment exercises mainly due to their inconsistency and widely differing methodologies employed. Therefore, it is extremely difficult to make reliable predictions on environmental impacts in the case of EIA exercises related to development projects. However, it has now been understood that there is a prime need for having baseline data on water quality in order to execute proper EIA exercises as a prerequisite for anticipated development projects and health assurance for the general public. Therefore, it is extremely important and topical to develop systematic methodologies and to implement monitoring programmes at least for a set of selected water bodies which represent all types of aquatic ecosystems in Sri Lanka.

The quality of Sri Lankan surface waters has been affected mainly by irrigation related watershed management, catchment landuse, direct discharge of untreated industrial and human wastes, traditional and modern industrial activities as well as some endemic geochemical factors. Among them, more prominent effects are those related to irrigative agriculture practices, catchment landuse and unplanned human settlement in highly urbanized areas. Water related problems in the country have already been identified as eutrophication, salination, water logging and siltation, increase in organic residues and industrial effluent and prevalence of water-borne diseases. Unfortunately, the magnitude of damage on abiotic and biotic components of aquatic ecosystems and its direct or indirect effects on human life are hitherto unknown.

It is noted that most of the low lying land in urbanized and semi-urbanized areas are used as sites for solid waste disposal. Leachates of those waste find their way into water courses where they may significantly affect both surface and ground water. Application of excess doses of fertilizer and the direct discharge of sewage into surface water cause hyper-eutrophication and contamination of surface and ground water with faecal coliform. More than that, a majority of industries directly empties untreated effluent into water ways. Therefore, it is important to identify water bodies that are already affected or are anticipated to be affected by future development projects. Twelve water bodies representing all types of surface water (i.e. rivers and streams, lagoons and estuaries, reservoirs and tanks, coastal reefs and canals) were selected on the basis of the type, characteristic aquatic life, and human association. In this review, the historical background of those water bodies with respect to their physical, chemical and biological properties and the rate of denaturing due to human activities over time will be critically analyzed. Consequently the existing data on water quality will be first compiled and then diagnosed for a critical analysis with a view to filling in the gaps of the required parameters when systematic quality assessment programmes are launched.

CHAPTER 1: KELANI RIVER

1.1 Introduction

Feth *et al.*, (1964), and Garrels and Mackenzie (1967) originally showed that the quality of pristine water could be related to the geomorphology and climate of a particular geographic region. Gibbs (1970), further elucidated three major aspects of the overall mechanism viz., precipitation, rock dominance and crystallization process which determine the chemical composition and physical properties of surface water. For example, a spring emerging from a mountainous watershed may contain dissolved salts at a concentration less than 100 ppm (Pilsbury, 1981) compared to the global mean salinity of river water of approximately 120 ppm. The composition of ionic species in surface water varies markedly among continents. Especially those draining well leached tropical watersheds are rich in Na^{+} and Cl^{-} which are atmospheric fallouts which have evaporated from the ocean (Feth, 1971). The dominance of Ca^{++} or Mg^{++} with HCO_3^{-} in temperate streams and rivers is an indication of the ionic composition which is controlled by the geochemistry of the drainage basin, since Ca^{++} and Mg^{++} dominant minerals are more susceptible to weathering and crystallization processes.

In addition, the chemistry of natural water involves numerous minerals, dissolved ionic species and gases as well as the interactions in sediment-water interface and air-water interface and the interactions between the aquatic medium and the organisms living in it. Therefore, the processes and functioning of a freshwater system is too complicated to be investigated by manipulating a laboratory system. However, it has been noted that the distribution of various chemical constituents in surface water shows only slight fluctuations under natural conditions (Davis & De Wiest, 1967).

Of the 103 river basins in Sri Lanka, the Kelani River with the second largest watershed plays an important role with respect to the island's overall economy, since it drains the most fertile land in the wet zone and intercepts the most populated and economically important administrative district (Western Province) including Colombo, the capital. The river drains an area of 2278 km^2 from sea level to an elevation exceeding 1500 m. This river is noted for its flood hazards at the densely populated and intensively cultivated lower reaches. Dangerous floods occurred in October 1913, May 1940 and August 1942 in Colombo. The Kelani River and its tributaries are the main source of drinking water for most of the inhabitants in the urbanized cities and townships located in the watershed. In contrast, this river also transports a majority of human and industrial wastes originating in the watershed. Nevertheless, the status of this river with respect to its water quality has been ignored for several decades.

Interest in water quality of the Kelani River was initiated with sudden and sporadic occurrence of fish mortality in the downstream near Colombo during early eighties. Several studies have been launched since then, and it has now been reported that the Kelani River has been subjected to severe organic and industrial pollution at least from the sea mouth to 50 km upstream. Evidently, the Kelani River has been noted for its heavy load of organic and industrial pollutants. However, neither the water quality nor the aquatic communities of the river has been systematically examined to date, in order to assess the level of pollution and its potential effects on human health. A fair amount of scattered information is available on several aspects of water quality recorded from site-specific surveys, project-oriented studies and client-based quality assessments. The available information is certainly insufficient to give an overall picture on site-specific and time-bound pollution trends in water quality of the Kelani River. Therefore, an attempt is made here to perform a critical analysis on the available information on water quality of the Kelani River as a prerequisite to drawing up a proper plan for implementation of a systematic monitoring programme to assess the water quality of this river from source to the mouth emphasizing man-made impacts on the river system.

1.2 Study Site

The Kelani Ganga, Sri Lanka's second longest river (144.3 km) drains an area of 2,278 km^2 in the wet zone. The headwater tributaries of the Kelani Ganga rise at an elevation exceeding 1,500 m above sea level on the steep slopes of the western rim of the central highland. In their descent through the highland and the upland to the coastal plain, the trunk stream and its numerous tributaries are entranced in deep V- shaped structurally controlled valleys, generally oriented in many directions at both higher and lower elevations. The trunk stream eventually empties into the Indian Ocean from the west coast of Sri Lanka near Crow Island. The catchment of the Kelani River receives an annual precipitation volume of 8692 million cubic meters (MCM) of which 62% discharges into the Indian Ocean. Despite intermittent flood hazards, this river has no acute threat to human inhabitants in its drainage basin. However, it has been noted that a majority of aquatic habitats of the Kelani River basin remains in a semi-natural state or shows vivid evidence of human influence (Giesler, 1967; Hubbard & Peters, 1984). These differences often are reflected in the diversity and abundance of aquatic life and quality of the water (Giesler, 1967).

The Kelani Ganga, the second largest watershed in Sri Lanka, which drains about 3.5% land area of the island (6^0.45'-7^0.12' N; 79^0.52'-80^0.74' E) is exclusively confined to the wet zone of the country (Fig. 1.1). In fact, the annual discharge at its mouth near Crow Island shows that the Kelani River is second in Sri Lanka only to that of the Mahaweli Ganga which has the largest watershed and discharge in the country. Since its headwater rises in the western slope of the central mountain massif, the highland catchment receives the full effect of the south-west monsoonal rainfall resulting in a large runoff. Of its 2278 km^2 watershed, 80% lies in the rugged highland and upland. The drainage pattern is characterized by a complex system of tributaries controlled not only by a northward trend in geological formation but also by transverse and oblique faults (HSCL, 1963).

1.3 Watershed

The Kelani River comprises myriads of streams and tributaries in the hill country and flows westward intercepting some of the most densely populated townships in addition to Colombo. The southern boundary of the Kelani Ganga watershed lies mainly along the northern boundary of the Kalu Ganga in the highland and the Bolgoda Lake in the lowland (Fig. 1.1). The south-east boundary of the watershed lies along the south-western edge of the Hatton Plateau (about 1400 m amsl), one of the most distinctive physiographic features of the central highland of the island. The eastern boundary of the Kelani watershed is bordered by the south-western slope of the Dolosbage Hills which rise from the Yatiyantota, Kitulgala-Ginigathena stretch and the north-east and the north-west boundaries which are marked by the divide between the westward flowing rivers, the Maha Oya and Attanagalu Oya respectively.

With its extended drainage network, the watershed of the Kelani River exhibits a contrasting diversity in physiography and climate. In addition, at present, significant changes could be seen in the land use and the natural forest cover from headwater to downstream. The upper most headwater tributaries of the Kelani River drain the south-western edge of the Hatton Plateau which comprises areas near Bogawantalawa, Maskeliya and Norton Bridge. A narrow strip of Peak Wilderness extending along the southern boundary of the river basin from Maliboda to the south-eastern tip is also drained by the headwater tributaries. From the north-east direction, the headwater tributaries drain ridges and valleys around Kitulgala, Deraniyagala areas and the Dolosbage Hills. The river has a steep gradient when it descends from highland to midland and drains a vast area of rolling and undulating terrain in the midland. The east-west boundaries of the Kelani River watershed in the midland are marked by lines from Aranayake to Kirindiwela in the north and from Maliboda to Padukka in the south (Fig. 1.1).

The contact between the midland and lowland plains of the Kelani River lies approximately along a line from Padukka to Kirindiwela via Kosgama. The segment of the Kelani Ganga watershed which lies in the lowland could be considered as one physiographic unit and marked by a line from Padukka to Wellawatte via Homagama, Pannipitiya and Nugegoda in the south and from Kirindiwela to Hendala via Radawana, Weliweriya and Ragama in the north.

Geologically speaking, the entire basin of the Kelani River is made up of highly crystalline, non-fossiliferous rocks of the Precambrian age belonging to one of the most ancient stable part of the earth's crust. Massive layers of charnockite and quartzite can be seen as a shield of relatively flat lying resistant rocks in the hill country. These charnockite and quartzite masses are most commonly and gently folded, although steep dips can be seen near Dikoya and Maskeliya. No transition zone can be discerned in the lowland watershed, although a surface laterite cover has masked all surface traces of rock formation. Being exclusively

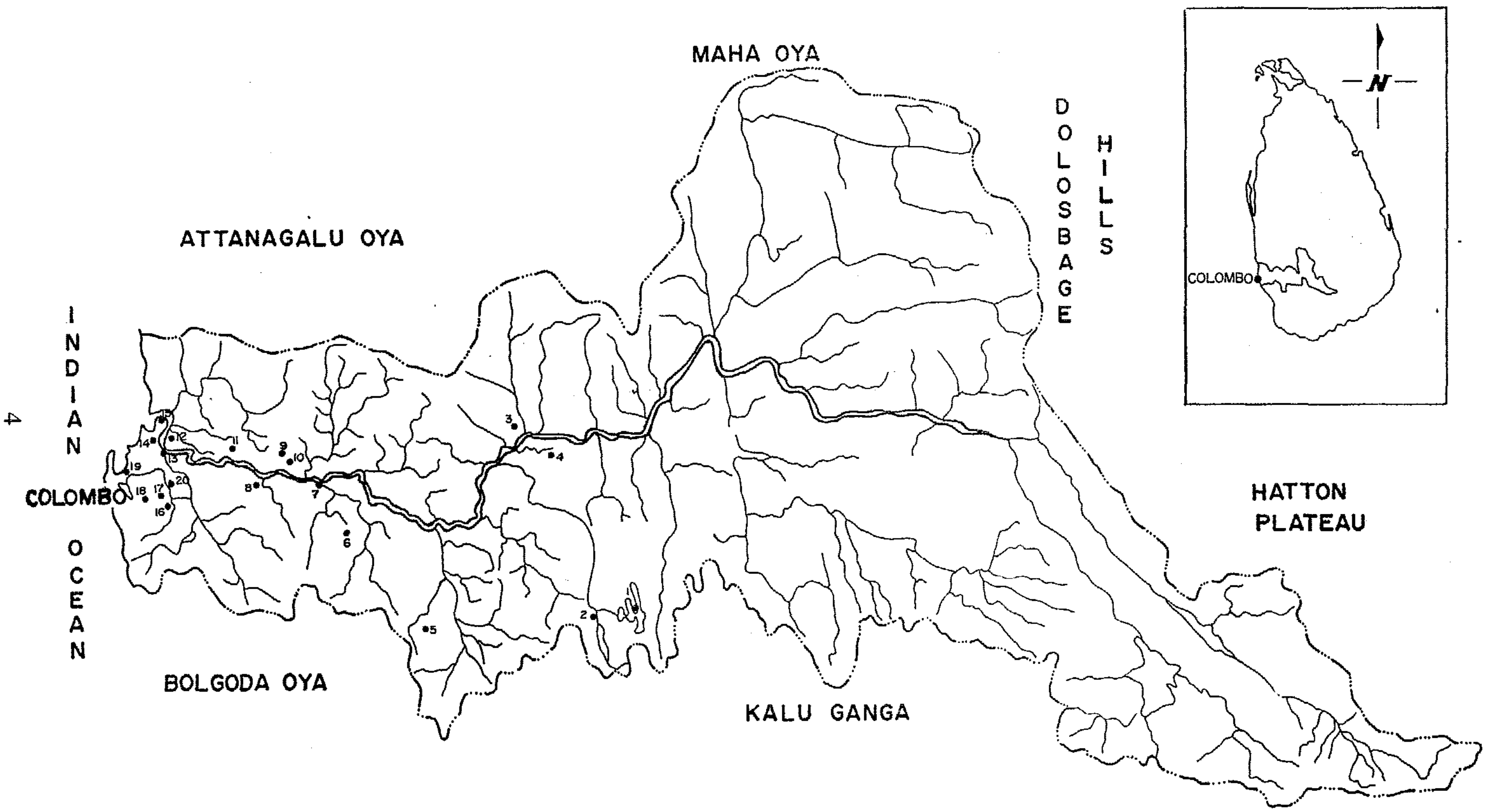

Figure 1.1 Geographic boundaries of the Kelani River watershed

confined to the wet zone, the Kelani River watershed exhibits a fairly narrow range of climatic condition which is influenced mainly by the monsoonal wind patterns and physiography of the terrain. The seasonal changes in climatic features (e.g. temperature, rainfall, wind, etc.,) are among the major determinants of the type of natural vegetation, the nature of catchment land use and the locations of human settlements in the watershed. The major runoff and the discharge pattern of the river are also determined by the seasonal climatic patterns. It can be clearly seen that the annual rainfall pattern in the Kelani basin is a combination of orographic nature of the terrain and cyclic changes of the monsoonal winds.

The south-west monsoon has a direct influence on the intensity and periodicity of rainfall in the highland of the Kelani basin except for a few rain shadow areas in the Hatton Plateau. The rainfall in the catchment of the Labugama-Kalatuwawa reservoir system is also directly favoured by the south-west monsoonal winds.

Accordingly, the highest annual average rainfall has been recorded at Yatiyantota (5598 mm), Ginigathena (5701 mm), Norton Bridge (3500 mm) and Padugoda (3300 mm) during the south-west monsoonal period (i.e. May - September). The rest of the watershed experiences heavy rains during two intermonsoons (i.e. March - April and October - November). Therefore, it is apparent that there are two distinctive rainfall zones in the Kelani basin; the south-west monsoon influences the upper course of the river and the intermonsoon dominates the lower reaches of the river (Fig. 1.3a). HSCL (1963) has defined the runoff regime of the Kelani Ganga using the records of river discharge at eight gauging stations that exist on the main river and its major tributaries. The flow profile of the main stream and the relationship between the area and the elevation for the basin are given in Figure 1.4. Accordingly, the river empties into the Indian Ocean at a flow rate of 213.8 m^3 sec^{-1}. The flow rate of the headwater (i.e. after confluence with the Maskeliya Oya) is 32.9 m^3 sec^{-1} which increases by about 12.5% when the mainstream merges with its major right bank tributary, the Gurugoda Oya. The flow rate increases by only 11% after merging with the Sitawaka Ganga on its left bank.

Water course: The headwater of the Kelani Ganga rises on the western flanks of the central mountain massif some 40 km east and slightly north of Ratnapura. The upper most headwater tributary (i.e. Hambantota Oya) originates in the south-eastern tip of the Peak Wilderness and drains several tea estates such as the Bogawana, Champion, Lynford, Bridwell, Chapelton, Teresia and Devonford (Fig. 1.2). The downstream of the Hambantota Oya which is known as the Kehelgamu Oya has been dammed 7.4 km above the Norton Bridge town creating the Castlereagh Reservoir (368 ha). At this stretch, the Kehelgamu Oya and the Mahaweli Ganga flow along parallel courses for about 20 km downstream at greatly different elevations though separated by only a few kilometers of intervening ridges. The Kehelgamu Oya turns westward at the Broadlands Estate about 1.5 km south-east of the village called Pitawala. At this point, the Kehelgamu Oya merges with the Maskeliya Oya whose headwater is exclusively confined to the south-western parts of the Peak Wilderness.

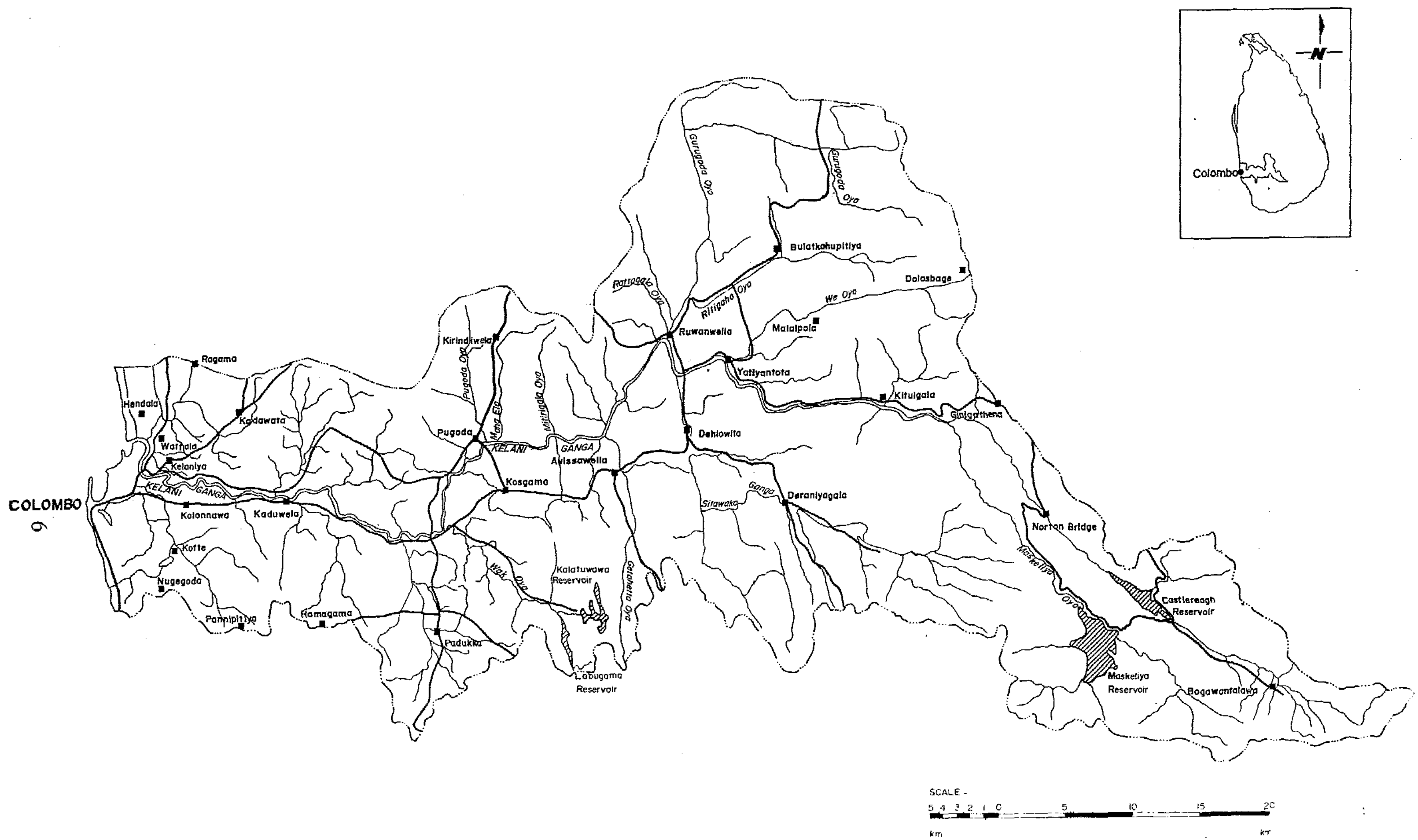

Figure 1.2 Watershed and the water course of the Kelani River

Despite its upper catchment, the Maskeliya Oya drains the Fairlawn, Gartmore, McKay and the Laxapana Group. The Maskeliya Oya has been dammed at Maussakelle, creating the Maussakelle Reservoir which inundates 996 ha at full supply level (FSL). Two adjacent headwater tributaries (i.e. Maskeliya Oya and Kehelgamu Oya) also flow parallel courses at different elevations for about 42 km downstream. These two tributaries are separated by only 3-4 km of intervening ridges. This physiographic feature has been exploited for the development of hydroelectric power by diversion of the flow from the Kehelgamu Oya at Norton Bridge into the adjacent valley of the Maskeliya Oya at the Laxapana Fall. The two streams connect together at the Broadlands Estate giving rise to the Kelani River proper (Fig. 1.2).

The Kelani River turns almost westward and flows parallel to the Avissawella-Ginigathena main road up to the Paleligama Estate where the river turns northwards twice (with a westward bend) before it intercepts the Yatiyantota town. At this stretch, the main stream receives water from the Liyan Oya on its right bank which originates as the Girankitte Oya and Ekk Oya. The We Oya which drains the Dolosbage Hills also connects on the right bank of the Kelani River at the Yatiyantota town. The river turns south-westward at Yatiyantota and flows 4.8 km downstream along the main road up to the Karawanella town. The main stream shows a sharp northward turn at Karawanella and flows 3.2 km downstream up to the Ruwanwella town where it bends south-westward. The Gurugoda Oya which originates as the Dadigama Oya and Alapalawela Oya receives water from the Kotagala Oya, Imbulana Oya and the Manalle Ela on its right bank while the Ritigala Oya and the Haloluwa Ela on its left bank. Then the Gurugoda Oya merges with the main stream of the Kelani Ganga on its left bank near Ruwanwella. Sitawaka Ganga, the largest left bank tributary of the Kelani Ganga merges with the main stream 10 km downstream at Ruwanwella. The Goraka Ela empties into the main stream on its right bank about 1 km upstream of the confluence of two major tributaries.

The Sitawaka Ganga whose headwater tributaries are located in the south-eastern slope of the Kitulgala-Maliboda range drains the area by five tributaries namely the Kadiran Oya, Mandagal Oya, the Halatura Ganga, Naye Ganga and Magala Ganga. The confluence of these five headwater tributaries gives rise to the Magala Ganga which merges again with three other tributaries on its right and left banks before it becomes the Sitawaka Ganga. The Magala Ganga merges with two left bank tributaries (i.e. Miyanawita Oya and Kumburugama Oya) and the Panamura Oya on its right bank and becomes the Sitawaka Ganga. The Sitawaka Ganga flows westward and connects with its left bank tributary the Kuda Oya near the village called Maldeniya. The Kuda Oya originates as the Gomalu Oya in the Badahelgoda Hills and its name changes to the Ambalampitiya Oya at the village called Ambalampitiya. Then the Sitawaka Ganga flows parallel to the Dehiowita-Eheliyagoda main road up to Alagoda and turns westward. A right bank tributary (known as Maha Oya) which drains the Deraniyagala area also connects the Sitawaka Ganga at Alagoda (Fig. 1.2). The Gatehetta Oya, another major left bank tributary of the Sitawaka Ganga merges with the main stream near the Avissawella town before it crosses the Avissawella-Deraniyagala road.

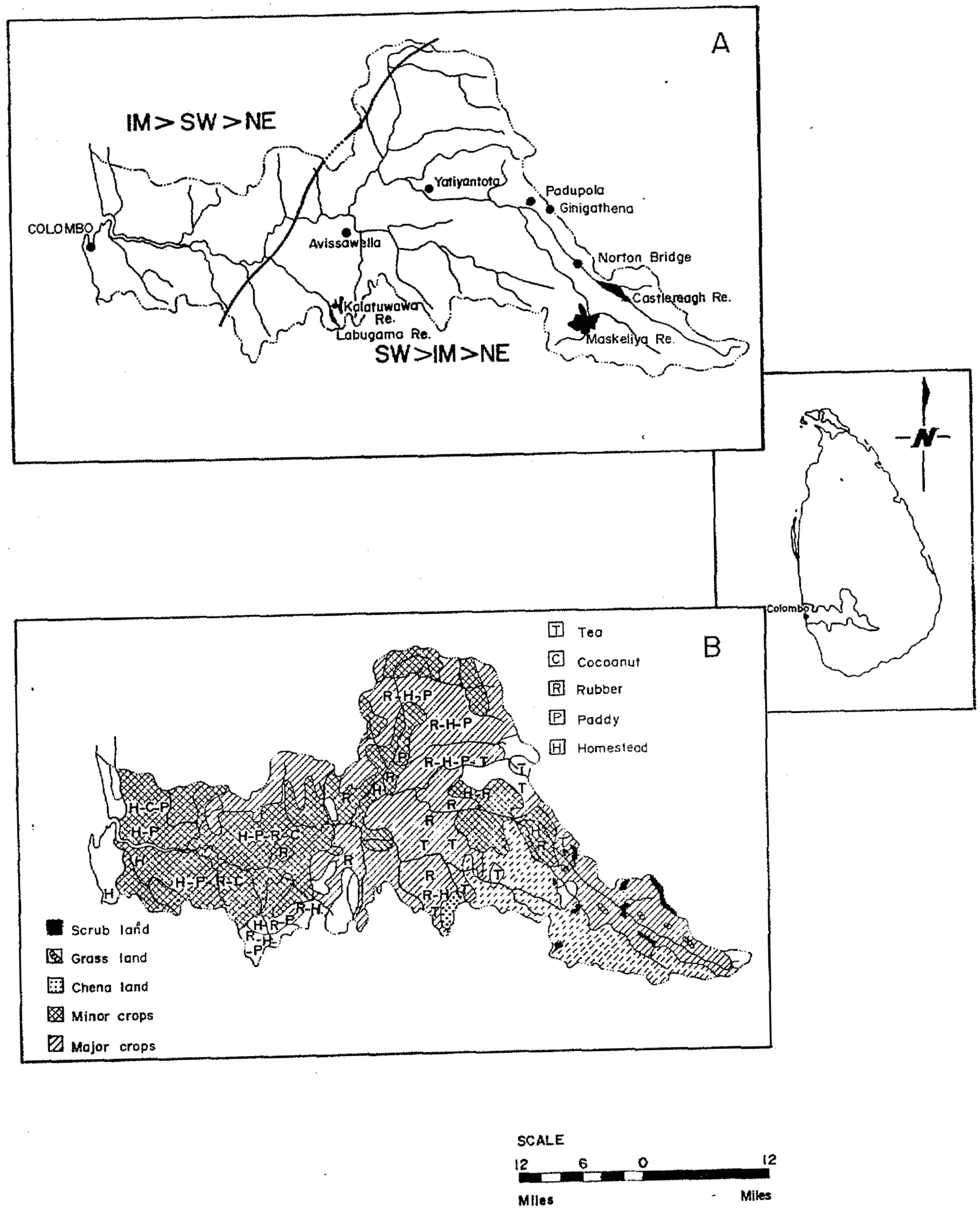

Figure 1.3 Rainfall and land use in the Kelani River basin

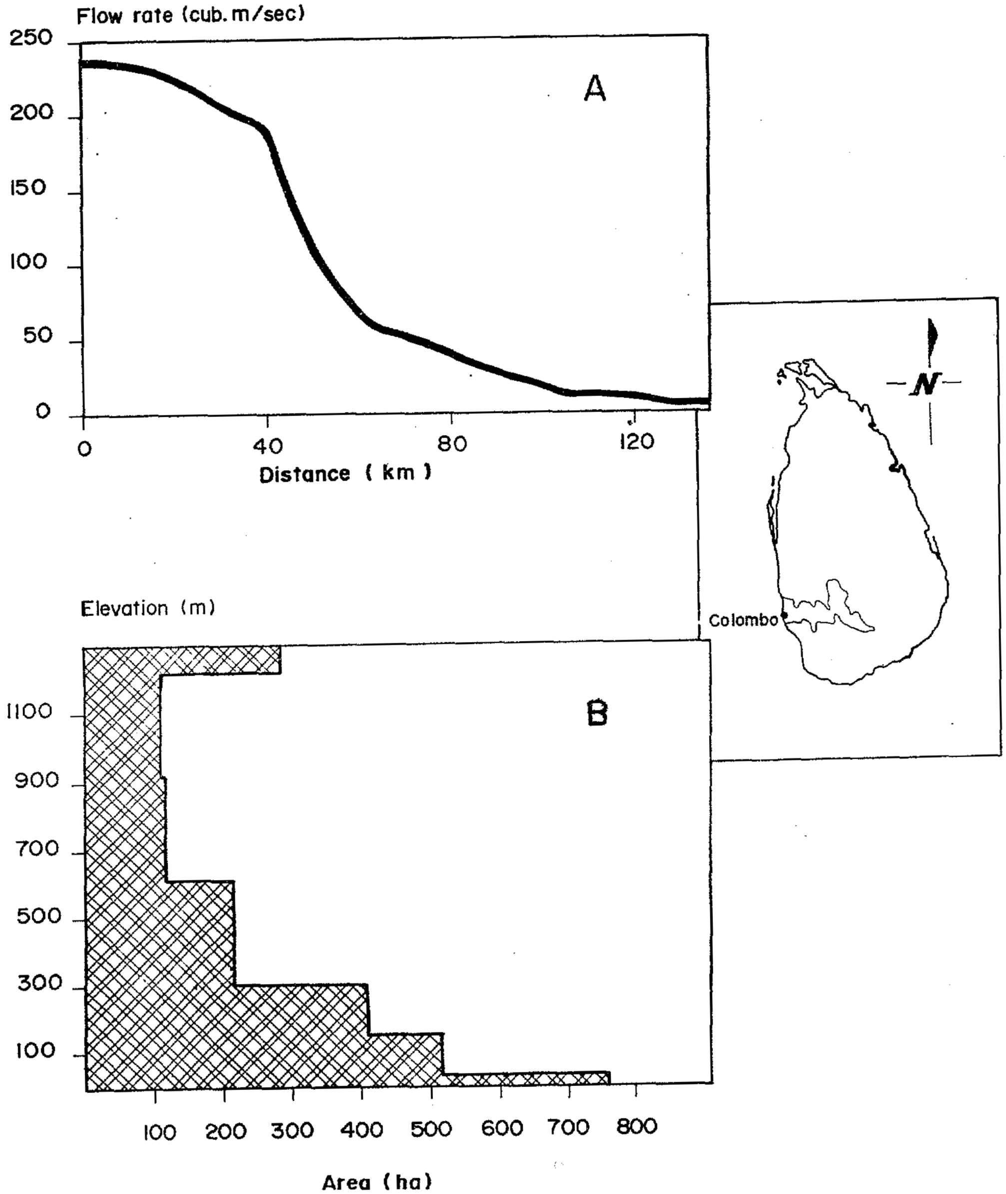

Figure 1.4 Flow profile of the main stream (A) and the elevation versus area curve (B) of the watershed

Then the Sitawaka Ganga turns sharply northward and descends about 3 km downstream and bends north-westward before it merges with the mainstream of the Kelani River (Fig. 1.2). After the confluence with the Sitawaka Ganga, the Kelani Ganga turns westward again and flows parallel to the Colombo-Avissawella main road up to Pugoda, a small township where the Pugoda Oya merges with the Kelani River on its right bank. The main river turns south-westward near Pugoda and flows about 10 km downstream before it intercepts the Hanwella township. The Wak Oya originates as the Kalatuwawa Ela in the Labugama- Kalatuwawa catchment and continues as the outflow of the Kalatuwawa and Labugama drinking water reservoirs for about 16 km before it meets the Kelani River. The river turns westward near Hanwella and meanders for about 37 km while increasing the river width until it empties into the Indian Ocean at Crow Island. At this stretch, the river receives tributary water from the Puswelli Oya which originates as the Angomuwa Ela, the Arukwatte Oya, Alig[illegible] Oya and the Panaluwe Ela which drain an area aroudn in Padukka, Bope and Meegoda.

The Pahuru Oya, a right bank stream which drains an area around Horagolla and Dekatana also merges with the mainstream at about 4 km upstream at Kaduwela near Malwana. Two other left bank streams commonly known as the Pallewela Oya and the Maha Ela also connects with the mainstream about 1 km upstream at Kaduwela. Before the Kelani River empties into the Indian Ocean, the north sector of the St. Sebastian Canal connects the main river at Totalanga on its left bank. At this stretch, two artificial water courses; the Old Dutch Canal which was constructed in the 15th century to facilitate paddy cultivation and transportation and the Hamilton Canal which was constructed during the British period specially for flood control, connect the Kelani River on its right bank. A perennial stream which originates in Ragama and Wattala areas also empties into the Kelani River as the Kalu Oya on its right bank at Hendala before the river discharges into the Indian Ocean.

Natural Vegetation and Land Use: The land use pattern of the Kelani River is shown in Figure 1.3b. Today, only less than 6% of the natural vegetation can be seen in the Kelani Ganga basin. These patches of natural forests are mainly confined to the highland sector of the Kelani Ganga basin and in the catchment of the Labugama-Kalatuwawa reservoir system. The natural vegetation in the Kelani River basin can be divided into woodlands and grasslands. In the case of woodlands, the tropical evergreen forest, the climax vegetation in the wet zone which exhibits a luxuriant growth with a dense canopy is the typical natural vegetation which occurs in the Labugama-Kalatuwawa catchment. A dense patch of this forest is rich in both species diversity and endemism. The second category of woodland vegetation, the submontane evergreen forest, is the dominant vegetation type in the Peak Wilderness Nature Reserve. Of the grasslands, only the wet patana which exhibits a patchy distribution in the higher elevations (e.g. Bogawantalawa, Norwood, Dikoya, Norton Bridge and Peak Wilderness) can be seen in the Kelani River basin. In addition, the watershed of the Kelani River has been subjected to a variety of catchment land use from the source to the mouth.

Since the Kelani River basin is the most populated watershed in the country, a substantial percentage of the land has been utilized as commercial and residential sections of the cities, towns and villages. A greater part of the urban settlement and associated non-agricultural land mapped in the Kelani River basin has been accounted for by Colombo and many smaller towns situated in the metropolitan area. Other large towns of the Kelani River basin are Homagama and Padukka on the lowland plane, Avissawella and Ruwanwella in the upland and Dikoya and Maskeliya in the highland.

Homestead garden is a conspicuous land use pattern in all parts of the Kelani River basin except the hill country of the extreme southern corner. Homestead gardens are especially extensive in the area bordered approximately by a line joining Colombo, Pugoda and Homagama. Here, a large extent of gardens, together with a much smaller tract of estate-grown rubber occupy all the higher land separating the narrow, depressional strip of paddy lying along the major and minor drainage lines. In the upland of the basin, rubber is the most extensive land use form and the home gardens and paddy-fields are again confined mainly to the valleys. In this area, the main concentrations of the paddy-garden complexes are those situated near Avissawella, Ruwanwella, Aranayake and Kitulgala. A small patch of coconut has been confined mainly to Kirindiwela, Radawana and Pugoda areas in the lowland of the Kelani River basin. Tea is the main perennial crop confined to the highlands. Most of it is grown at a high elevation near Hatton, Dikoya, Maskeliya and Bogawantalawa in the south-eastern region, a major part of the Kelani River basin in the Dolosbage Hills and the west and north-west of Nawalapitiya. There are also some fairly extensive tracts of estate-grown mid-country tea in Aranayake. Several patches of wet zone chena are also found mainly in isolated areas of the Kelani Ganga basin, the largest of which are situated near Kitulgala and Warakapola on the Ruwanwella road. However, there are also small scattered patches of chena elsewhere.

Human Interference: The Kelani, was the first river in Sri Lanka from which water has been tapped for commercial based hydroelectric power generation. Since 1950, three hydroelectric reservoirs have been constructed by damming the Kehelgamu Oya and Maskeliya Oya to feed five power stations of a total capacity of 311 MW (Table 1.1).

Table 1.1 Hydroelectric reservoirs in the Kelani River basin and the capacity of their respective power stations

Year	Reservoir	Stream	Power Station	Capacity (MW)
1950	Norton Bridge	Kehelgamu Oya	Laxapana	50
1965	Castlereagh	Hambantota Oya	Wimalasurendra	50
1969	Laxapana Pond	Kehelgamu Oya	Polpitiya	75
1974	Maussakelle	Maskeliya Oya	New Laxapana	100
1982	Maussakelle	Maskeliya Oya	Canyon	36

Since its location is confined to the wet zone of Sri Lanka, the Kelani River has been hardly subjected to major irrigation related stream flow regulation. There are about 23 existing irrigation works of which 18 are small anicuts. A few weirs and bunds have also been constructed across tributary streams specially for flood control. In addition, two tributary streams of the Wak Oya have been blocked by cement dams, creating two drinking water reservoirs at Kalatuwawa and Labugama.

Navigation is minimum in the Kelani River, but transportation of timber logs by rafts in the river is a well known traditional exercise. Even today, this river is the major means of transportation of timber logs from Kitulgala to Kaduwela under state approval. In addition, the Kelani River and its tributaries are intensively utilized by the inhabitants along the course for various basic needs such as bathing, washing and homestead agriculture. Despite the availability of a few cages on either bank downstream Hanwella to trap freshwater giant prawn (*Macrobrachium rosenbergii*), fishing is not a commercially established enterprise in the Kelani River.

The Kelani River has been extensively exploited for sand mining for construction purposes. Removal of bed materials will certainly affect channel morphology, water depth and bed-load sediment transport and upstream salt water intrusion. The sediment loading in the Kelani estuary and in the river delta determines beach formation due to sand replenishment. The productivity of the near shore and the estuarine environments of the Kelani River may also be affected due to changes in sediment transport. The extraction of water at Ambatale for domestic and industrial uses of the metropolitan area could also be considered as a significant human interference with the river system. The present intake at Ambatale (60 million gallons d^{-1}) is anticipated to increase upto 100 million gallons d^{-1} in near future. This is equivalent to increasing the flow rate of the river from 3.2 MCM sec^{-1} to 5.3 MCM sec^{-1} which is insignificant for a large river like the Kelani. However, this may have significant effects with respect to salt water intrusion during the dry season when the discharge or flow rate is at its lowest (Karunakaran, 1991).

This river could be ranked as the largest recipient of industrial effluent of the country. The Central Environmental Authority (CEA) has identified 23 existing major industries in the Kelani River watershed (Table 1.2) of which 20 discharge their effluent either directly into the river or into tributaries or artificial canals which eventually reach the mainstream (CEA, 1985 a, b). The pollution burden of this effluent is quite diverse ranging from waste water generated by treatment plants located at Ambatale and Kalatuwawa to heavy industrial discharges from the petroleum refinery, textile factories, tanneries, breweries, etc. It should be noted that the St. Sebastian/Dematagoda Canal network empties a heavy load of industrial effluent into the Kelani River draining from chemical, cosmetic and other industries located along its banks. Further, this river receives the highest amount of domestic sewage and other organic waste and nearly 90 x 10^6 l of biogenic effluent is discharged into the river daily only from the Colombo municipality. One ml of this effluent contains about 400 mgl^{-1} COD, 25

mgl^{-1} total nitrogen and 18500 coliform counts per 100 ml (CEA, 1985 a,b).

Table 1.2 Untreated effluent outfalls into the Kelani River from industries

Industry	Location	Effluent type	Discharge type
Kalatuwawa Water Works	56.2 km on Wak Oya	Water treatment effluent	Direct (TS)
Labugama Water Works	55 km on Wak Oya	Water treatment effluent	Direct (TS)
Pugoda Textiles	44 km upstream	Textile effluent, treated domestic sewage	Direct (MS)
Plywood Corporation	40 km on Kalangoda Ela	Domestic waste, glue mixtures	Indirect (TS)
McCallum Brewery	30 km upstream	Brewery effluent	Indirect (TS)
Steal Corporation	25 km off the bank	No	--
Ceylon Cold Stores Bottling Plant	20 km upstream	Bottle washed water, oil, grease	Indirect (MS)
Ambatale Water Treatment Plant	14 km on Ambatale Ela	Water treatment effluent	Indirect (TS)
Petroleum Refinery	12 km upstream	Petroleum effluent	Direct (MS)
Fertilizer Corporation	12 km upstream	Fertilizer effluent	Direct (MS)
Tyre Corporation	9 km upstream	Waste water, domestic waste	Indirect
Central Transport Board	5.5 km upstream	Service station waste	Direct (MS)
Kelanitissa Power Station	4.5 km upstream	Various types	Direct (MS)
Madampitiya Sewage Works	4 km upstream	Domestic sewage	Direct (MS)
Tanning Factory	1.2 km upstream	Tannery effluent	Direct (MS)
Lankem Ltd..	St. Sebastian Canal	Bitumen/Asbestos	--
Synthetic Textiles	St. Sebastian Canal	Dyes	--
Lever Brothers	St. Sebastian Canal	Various types	--
British Ceylon Corporation	St. Sebastian Canal	Organic waste	--
Petroleum Storage	St. Sebastian Canal	Oil spillage	--

TS = Tributary stream; MS = Main stream

1.4 Water Quality

During his survey on limnology and ichthyology of the south-western region of Sri Lanka in 1965, Geisler (1967) reported several physical, chemical and biological characteristics of two streams emptying into the Kelani River at about 11 km south-west of the Hanwella town. These streams contained clear water with very low dissolved salts and a markedly high content of organic matter.

An extensive survey was launched on the Kelani River in 1970 during the Austrian-Ceylon Hydrobiological Mission carried out by the Institute of Zoology of the University of Vienna and the Department of Zoology of the University of Vidyalankara, Kelaniya (Costa & Starmuhler 1972; Weninger, 1972). Fifteen sites representing the main stream of the Kelani River and its tributaries, brooks and creeks in the watershed from the sea mouth to Adam's Peak were examined for water quality and aquatic flora and fauna during this survey. Further, investigations on several chemical constituents and some pollution indicative parameters (i.e. BOD_5, NH_3) of the Kelani River were conducted at a river site at Hanwella for a period of 22 months from July 1972 to March 1974 (Gunatilaka, unpublished). He also compared several parameters (e.g. dissolved oxygen, BOD_5, NH_4-N, NO_3-N and PO_4^{-3}) between the upper course (Kehelgamu Oya at Maskeliya) and the lower reaches (Victoria Bridge at Colombo) of the Kelani River. In addition, the National Building Research Organization (NBRO) has reported some pollution related water quality parameters (i.e. suspended solid, total-N, COD, NO_3-N, free-NH_3) for six sites downstream from Kitulgala inclusive of a site at the Ambatale Water Intake between 1973 and 1974 (source NBRO, 1986). Several water quality parameters at the Ambatale Water Intake have been monitored by the National Water Supply and Drainage Board (NWSDB) since 1968 to date (Padmasiri, personal communication).

Kodikara (1981), investigated the bacteriological characteristics of the source water of the Kalatuwawa and Labugama drinking water reservoirs and the Ambatale Water Intake from January to December 1979. Biochemical oxygen demand (BOD_5), dissolved oxygen (DO) and bacteriological counts (Most Probable Number=MPN) were determined in the Kelani River from August to September 1982 when fish mortality was reported at Totalanga, a highly congested tenement area in close proximity to a land reclamation site and the sewage drain which emits untreated sewage into the Kelani River (Fernando *et al.*, 1983). A detailed investigation was conducted on bacteriological parameters which reflect organic pollution of the surface water in the lower estuary of the Kelani Ganga by the National Aquatic Resources Agency (NARA) in 1983 September (De Silva *et al.*, 1984). The second detailed site-specific study on water quality of the Kelani River at five locations from the Ambatale Water Intake to Crow Island was conducted monthly for a period of eight months from August 1982 to March 1983 (Dissanayake, 1985).

In October 1982, as directed by the Development Secretariat Committee with the occurrence of fish kills in the Kelani River, the Central Environmental Authority was entrusted to undertake a preliminary study on the discharge of industrial effluent into the river (CEA, 1985a). Subsequently, the Ceylon Institute of Scientific and Industrial Research (CISIR) was commissioned to execute a survey on major industries whose effluent is directly or indirectly discharged into the main course of the Kelani River. They identified 20 state owned and private sector industries whose effluent finally reach the Kelani River and reported the nature and type of effluent and the frequency and magnitude of discharge (CEA, 1985a,b).

A rapid cross-sectional analysis was conducted by Dissanayake *et al.*, (1985) to determine major cations and anions and several heavy metals at 15 sites in the main stream of the Kelani River and 4 tributary stream sites downstream from Pugoda to the sea mouth. In 1984, a qualitative assessment of water quality of the metropolitan area enclosed by the Kelani River was conducted using Ultra Light Aircraft Photography by Buwalda BNA and BKH Consultancy Engineers Bangaerts, Kuyper and Huiswaard with the sponsorship of the Netherlands Ministry of Housing, Physical Planning and Environment and the Central Environmental Authority (CEA, 1987a,b). The main objective of this study was to obtain a complete environmental assessment of the metropolitan area of the Colombo city including the surface water quality and industrial effluent discharge etc.

The environmental unit of the National Aquatic Resources Agency (NARA) compared the water quality of upstream and downstream of the effluent outfall of the Biyagama Free Trade Zone for a period of 23 months, from August 1987 to June 1989 (De Alwis, 1991). Eighteen parameters were monitored fortnightly from August 1987 to December 1988 and then monthly sampling was carried out up to June 1993.

Further, a study on the water quality of the Kelani River was conducted by the Danish Hydraulic Institute (DHI) in collaboration with the National Water Supply and Drainage Board (NWSDB) in 1990 with particular attention to salinity and pollution levels at the Ambatale Water Intake using one dimensional and one- and two- dimensional mathematical models developed by the DHI. The problems of salinity intrusion affecting water quality at the intake was highlighted during the course of this study when a severe drought was experienced in the south-western parts of the island during the first intermonsoon of 1992.

Various studies, surveys or qualitative assessments, conducted since Giesler's pioneer work to date on the water quality of the Kelani River can be subdivided into four major categories on the basis of the type and nature of the work (Table 1.3).

* Pioneer work
* Cross-sectional analysis
* Point sampling
* Inter-site comparison

The above categories will be analyzed separately and comparatively in order to examine the reported status of the water quality of the Kelani River emphasizing trends in pollution. Giesler's pioneer work is summarized in Table 1.4. The water quality of two sites at the highest elevation determined in 1970 (Weninger, 1972) is shown in Table 1.5. The physico-

Table 1.3 Four categories of water quality studies carried out in the Kelani River

Year	Nature of Study	Source
1965	Pioneer work	Giesler, 1967
1970	Cross-sectional	Weninger, 1972
1973-1974	Cross-sectional	Gunatilaka, unpublished
1973-1974	Point sampling	NBRO, 1986
1979	Point sampling	Kodikara *et al.*, 1981
1982	Cross-sectional	Fernando *et al.*, 1983
1982	Cross-sectional	CEA, 1985 a,b
1982-1983	Inter-site	Dissanayake, 1985
1984	Cross-sectional	Dissanayake *et al.*, 1985
1986-1987	Cross-sectional	CEA, 1987 a,b
1987-1988	Inter-site	De Alwis, 1991
1989-1993	Point sampling	NBRO, unpublished

chemical parameters (i.e. conductivity, pH, Ca, Mg, Na, K, Fe, Al, NH_3, NO_3^-, Cl^-, F^-, permanganate consumption, humic acid, P_2O_5 and total hardness) reported in the above study are plotted against elevation in Figures 1.5a and 1.5b. The seasonal variations of ten water quality parameters of the Kelani River at Hanwella found by Gunatilaka in 1973 (unpublished) are shown in Figure 1.6. The seasonal variations of five pollution indicative water quality parameters (Gunatilaka, unpublished) between two sites (Maskeliya Oya and Kelani Bridge) are compared in Figure 1.7. The water quality parameters reported at four sites downstream of the Ambatale Water Intake (Dissanayake, 1985) were analysed employing a one-way ANOVA to examine the inter-site variability and the means were compared with F statistics (Table 1.6). Similar statistical treatments were employed to examine the inter-site variability for four sites located near the upstream of the Ambatale Water Intake (De Alwis, 1991) and the results are summarized in Table 1.7. The concentrations of major cations and anions including several heavy metals and micro-nutrients (i.e. N and P) reported for 19 sites downstream at Pugoda (Dissanayake *et al.*, 1985) were analyzed for means and standard deviations (Table 1.8).

The long term trends in six water quality parameters (i.e. conductivity, pH, suspended solid, NO_3^-, SO_4^{2-} and Cl^-) reported by several authors from 1989 to 1992 for the river site at the Ambatale Water Intake are shown in Figure 1.8.

Table 1.4 Pioneer information on water quality of the Kelani River at Hanwella (Giesler, 1967)

Parameter	Site 1	Site 2
Elevation (m)	370.0	370.0
Temperature (°C)	26.5	26.3
pH	6.46	6.17
HCO_3^- (ppm)	7.5	5.3
Hardness (°DH)	0.21	0.19
Total Iron (ppm)	0.10	0.05
NH_4^+ (ppm)	0.05	0.06
NO_3^- (ppm)	0.00	0.25
Cl^- (ppm)	2.00	2.80
PO_4^{3-} (ppm)	0.010	0.004
EC (μ°S)	17.8	13.3
Permanganate value (ppm)	20.5	33.8

Table 1.5 Water quality of two sites at the highest elevation in 1970 (extracted from Weninger, 1972)

Parameter	Gartmore Estate	Adam's Peak
Altitude (m)	1850	2200
EC (μ°S)	8.8	22.2
pH	5.68	6.10
Humic Acids (ppm)	1.02	0.49
Hardness (°DH)	0.08	0.30
Calcium (ppm)	0.24	1.81
Magnesium (ppm)	0.26	0.30
Sodium (ppm)	0.60	1.90
Potassium (ppm)	0.20	0.60
Total Iron (ppm)	0.01	0.01
Ammonia (ppm)	0.25	0.23
Nitrate (ppm)	0.05	0.26
Chloride (ppm)	0.14	2.84
Fluoride (ppm)	0.05	0.05
Phosphate (ppm)	0.00	0.01

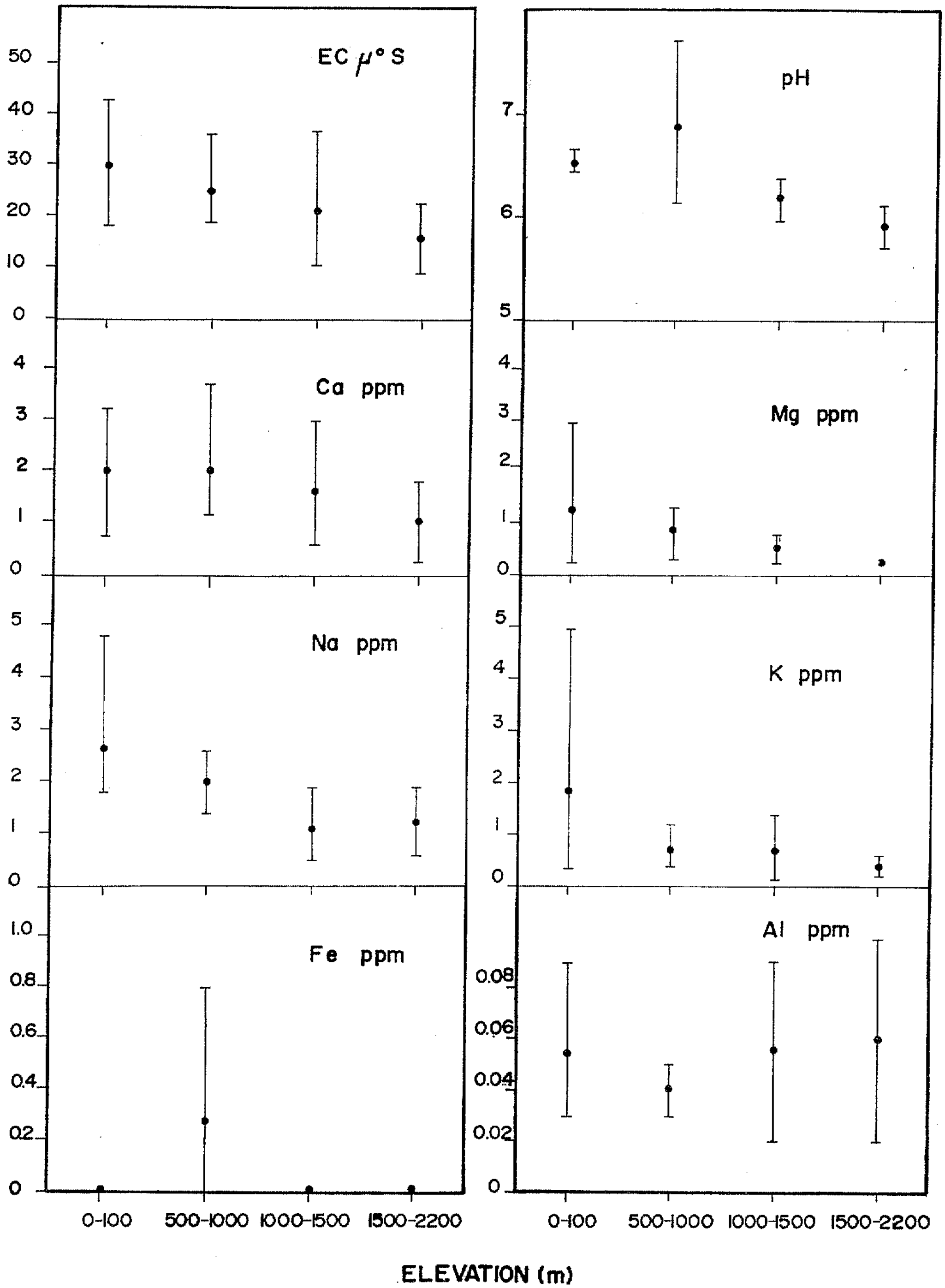

Figure 1.5a Conductivity, pH, Ca, Mg, Na, K, Fe and Al against elevation

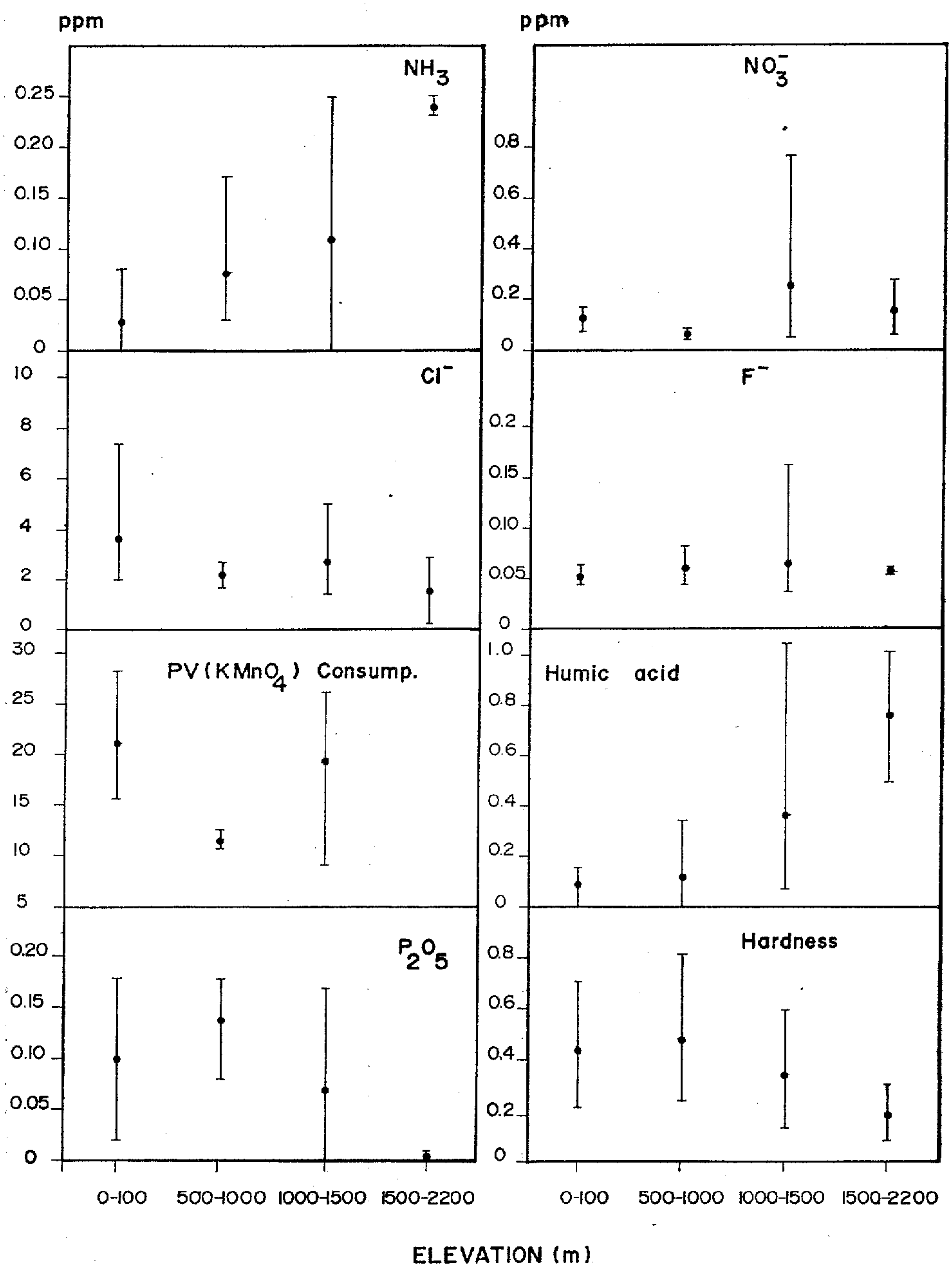

Figure 1.5b Concentrations of NH_3, NO_3^-, Cl^-, F^-, P_2O_5, humic acid and permanganate consumption and total hardness against elevation

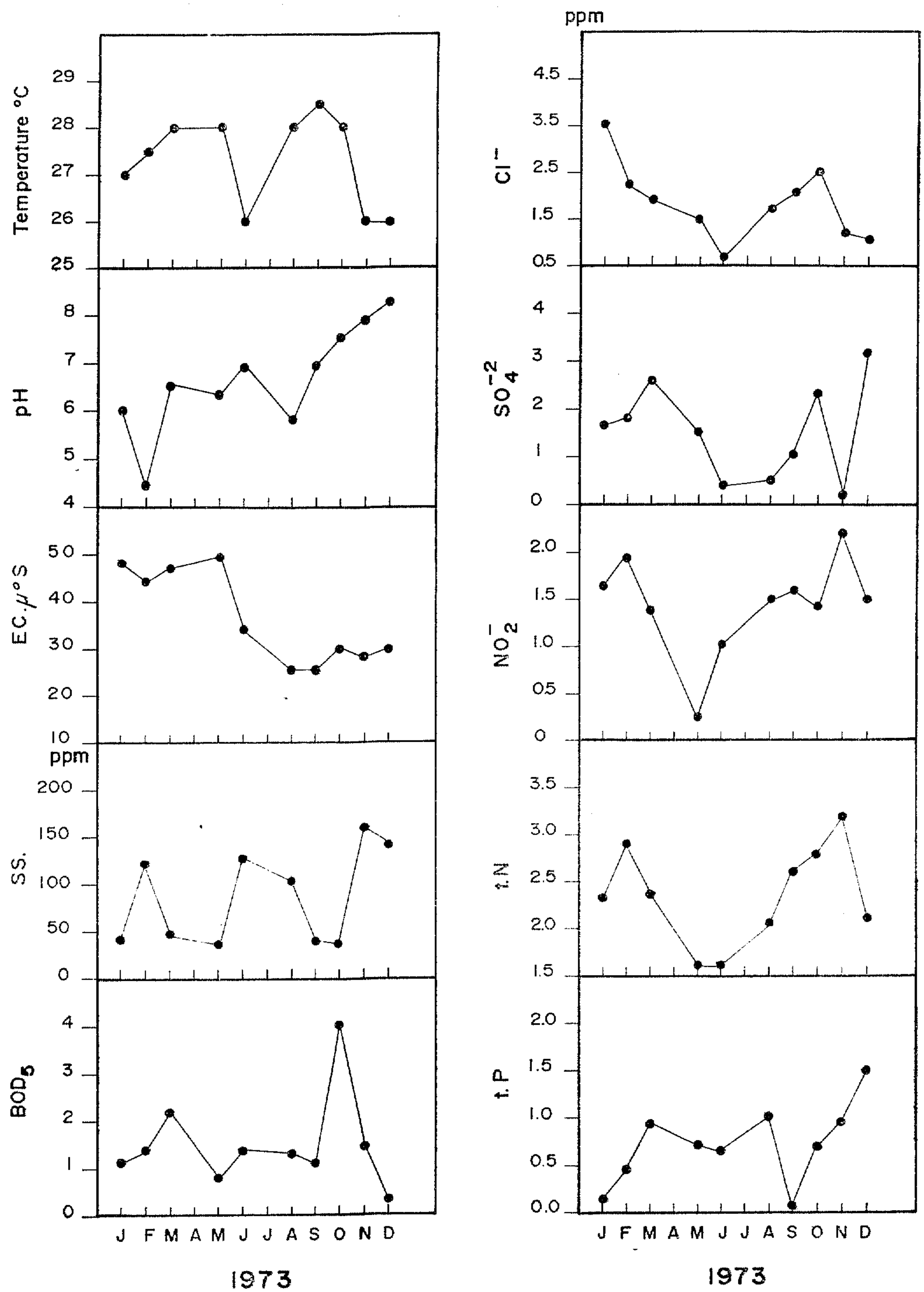

Figure 1.6 Seasonal variations in 10 water quality parameters of the Kelani River at Hanwella in 1973 (Gunatilaka, unpublished)

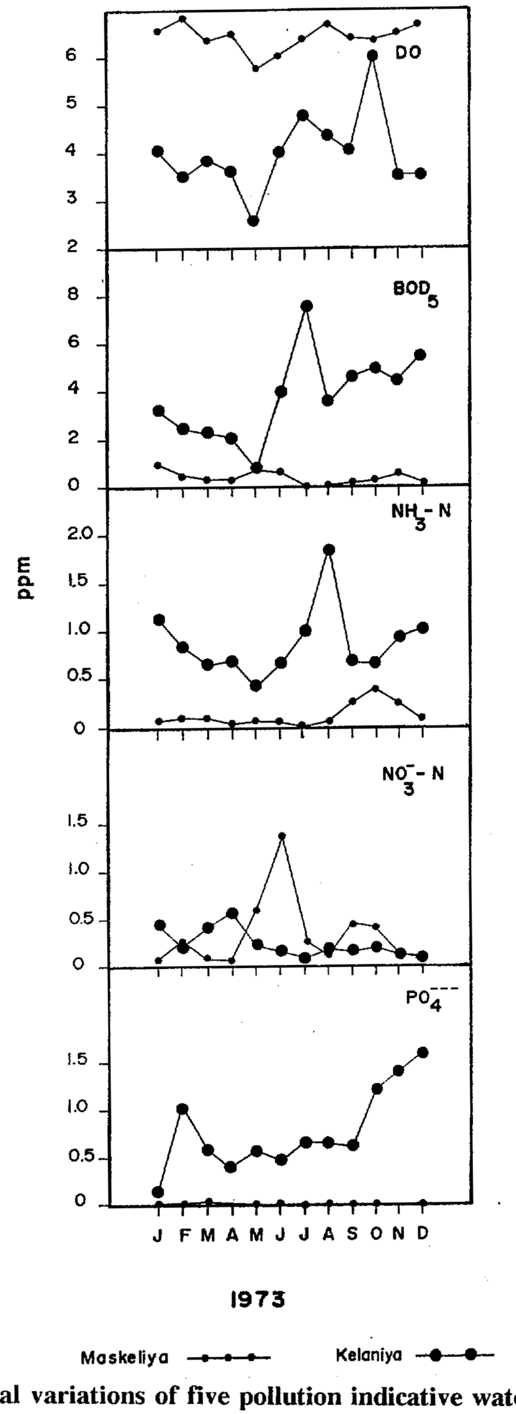

Figure 1.7 Seasonal variations of five pollution indicative water quality parameters (Gunatilaka, unpublished) compared between two sites (Maskeliya and Kelani Bridge)

Table 1.6 Inter-site variability of water quality, downstream of Ambatale during 1982-1983 (extracted from Dissanayake, 1985)

Parameter	Site 1	Site 2	Site 3	Site 4	F-Ratio	P<F
Distance (km)	14.4	12	9	5	-	-
EC ($\mu^{o}S$)	45	33	110	1208	5.57	0.001
Turbidity (NTU)	11.0	12.1	13.6	13.9	0.14	0.934
pH	7.01	7.09	6.97	6.46	12.83	0.0001
DO (ppm)	7.31	7.24	7.22	6.75	1.93	0.134
Cl (ppm)	56.3	56.9	58.3	3293	5.02	0.002
BOD_5 (ppm)	4.14	3.67	3.68	5.35	2.47	0.071
Ammonia (ppb)	195	226	262	333	0.23	0.873
NO_3 (ppb)	564	274	1799	563	0.78	0.511
NO_2 (ppb)	352	325	319	401	0.11	0.955
PO_4^{3} (ppb)	1.47	1.48	1.42	1.41	0.72	0.544
Suspended solid (ppm)	19.6	16.2	16.9	15.9	0.13	0.939
COD (ppm)	2.03	1.33	1.54	1.40	1.03	0.380

Table 1.7 Inter-site variability of water quality at Ambatale in 1989 (extracted from De Alwis, 1991)

Parameter	Site 1	Site 2	Site 3	WHO*	F-Ratio	P<F
EC ($\mu^{o}S$)	76.85	74.05	73.14	3500	0.07	0.9341
Turbidity (NTU)	12.15	14.9	12.5	5.0	0.56	0.5712
pH	6.64	6.62	6.67	6.5-9.0	0.05	0.9534
TH (ppm)	12.35	14.12	12.47	500	0.90	0.4134
DO (ppm)	6.54	6.67	6.68	4.0	0.18	0.8373
Cl (ppm)	34.18	32.86	32.14	250	0.03	0.9743
BOD_5 (ppm)	14.97	18.11	15.74	2-4	2.66	0.0790
Ammonia (ppb)	376	534	496	60	0.38	0.6820
NO_3 (ppb)	99	172	109	4400	0.64	0.5304
NO_2 (ppb)	5	20	25	30	0.12	0.8853
PO_4^{3} (ppb)	25	30	20	2000	1.00	0.3747
Total coli. (per 100 ml)	5036	5250	4048	0	0.29	0.7461
Faecal coli. (per 100 ml)	2186	2513	2422	0	0.10	0.9054

* = WHO permissible levels

Table 1.8 Mean ± SD of major ions and several trace elements at 19 sites downstream of Pugoda (extracted from Dissanayake *et al.*, 1985)

Ions	Mean	± SD
Ca (ppm)	5.04	4.08
Mg (ppm)	2.12	1.29
Fe (ppm)	1.89	2.43
NH_3 (ppm)	1.61	2.84
NO_2 (ppm)	0.04	0.01
NO_3 (ppm)	6.45	5.71
Cl (ppm)	25.7	5.14
SO_4^{2} (ppm)	15.5	14.43
Total P (ppm)	374.7	116.7
Dissolved P (ppm)	273.2	73.5
Pb (ppb)	7.4	5.1
Cd (ppb)	2.7	1.3
Cu (ppb)	10.2	5.6
Zn (ppb)	52.5	29.8
Mn (ppb)	650	580

It is apparent that the Kelani River water contained low dissolved salts from headwater to downstream (Tables 1.5, 1.6 and Figs. 1.5a, 1.5b). The low electrical conductivity is an indicator of low dissolved salts in the water. In the case of cations, the Kelani River water contained more or less similar amounts of Na and Ca indicating that leaching of calcarious rocks may not predominate the watershed. Higher concentrations of Na, K and Cl ions in Adam's Peak compared to the site at the Gartmore Estate where the elevation is relatively low (Table 1.5), may be attributed to a large number of pilgrim visits to Adam's Peak. The studies conducted at Hanwella indicated that there was a decreasing trend in electrical conductivity as well as dissolved salts with the onset of the south-west monsoonal rainfall due to dilution effect (Gunatilaka, unpublished). The changes of electrical conductivity from 8.85 μ^0S to 42.6 μ^0S from headwater to downstream (i.e. 144 km) further indicated the low dissolved salt content in the Kelani River system because, the cumulative weight of the total dissolved salts per unit volume (salinity) is a function of electrical conductivity and temperature (Silva, 1988).

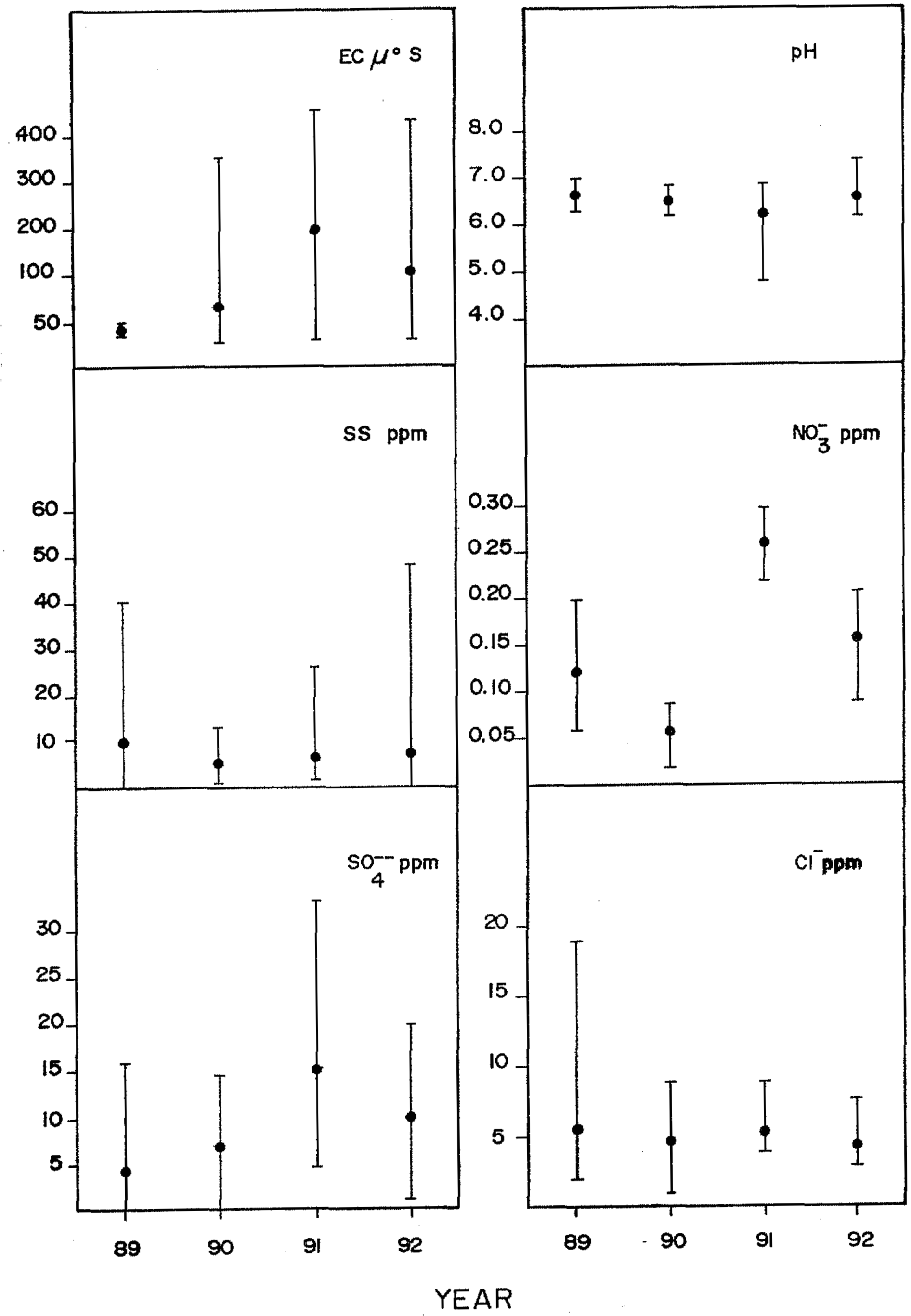

Figure 1.8 Changes in six water quality parameters at Ambatale Water Intake from 1989 to 1992 (extracted from several authors)

The variability in electrical conductivity at four sites within 14 km river distance from Ambatale to the Kelani Bridge in 1982-1983 (Table 1.6) may be attributed to the upstream intrusion of sea water with tidal flood and incomplete mixing. The variation in electrical conductivity among the three sites within one km river distance near Ambatale was not significantly different (Table 1.7). However, the conductivity was relatively higher in 1989 (De Alwis, 1991) than those values recorded in 1982-1983. This trend is further confirmed by the increase in electrical conductivity 1 km upstream at Ambatale (Weliwita Foot Bridge) from 1989 to 1992 (NBRO, unpublished). There was an increasing trend in the upstream salinity in the Kelani river with the highest electrical conductivity so far being recorded at Weliwita, 0.5 km upstream of the Ambatale Water Intake which was 450 μ^0S in March 1991 and the lowest being 26 μ^0S at the same site in November 1992. In addition, high salinity levels have been detected in the vicinity of the Ambatale Water Intake during the first intermonsoon in 1992 (NWSDB, unpublished).

Since Giesler's pioneer investigation in 1965 to date, relatively higher levels of organic matter have been detected in the Kelani River water. Higher permanganate consumption of the Kelani River water detected by Weninger (1972) have been attributed to high concentration of humic substances. In addition, an increasing trend in humic acid contents could be seen with increasing elevation which was similar to permanganate consumption of the Kelani River water 500 m above mean sea level (Weninger, 1972). Higher permanganate values in the lower reaches of the Kelani River water may be attributed to organic matter loading into the water course from densely populated urbanized areas.

This interpretation was supported by relatively high BOD_5 values found at the Kelani Bridge compared to the site at the Maskeliya Oya (Fig. 1.7, Gunatilaka, unpublished). In contrast, there was an increasing trend in BOD_5 over time, downstream of the Ambatale Water Intake (Tables 1.6, 1.7, Dissanayake, 1985; De Alwis, 1991). The BOD_5 values recorded by De Alwis (1991) were far above the WHO standard and the proposed BOD_5 standard for Sri Lankan surface water. Extremely high counts of total coliform and *E.coli* per 100 ml and ammonia concentration have been reported for the Kelani River water at Ambatale (Table 1.8). With respect to inorganic nitrogen (i.e. NH_3-N, NO_3-N) in the Kelani River water, it has been reported that there were always high concentrations of NH_3-N and NO_3-N (Table 1.7, 1.8). Weninger (1972) has shown a marked increase in NH_3-N and humic acid concentrations towards headwater (Fig. 1.5b). The high concentration of ammonia in the headwater may be a result of incomplete nitrification of humic acid. Less humic acid and high nitrate concentration has been found in Adam's Peak compared to the site at the Gartmore Estate (Table 1.5). This may be due to organic pollution in Adam's Peak which is related to human waste.

The diagnosis of nitrate concentrations upstream of Ambatale from 1989 to 1992 (Fig. 1.8) indicated that there was an increasing trend in nitrate in the river water. However, this trend of nitrate in the river water at Ambatale was inconsistent with the nitrate values reported in

1989 (De Alwis, 1991) for the same site but comparable with the values reported by Dissanayake, (1985) for 1982 (Tables 1.7, 1.8).

The ammonia concentrations in the river water at Maskeliya was significantly lower compared to the site at the Kelani Bridge in 1973 (Fig. 1.7) and it has increased tremendously further downstream over time (Tables 1.7, 1.8). Relatively high concentrations of nitrate have been reported in the Kelani River since the work of Giesler (1967). The nitrate value reported by Weninger for the Kelani River water at Adam's Peak (263 ppb) was 5.4 time greater than the value reported at the site at the Gartmore Estate which is located 350 m below mean sea level (Table 1.5). This situation may be attributed to the impact of the pilgrim visits to Adam's Peak because Na^+, K^+ and pH were also higher at Adam's Peak compared to the site at the Gartmore Estate.

Evidently, of the 20 industries located along the Kelani River, 12 industries directly discharge organic carbon rich effluent into the river (Table 1.9). The Madampitiya Sewage Works discharges the highest amount of organic waste in terms of COD (36,000 kgd^{-1}) which was 78.3 % of the total COD loading into the river. The Ambatale Water Treatment Plant ranks as the second highest organic polluter with respect to COD loading into the river (10.5 % of total loading). The rest of the industries loaded less than 0.5 % of the total COD per day. Even though, COD levels of the industrial effluent have been determined (CEA 1985 a,b), COD levels in the river water were not analysed. Dissanayake *et al.*, (1985) reported COD levels at four sites from the Ambatale Water Treatment Plant up to the Victoria Bridge (Table 1.6).

Table 1.9 COD loading into the Kelani River as industrial effluent (extracted from CEA 1985 a,b)

Industry	COD (kgd^{-1})	%
Madampitiya Sewage Works	36,000	78.3
Ambatale Water Treatment Plant	4810	10.5
British Ceylon Corporation	2000	4.3
Pugoda Textiles	1580	3.4
Plywood Corporation	1200	2.6
Kalatuwawa Water Works	234	0.51
Biyagama Water Treatment Plant	110	0.24
Leather Products Corporation	55.9	0.12
McCallum Brewery	23.8	0.05
Ceylon Cold Stores (Kaduwela)	18	0.04
Synthetic Textiles Ltd.,	13.3	0.03
Central Transport Board (Peliyagoda)	1.44	0.003

The values reported by Dissanayake *et al.*, (1985) were relatively low compared to the permissible level for surface water. In addition, there was an even distribution of COD level with a slight increase towards the sea mouth.

In the case of PO_4^{-3} concentration in the Kelani River, Weninger (1972) reported higher P_2O_5 levels at Adam's Peak compared to the site at the Gartmore Estate (Table 1.5). In addition, the total P_2O_5 levels reported by the same author showed a seaward increase (Fig. 1.5b). These values were incredibly low compared to the PO_4^{-3} values reported for the Kelani River water at Hanwella and Kelaniya by Gunatilaka (unpublished) during 1973-1974 (Figs. 1.6, 1.7). In contrast, lower PO_4^{-3} values reported downstream of Ambatale (Tables. 1.7, 1.8) were well below the permissible level of PO_4^{-3} for surface water.

The phosphate values reported by Dissanayake *et al.*, in 1985 were analyzed using basic statistics (Table 1.8). Incredibly high mean values and standard deviations for both the total and dissolved phosphorous from downstream of Pugoda to the sea mouth showed localization of high PO_4^{-3} which is very unlikely for a running water system. If the stream flow was highly polluted by fertilizer or human waste, there might be site-specific variability. With respect to the reported values of heavy metal concentrations (Table 1.8) in the Kelani River water, there was contamination by certain trace elements viz., Zn, Mn and Pb.

1.5 Trends in Pollution

The Kelani River has been subjected to a variety of deteriorations in respect to water quality according to the already available data. Relative increase in chemical constituents at Adam's Peak compared to the downstream is an indication of pollution due to a large number of pilgrim visits. Salinity in the downstream (from sea mouth to Ambatale) has been influenced by sea water intrusion. However, though there was a seasonal change in salinity, the reported values for surface water (in terms of conductivity) were more acceptable for the ambient salinity standard. Increasing salinity may be exacerbated by two major ongoing human activities (i.e. water abstraction for drinking and sand removal for construction).

The removal of sand from the river bed especially at the lower reaches has already resulted in serious degradation in channel morphology over the last decade. The sediment loading in the river bed allows salt water to penetrate upstream during the dry season leading to an increase in salinity. Further, water abstraction rates and sand mining may collectively affect the present level of salinity.

The general trend in water quality of the Kelani River is that the river has been affected by both biogenic waste and technogenic effluent. There is very little information with which it is difficult to show the pollution level of the river along with the effects of sand mining and water abstraction. The levels of pollution indicative parameters (e.g. BOD_5, COD, NO_3-N, NH_3-N, etc.) should be properly monitored to identify the magnitude and trends in pollution over time. Similar emphasis should be placed on heavy metal concentrations in the river water. Certainly, there is a potential to contaminate the river water with heavy metals especially with Pb, Zn and Mn since the river intercepts the industrial and economic capital of the country. However, one cross-sectional analysis on heavy metals is insufficient to draw reliable conclusions on site-specific and time-bound distribution of trace elements. In addition, the levels of agrochemicals especially pesticides draining from intensively cultivated areas of the watershed should be monitored on a seasonal and spatial basis. Most of the pollutants that are already contaminated with the river water may not be acute in terms of toxicity but the impact would be chronic for both the aquatic flora and fauna living in the riverine ecosystem and for the people who consume the river water without appropriate treatment.

1.6 Recommendations

- Selection of sampling sites and the sampling frequency should be systematized for a better understanding of the water quality of the Kelani River.

- A set of basic parameters should be established for monitoring purposes. Specific parameters should also be identified in the case of direct effluent discharge.

- Cost-effective pollution indicators (e.g. bio-indicators) should be identified for quality assessment and subsequent implementation of mitigation measures.

- Unified and precise methods should be employed during sampling and analysis respectively.

- Site-specific and time-bound information on water quality should be collected for a complete climatic cycle and the data should be critically analyzed in order to re-confirm the number of sampling sites, parameters and frequency of sampling necessary for future monitoring.

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CHAPTER 2: KELANI ESTUARY

2.1 Introduction

Sri Lanka's 103 rivers which radially drain the entire island empty into the Indian Ocean. All major rivers draining the wet zone originate in the central highland and they discharge into the Indian Ocean from the west coast. Some of the rivers form basin estuaries or lagoons before they empty into the sea. An estuary is a semi-enclosed coastal water body open to the sea and tidal water is markedly mixed and diluted by the freshwater that drains the basin. Estuarine ecosystems are of two kinds namely the basin estuaries (lagoons) and riverine estuaries. A riverine estuary is formed by a river when it discharges directly to the sea by means of a relatively narrow channel. The Kelani Ganga, the second largest river, flows into the Indian Ocean at Crow Island via a riverine estuary (see Chapter 1 in this volume).

Estuarine ecosystems are considered to be the most important compartments of the coastal resources because of their ecological, economic and aesthetic values. These ecosystems are rich in biodiversity, productive in fisheries and attractive in scenic values. The estuarine habitats in Sri Lanka are fairly rich in commercially important aquatic fauna. The commercially important species are either catadromous or anadromous in nature and captured when they arrive as active or passive migrants from the sea to complete their life cycles. This phenomenon depends mainly on the estuary's mixture of freshwater and marine water in providing and renewing nutrients, organic materials and oxygen. Estuaries and lagoons are also important with respect to environmental geochemical cycles, because they are interfaces between athalassic watersheds and oceanic environments. The water circulation patterns in estuaries therefore, enhances the mixing rate between fresh and sea water. Further estuaries are potential sites for recreation and valuable ecosystems to test ecological hypotheses. Sand transported by rivers into the sea via riverine estuaries is important for beach formation. The importance of the estuarine ecosystems in Sri Lanka is hardly explored to date. At present, these ecosystems are either over-exploited or are being used directly or indirectly as disposal sites for biogenic waste or technogenic effluent.

Certainly, the properties of estuarine water could be considered as fundamental determinants of the structure and function of these ecosystems. The nature of these ecosystems changes with human interference. The Kelani Estuary which is located in the administrative and industrial nucleus of the country is a classic example for a stressed riverine estuary. The Kelani Estuary is neither being utilized for a commercially important fishery nor for other estuarine activities (e.g. transport, aquaculture, etc.,). The immediate upstream of this estuary however, is the source of drinking water for about 2.5 million inhabitants of the metropolitan area. In contrast, this estuary is the recipient of untreated or partially treated sewage and industrial effluent originating in the northern segment of the metropolitan area. The surroundings of the Kelani Estuary is highly congested due to human settlement, or else substituted by industrial and commercial sites. Further, ongoing human activities in the vicinity would directly or indirectly affect the indigenous natural values of the estuary and the present use of the upstream as a drinking water source. Therefore, needless to say that the water quality of the Kelani Estuary should be maintained within the limits of ambient water quality standards proposed for coastal and estuarine habitats.

2.2 Study Site

The Kelani Estuary (6^0 59' N; 79^0 58' E) is located 5 km north of Colombo, the capital of Sri Lanka. A small island, popularly known as the Crow Island, covering about 30 ha. has been carved out by the delta of the Kelani River before it reaches the sea (Fig.2.1). The Colombo Harbour is located in the south-west direction of the mouth of the Kelani River. The Muthurajawela Marsh and the floodplain of the Kelani River form prominent features of the physical setting of the area. Although the beach to the north of the river is a relatively straight sandy beach, it becomes crescentic around the Mutwal Fishery Harbour in the south. Sheltered by a submerged offshore reef, the Kelani Estuary is essentially a dynamic sedimentary environment, prone to modification by all processes operating at its land and sea interface. The problems of beach erosion and water logging have created some concern in recent years particularly in view of the rapid rate of land reclamation and housing development (Madduma Bandara *et al.*, 1987).

The construction of the Colombo Harbour, the Hamilton Canal, the Old Dutch Canal and the Kelani Flood Protection Works have affected the stability of the estuary in different ways. The increasing soil erosion rates in the upper Kelani basin have produced river sediment that nourished the beaches particularly during the plantation era. Periodic de-silting of the harbour which led to the removal of over 10 million cubic meters (MCM) of material and removal of sand from the river in large quantities (at present over 2 MCM annually) and the destruction of the offshore reef may have affected the sediment budget of the estuary.

2.3 Watershed

The Kelani Ganga, the second largest river in Sri Lanka has an annual runoff which is about 5,500 MCM with a long history of floods. The upstream boundary of the estuary is not permanent. The estuarine area generally lies from the river mouth to the upstream boundary where fresh and sea water mixing is zero. The upstream boundary varies with changes of the river flow and tidal floods. Generally, it can be considered that truly estuarine conditions occur only upto several kilometers upstream from the river mouth. However, sea water penetration occurs upto about 15 km upstream during the dry season. The Old Dutch Canal and the Hamilton Canal connect on the right bank of the estuary at the westward bend, between Peliyagoda and Lansiyawatte (Fig. 2.1).

The St. Sebastian Canal (North Colombo Drainage Canal) connects with the Kelani Estuary on its left bank near Totalanga. The Kelani Estuary is a geographic boundary of the northern

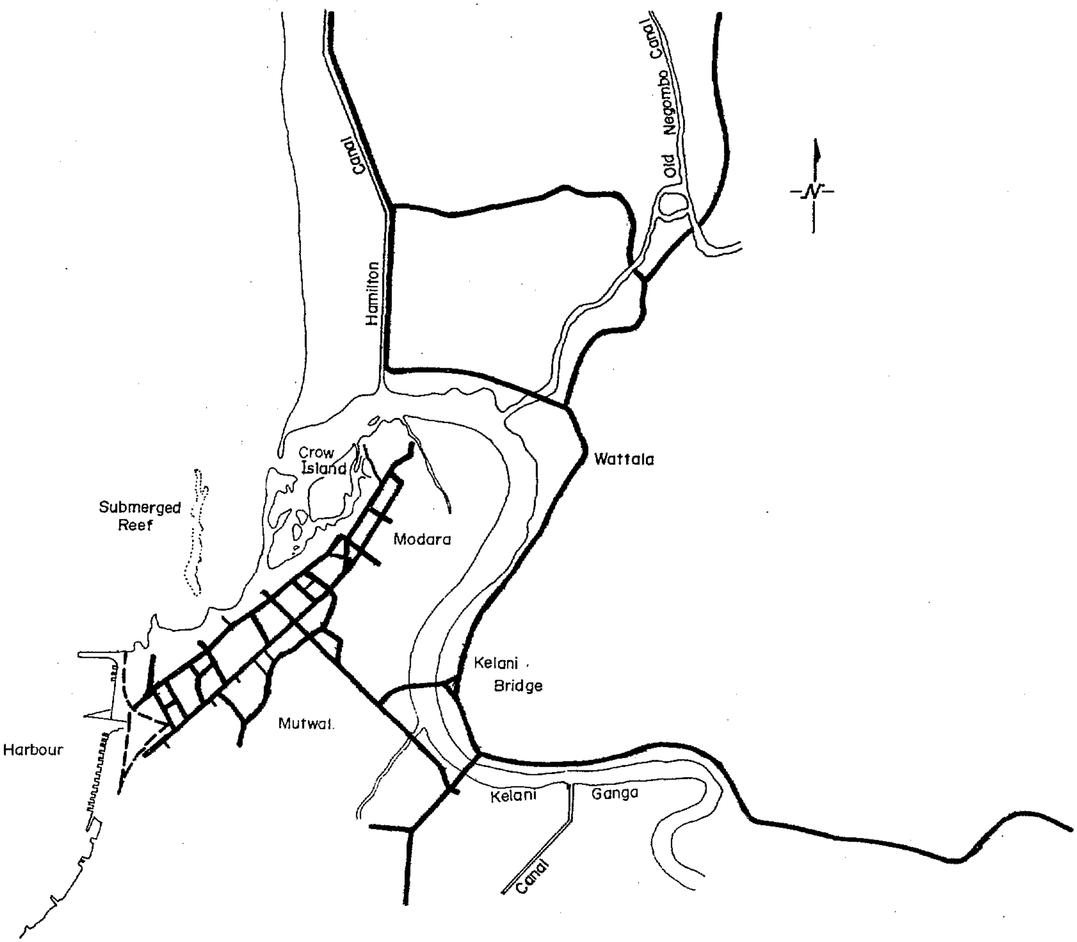

Figure 2.1 The Kelani Estuary and its environment

city limit of Colombo. Being located within the metropolitan area of Colombo, both the left and right banks of the Kelani Estuary have been subjected to a more or less urbanized land use.

Natural vegetation is almost zero in the floodplain of the estuary except for the existence of mangroves and a small patch of scrub jungle on the right bank near the sea mouth. Agricultural land use is not prominent except for the occurrence of a small patch of paddy-fields located close to the right bank bordering the Wattala-Hendala road. There is a sparsely planted coconut cultivation adjacent to the small jungle (Fig. 2.1). The area between the connections of the Hamilton Canal and the Old Dutch Canal with the right bank of the Kelani River is mainly formed of commercial land while the rest of the land along the right bank flows through high density residential areas. The land along the left bank from the Kelani Bridge to the sea mouth can also be considered as an industrial or commercial land. The Kelani Tissa Power Station, the Madampitiya Sewage Plant and the Leather Corporation are the three major industries located along the left bank of the estuary. The left bank of the estuary around the Crow Island is also a high density residential area.

The truly estuarine area of the Kelani River is not utilized by the people in the vicinity for washing or bathing. Up to 50 km upstream, the Kelani Estuary has become a recipient for several industrial effluents. Some of the industrial effluents are directly discharged into the river while others are dumped into the St. Sebastian Canal which ultimately drains into the estuary. A list of industries and the nature and type of the effluent they discharge directly or indirectly into the river is given in the previous chapter. It should be noted that sewage from north Colombo is also directly discharged into the Kelani Estuary at Madampitiya. The Colombo North Sewer System is now being upgraded and has been extended to minimize the overflows.

2.4 Water Quality

A fair amount of information is available on some physico-chemical characteristics and hydrography on certain lagoons in Sri Lanka, although the riverine estuaries are not properly examined as yet with respect to water quality. The Kelani Estuary has been subjected to several investigations on water quality and pollution indicative parameters since 1970 to 1994. More attention has been paid to the Kelani Estuary following the sudden occurrence of fish mortality in 1982. It has been generally accepted that the changes in quantity and timing of freshwater inflow, discharge of industrial effluent, disposal of domestic sewage and solid waste and dumping of waste oils from mechanized boats are major factors responsible for affecting the water quality of the Kelani Estuary.

The water quality of the Kelani Estuary was first examined during the Austrian-Ceylon Hydrobiological Mission in 1970 (Weninger, 1972). Subsequently, some pollution indicative water quality parameters were examined (i.e. DO, BOD_5, NH_3-N, NO_3-N and PO_4^{-3}) at the Kelani Bridge from January 1973 to December 1975 on twelve occasions (Gunatilaka, unpublished). In 1982, some bacteriological characteristics, biological oxygen demand (BOD_5) and dissolved oxygen (DO) in the Kelani Estuary near the Crow Island and Totalanga where untreated sewage is emitted to the Kelani Estuary were also examined following the occurrence of fish mortality (Fernando *et al.*, 1983).

An investigation on the levels of pollution in the Kelani Estuary at two sites (river mouth and the Kelani Bridge) was carried out for a period of eight months from September 1982 to March 1983 (Dissanayake, 1985). A detailed and comprehensive analysis of bacteriological properties of the Kelani Estuary was conducted in September 1984 by the National Aquatic Resources Agency (De Silva *et al.*, 1984). The Ceylon Institute of Scientific and Industrial Research (CISIR) identified the state owned and private sector industries whose effluent is emitted directly to the Kelani Estuary and subsequently reported the nature and type of the effluent and the frequency and magnitude of discharge (CEA, 1985a,b). Several heavy metals were also analysed in the estuarine sites in 1984 (Dissanayake *et al.*, 1985). In 1986, a qualitative assessment was conducted on the water quality and the nature of the industrial effluent discharged into the Kelani Estuary using Ultra Light Air Craft Photography (CEA, 1987a,b). Several water quality parameters of the Kelani Estuary were determined in relation to the tidal variation (during low and high tides at neap and spring tides) during August-September 1986 by the National Aquatic Resources Agency (Dassanayake *et al.*, 1986), at three sites from the river mouth up to the Kelani Bridge. During this study, dissolved oxygen concentration, NH_3-N, *E. coli* and faecal coliform were determined as pollution reflecting parameters. In a recent study, the concentration of chromium ions in the water and sediment was analyzed along with an investigation conducted on chromium speciation in the Kelani Estuary near a tannery effluent outfall (Wijegoonawardena, 1995).

The results of the studies carried out on water quality of the Kelani Estuary by Weninger (1972), Gunatilaka (unpublished), Dissanayake (1985) and Dissanayake *et al.*, (1985) are summarized in Table 2.1. The water quality information reported by Weninger (1972) revealed that most of the parameters examined were within the ambient water quality standards proposed for coastal brackish water (Table 2.1). It should be noted that the permanganate consumption values for the Kelani Estuary near the river mouth were less than that of the rest of the upstream sites located at Hanwella, Kitulgala and Adam's Peak except the Kelani Bridge (see Chapter 1 in this volume & Weninger, 1972). The permanganate consumption was about twofold that of the water near the Kelani Bridge compared to that of the estuarine water near the river mouth (Table 2.1). The dissolved oxygen values recorded by Gunatilaka (unpublished) from 1973 to 1975 varied from 2.50 mgl^{-1} to 6.00 mgl^{-1} with a mean value of 4.00 $\pm$ 1.23SD mgl^{-1} indicating that the estuarine water near the bridge was poorly oxygenated on several occasions (Table 2.1). Poor oxygenation may be attributed to the stagnant nature of the water and the high microbial and zooplankton biomass therein. A wide range of BOD_5 determined during this survey (0.65-7.65 mgO_2l^{-1}) for the Kelani Estuary at the railway bridge, signaled that the Kelani Estuary had been subjected to a great deal of organic pollution. The nature of organic pollution in the Kelani Estuary during the first half of the 1970s was further indicated by high levels of NH_3 in the water. The NH_3 concentration at the Kelani Bridge varied from 440 μgl^{-1} to 1850 μgl^{-1} (Table 2.1) during the survey conducted by Gunatilaka. The concentrations of NO_3^- and PO_4^{-3} were also relatively high in the Kelani Estuary at the railway bridge as recorded in this study (Table 2.1). The studies conducted in 1982 following the occurrence of sudden fish mortality in the Kelani River (Fernando *et al.*, 1983) indicated gross organic pollution in the estuarine habitat. In their results, BOD_5 ranged from 24.0 mgl^{-1} to 53.2 mgl^{-1} and exceeded the permissible level for coastal surface water which is between 20 and 25 mgl^{-1}. They also reported anoxic conditions near the sewage outfall of the Madampitiya Sewage Works. With respect to bacteriological counts (Fernando *et al.*, 1983), both MPN and *E. coli* exceeded the permissible levels for drinking water and indicated high faecal contamination. The MPN values for total coliform ranged from 8 to 2500 per 100 ml while *E. coli* ranged from 17 to 350 per 100 ml. The conclusion of this study (Fernando *et al.*, 1983) was that the upstream of the estuarine water of the Kelani Estuary was detrimental for drinking and not suitable for domestic uses.

In contrast, Dissanayake (1985) reported relatively low values for several organic pollution reflecting water quality parameters including COD and extremely high values for micro-nutrients in some occasions for two sites (i.e. mouth of the estuary and Kelani Bridge) during the period September 1982 - March 1983 (Table 2.1 & 2.2). As reported by Dissanayake (1985), the Kelani Estuary was either neutral or slightly acidic and the dissolved PO_4^{-3} level increased upto 5,800 μgl^{-1} (Table 2.2). The maximum value reported for NO_2^- was 2,950 μgl^{-1}. The BOD_5 ranged from 1.5 to 11.5 mgl^{-1} and from 3.00 mgl^{-1} to 8.50 mgl^{-1} for the waters at the river mouth and at the Kelani Bridge respectively. The reported concentrations of NO_3^- and NH_3 were also extremely high in some instances (Table 2.2). The COD ranged from 0.2 mgl^{-1} to 5.4 mgl^{-1} and between 0.2 mgl^{-1} and 3.7 mgl^{-1} for the waters at the railway bridge and at the river mouth respectively. Extremely high bacteriological counts were reported for the Kelani Estuary during the study conducted in June and September 1984 at 12 sites from the river mouth to 12 km upstream by De Silva and co-workers (Table 2.3). Accordingly, the Kelani Estuary showed gross organic pollution. With respect to heavy metals in the Kelani Estuary, Dissanayake *et al.*, (1985) reported periodic high values for certain heavy metals in both river sediment and water (Table 2.1). The authors showed a relative enrichment of several heavy metals (i.e. Pd, Cd, Cu and Zn) in estuarine water when compared to the background levels. In addition, high concentrations of Zn and Ti were found in estuarine sediment. It was evident that these metals entered through water ways as industrial effluent. Relatively high enrichment of Zn and Pb in the estuarine water has been attributed to extensive emanation of automobile exhaust fumes as well as the wide use of galvanized materials as household utensils and appliances (Dissanayake *et al.*, 1985).

Table 2.1 Water quality parameters of the Kelani Estuary (extracted from Weninger 1972 (A), Gunatilaka unpublished (B), Dissanayake 1985 (C) and Dissanayake *et al.*, 1985 (D))

	Period				
Parameter	A (1970)		B (1973-75)	C (1982-83)	D (1984)
	Estuary	Bridge	Estuary	Estuary	Estuary
Turbidity (NTU)				2.0-57.0	
Conductivity (μS)				21-11000	
Suspended solid (mgl^{-1})				1.8-39.8	
DO (mgl^{-1})			2.5-6.0	5.8-8.0	0.3
BOD_5 (mgl^{-1})			0.65-7.65	1.5-11.5	
pH	6.4	6.5		6.05-7.05	6.0
NH_3-N (mgl^{-1})			0.03-0.4	0-21.6	
NO_3-N (mgl^{-1})			0.07-1.4	0.16-3.4	3.33
NO_2-N (mgl^{-1})				0.01-1.8	0.03
PO_4^{-3} (mgl^{-1})			0.15-1.6	0.18-4.7	0.42
Cl (mgl^{-1})	85.2	7.38		40-27720	22
Pb (μgl^{-1})					90
Cd (μgl^{-1})					10
Cu (μgl^{-1})					70
Zn (μgl^{-1})					270
Mn (μgl^{-1})					120
Fe (mgl^{-1})					2.3
Mg (mgl^{-1})	5.81	2.96			1.72
Ca (mgl^{-1})	1.15	2.09			3.2
Al (mgl^{-1})	0.09	0.04			
Na (mgl^{-1})	1.00	4.8			
K (mgl^{-1})	3.5	5.0			
NH_4 (mgl^{-1})	0.04	0.015			
P_2O_5 (mgl^{-1})	0.08	0.04			
SiO_2 (mgl^{-1})	6.95	3.0			
HCO_3 (mgl^{-1})	0.44	0.36			
Humic Acids (mgl^{-1})	0.151	0.038			
Permanganate value (mgl^{-1})	13.3	28.4			
COD (mgl^{-1})				0.2-3.7	

Table 2.2 Pollution indicative water quality parameters (mean and range) of the Kelani Estuary at the river mouth and the railway bridge (extracted from Dissanayake, 1985)

Parameter	Estuary	Bridge
pH	6.46 (6.05-7.05)	6.6 (6.05-7.05)
DO	6.7 (5.8-8.00)	6.31 (4.2-8.5)
BOD_5	5.35 (1.5-11.5)	5.61 (3.0-8.5)
COD (mgl^{-1})	1.4 (0.2-3.7)	2.33 (0.2-5.4)
Nitrate (mgl^{-1})	0.53 (0.1-3.4)	0.55 (0.03-2.9)
Nitrite (mgl^{-1})	0.42 (0.01-1.8)	0.85 (0.03-2.95)
Phosphate (mgl^{-1})	1.42 (0.18-4.7)	1.47 (0.02-5.8)
Ammonia (mgl^{-1})	0.33 (0 -2.1)	0.17 (0 -0.48)

Table 2.3 The bacterial counts per 100 ml of surface water in the lower estuary of the Kelani River (extracted from De Silva *et al*, 1984)

Sampling station	Total coliform		Faecal coliform	*E. coli*	
	24.9.84	**4.6.84**	**24.9.84**	**26.9.84**	**6.9.84**
Lagoon end	540,000	54,000	540,000	70,000	35,000
Open lagoon	280,000	54,000	70,000	31,000	17,000
Lagoon mouth	160,000	240,000	1,600,000	34,000	35,000
River mouth	1,600,000	170,000	920,000	170,000	17,000
Leather Corp. discharge	2,400,000	2,400,000	2,400,000	1,600,000	2,400,000
Sewage discharge	2,400,000	2,400,000	2,400,000	2,400,000	2,400,000
Point of entry of Jadi Ela	110,000	110,000	79,000	140,000	70,000
Point of entry of canal from Kelani Tissa Power Station	49,000	160,000	33,000	13,000	54,000
Railway Bridge at Kelaniya	49,000	17,000	49,000	11,000	17,000

The studies carried out in 1986 by NARA attempted to highlight the magnitude of sea water intrusion into the estuary and to examine the status of organic pollution of estuarine water with respect to tidal amplitude and rhythm (Dassanayake *et al.*, 1986). An attempt was made to interpret those results after transforming them into log scale. Subsequently the log values were plotted as bar charts. These bar diagrams hardly showed any variation in water quality parameters determined during low and high tides at neap and spring tides in the surface and bottom waters in the Kelani Estuary. Therefore, the data was re-transformed into a linear scale and summarized in Table 2.4. However, the data was not statistically treated to examine whether significant variations could be found along the gradient (inter-site), between the layers (surface and bottom) and the tidal rhythm (low and high tides) and amplitude (neap and spring tides). Since the raw data was extracted from bar charts, the analytical methods were not stated and some analytical parameters were not detectable (e.g. NH_3, Ca, Mg), these results were inconsistent with the earlier reported values. In this case, it was sufficient to analyse only two parameters viz., electrical conductivity and faecal coliform to achieve the anticipated objectives (i.e. salt intrusion and organic pollution). Salinity is a function of conductivity and temperature, and the number of total counts per 100 ml of water is the best indicator for organic pollution.

The linear data showed that there were marked variations in electrical conductivity between sites, layers and during different tides (amplitude and rhythm). However it is important to report that the surface conductivity ranged from 31.6 μ^0S to 1000 μ^0S which was earlier reported as 25 - 1258 μ^0S. The lower value is extremely small for brackish water. With respect to organic pollution, extremely high counts were reported for the total coliform irrespective of the site, layer and tide (Table 2.4) indicating heavy loading of human excreta into the estuary. The authors were unable to interpret the process and rate of sea water intrusion into the estuary in relation to the five parameters investigated (i.e. total hardness, Ca^{++}, Mg^{++}, electrical conductivity and Cl^-) during low and high tides at neap and spring tides.

In the case of pollution reflecting parameters, there were no significant differences in the concentration of dissolved oxygen in the surface and bottom waters at the three sites during low and high tides at neap and spring tides. It is interesting to note, the authors found that the NH_3 concentration in the bottom water was not detectable during low tide at spring tide in three sites (Table 2.4). The NH_3 concentrations were relatively high in both surface and bottom waters at all three sampling sites during low and high tides at neap tide (Table 2.4). Irrespective of the sampling sites or tidal rhythm and amplitude, extremely high bacteriological counts (i.e. total counts and faecal coliform) were found during this survey and it ranged from 10^2 to 10^6 cells per 100 ml (Table 2.4). A relatively lower count was observed for the upstream site compared to the site close to the river mouth.

Table 2.4 Hydrographic and bacteriological parameters in the Kelani Estuary during low and high tides at neap and spring tides (extracted from Dassanayake *et al.*, 1986)

Parameter		Neap Tide Low Tide Surface	Bottom	High Tide Surface	Bottom	Spring Tide Low Tide Surface	Bottom	High Tide Surface	Bottom
EC	St 1	1000	562.34	100	707.94	446.6	79.4		
	St 2	630.9	1258.9	562.34	630.9	31.6	25.11	31.6	31.6
	St 3	56.23	562.34	100	177.8	100	31.6	31.6	44.6
TH	St 1	--	562.34	--	1995.26	63.09	44.66	175.8	63.09
	St 2	100	--	--	--	63.09	63.09	63.09	56.23
	St 3	--	63.09	--	100	63.09	100	39.81	39.81
Cl	St 1	398.1	1778.27	316.22	3162.27	446.68	316.22	223.87	316.22
	St 2	199.52	141.25	177.82	141.25	199.52	251.18	316.22	316.22
	St 3	141.25	--	177.82	177.82	199.52	125.89	199.52	251.18
Ca	St 1	--	63.09	--	100	19.95	4.46	4.46	10
	St 2	17.78	--	--	--	6.30	1.707	10	7.78
	St 3	--	--	--	31.62	17.78	12.58	11.22	7.94
Mg	St 1	--	79.43	--	100	5.62	5.62	17.78	10
	St 2	17.78	--	--	--	6.30	5.62	12.58	5.62
	St 3	--	--	--	31.62	17.78	10	5.62	10
DO	St 1	6.30	3.98	5.62	5.01	6.30	7.94	3.98	6.3
	St 2	5.62	6.3	5.88	5.75	3.9	6.30	6.30	8.91
	St 3	6.3	6.3	5.62	5.88	4.46	5.01	10	8.91
T.coliform	St 1	316227.7	251188	1778279	125892.5	125892.5	125892.5	3162.2	10000
	St 2	3162277	79432.8	446683.5	1778279	398.10	3981.0	4466.8	4466.8
	St 3	19952.62	5623.4	17782.75	630957.3	630.85	630.95	--	--
F.coliform	St 1	199526.2	63045.73	562341.3	79432.82	398107.1	316227	31622.7	1000000
	St 2	39810.71	35481.33	1995.26	1000000	3162.27	3548.13	6309.57	31622.7
	St 3	17782.79	5623.41	17782.79	79432.82	630.95	100	562.34	5623.41
NH_3	St 1	3.98	6.30	2.51	6.3	1.25	--	1.25	10
	St 2	1.77	3.98	3.98	1.77	--	--	--	1.25
	St 3	3.16	1.77	3.1	1.58	3.16	--	1.25	--

2.5 Trends in Pollution

The already available water quality data on the Kelani Estuary since 1970 to 1994 indicates that this riverine estuary has been subjected to conventional organic pollution. The organic pollution of the estuary could be directly attributed to the direct discharge of untreated sewage and other organic matter into the estuary. This situation may be further aggravated by transportation of non-degraded and partially decomposed organic matter draining the entire watershed. As mentioned in the previous chapter, the Kelani River receives diffused and point source pollutants from headwater to downstream. In addition, agrochemicals applied in the basin may also drain down to the estuary since fertilizer application is not systematic. However, it can be seen that a great variability exists in pollution indicative water quality parameters in different studies. This variability could certainly be attributed to marked errors involved in sampling and analysis. A majority of the studies did not explain the methodologies employed during sampling and analysis. Although several studies have paid attention to organic pollution reflecting parameters such as BOD_5, DO, NH_3, total coliform and *E. coli*, etc., only one study measured COD values of the estuarine water (Dissanayake, 1985). Apparently, no study has paid any attention to determine the levels of organic residues (i.e. pesticides, insecticides, etc.,) which are used in excess in the basin. The levels of the other organic substances such as tar, oil and grease may also be available beyond permissible levels in the Kelani Estuary because of the location of a major sea port in the vicinity.

With respect to heavy metal pollution, it is premature to conclude whether the estuary is enriched by heavy metals or not. There is also a possibility that the estuarine water is enriched with heavy metals because of the enormous amount of industrial and urbanized activities taking place in the northern part of the Colombo city. As mentioned by Dissanayake *et al.*, (1985), emanation of automobile exhaust fumes was so intense that it may also be the most predominant contributor for certain heavy metals. The availability of certain heavy metals in estuarine sediment (Dissanayake *et al.*, 1985) and the high chromium levels in sediment and in benthivorous fish (Wijegoonawardena, 1995) signals the potentiality of an increasing trend of heavy metals in the Kelani Estuary. Several studies have also shown that salt intrusion occured up to the Ambatale Water Intake during the dry seasons. Therefore, care should be taken since the mode of speciation, cycling and rate of dispersion of heavy metals are not properly understood as yet.

The pollution status of the Kelani Estuary could certainly be estimated by examining the aquatic biodiversity of the estuarine habitat. Unfortunately, there is no past information or any information regarding the present status of aquatic biodiversity in the Kelani Estuary. Regular and progressive investigations on aquatic biodiversity as an index of pollution do not involve sophisticated technical analysis and would be more appropriate for countries like ours because of cost-effectiveness and availability of manpower. In view of the fact that the water from the Kelani River 14 km upstream is used as a drinking water supply for Colombo and the suburbs, regular monitoring of pollution reflecting parameters of the estuary is also absolutely essential.

2.6 Recommendations

- A systematic monitoring programme on water quality assessment should be immediately implemented by the National Aquatic Resources Agency which is located adjacent to the Kelani Estuary.

- More emphasis should be placed on speciation and accumulation of heavy metals in different components of the estuarine system.

- Attempts should be made to examine pollutants transported into the estuary due to activities taking place in the Colombo Harbour.

- Necessary steps should be taken to establish at least a primary treatment plant for sewage before it discharges into the estuary at Madampitiya.

- Untreated effluent should not be permitted to reach the estuary through St.Sebastian's Canal.

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CHAPTER 3: NEGOMBO LAGOON

3.1 Introduction

A lagoon is essentially a semi-enclosed open water body between the sea and a river delta. It is a mixing ground not only for sea water coming in through the tidal inlet and freshwater entering through the river delta but also for dissolved inorganic and organic constituents, and particulate matter, sediment and biomass. Therefore, its physical nature, chemical composition and biological diversity are always determined by the diurnal and seasonal tidal rhythm and the catchment induced freshwater inflow.

Of the 45 brackish water bodies found along the coast of Sri Lanka, the Negombo Lagoon plays an important role with respect to shellfish and fin fish fishery. The Negombo Lagoon is commonly known as the "blue lagoon" because of the colour of its water during spring. Being located in the Western Province, 32 km north of Colombo, this lagoon has been subjected to a variety of activities including scientific research.

Several development projects have taken place in the vicinity of the lagoon during the last two decades. Primarily, the establishment of the Ekala Industrial City and the Katunayake Free Trade Zone may have direct or indirect impacts on the water quality of the Negombo Lagoon. Information is scarce especially on pollution indicative chemical and bacteriological parameters of the Negombo Lagoon. In October 1990 an unusual mortality of fish was observed in the Ja Ela, an artificial canal constructed for flood control at the downstream of the Attanagalu Oya. This canal intermittently receives industrial waste from the Ekala Industrial City. Therefore, there is an urgent need to make a meaningful assessment of the water quality of the Negombo Lagoon prior to implementing regulatory measures in order to maintain the quality of water and to conserve its flora and fauna. As a prerequisite, an attempt will be made here to compile the already available data on water quality of the Negombo Lagoon from the historical past to date.

3.2 Study Site

The Negombo Lagoon (7^0.4'-12' N; 79^0.47'- 51' E), one of the most productive brackish water bodies in Sri Lanka is situated in the Western Province (Fig. 3.1). The lagoon, is the recipient water body of the Attanagalu Oya drainage basin and has become a dominant morphological feature of the watershed. The brackish water mass measures 3164 ha and is now considered to be the estuarine part of the contiguous wetland system of the Muthurajawela Swamp and the Negombo Lagoon (Scott, 1989). The Negombo Lagoon links with the open sea at its northern mouth and receives freshwater from the Attanagalu Oya which empties as the Dandugam Oya and the Ja Ela at its southern tip.

The Negombo Lagoon served as the chief sea port for trading in cinnamon and other commodities under Vira Parakrama Bahu VIII (15th Century), who constructed the Dutch Canal along the eastern boundary of the Muthurajawela Marsh linking the Negombo Lagoon and the Kelani River. During the following Portuguese period the Negombo Lagoon continued to serve as the foremost sea port for maritime trading.

The Dutch who succeeded the Portuguese, developed Colombo as a sea port and subsequently, the commercial importance of the Negombo Lagoon was superseded. The British constructed the Hamilton Canal along the western margin of the Muthurajawela Marsh connecting the Kelani River and the Negombo Lagoon in the beginning of the 19th century. Since then it served as a major sea port and a commercial centre, and its economic importance has rested entirely on its role in subsistence lagoon and marine fisheries.

In a recent publication (GCEC, 1991a), it has been stated that human interference with the Negombo Lagoon has been in existence for a variety of purposes since the 15th century to date. However, the Negombo Lagoon remains more or less in an undisturbed state even today in the densely populated and largely urbanized western province of the country. This statement was one of the conclusions of the environmental profile of the Muthurajawela and the Negombo Lagoon (GCEC, 1991a) prepared along with the Master Plan (GCEC, 1991b) for the development of this wetland ecosystem. The information gathered during the above survey is insufficient to forward a positive conclusion with respect to the water quality of this lagoon because the GCEC carried out a survey of selected water quality parameters for only a period of 5 months. The limited scope of this survey, the sampling strategies, analytical techniques and the absence of comparisons against past data may allow only limited interpretation rather than affirmative conclusions. In addition, the same report indicated extremely high levels of faecal coliform and unacceptable levels of chromium ions for several locations of the Negombo Lagoon.

3.3 Watershed

Since the Negombo Lagoon is located in the west coast of Sri Lanka (Fig. 3.1), the climatic and weather conditions of the area are mainly determined by the South Asian monsoon and atmospheric pressure changes in the Bay of Bengal. The rainfall of the area is mainly influenced by the south-west monsoon but it also receives a considerable amount of rain throughout the year. The annual average rainfall varies between 2000 and 2500 mm and the area from Negombo to Colombo lies within the 2500 mm isopleth. A sharp peak of rainfall occurs in the area with the onset of the south-west monsoon (April-May) and the second peak coincides with the second intermonsoon from October to November.

The long term trend of the rainfall shows an intermonsoon dominant pattern in the area which is characteristic for the northern part of the wet zone of Sri Lanka. The hydrographic studies conducted by the National Aquatic Resources Agency (NARA) in 1992 showed that evaporation exceeds rainfall only from January to March. In all the other months there was

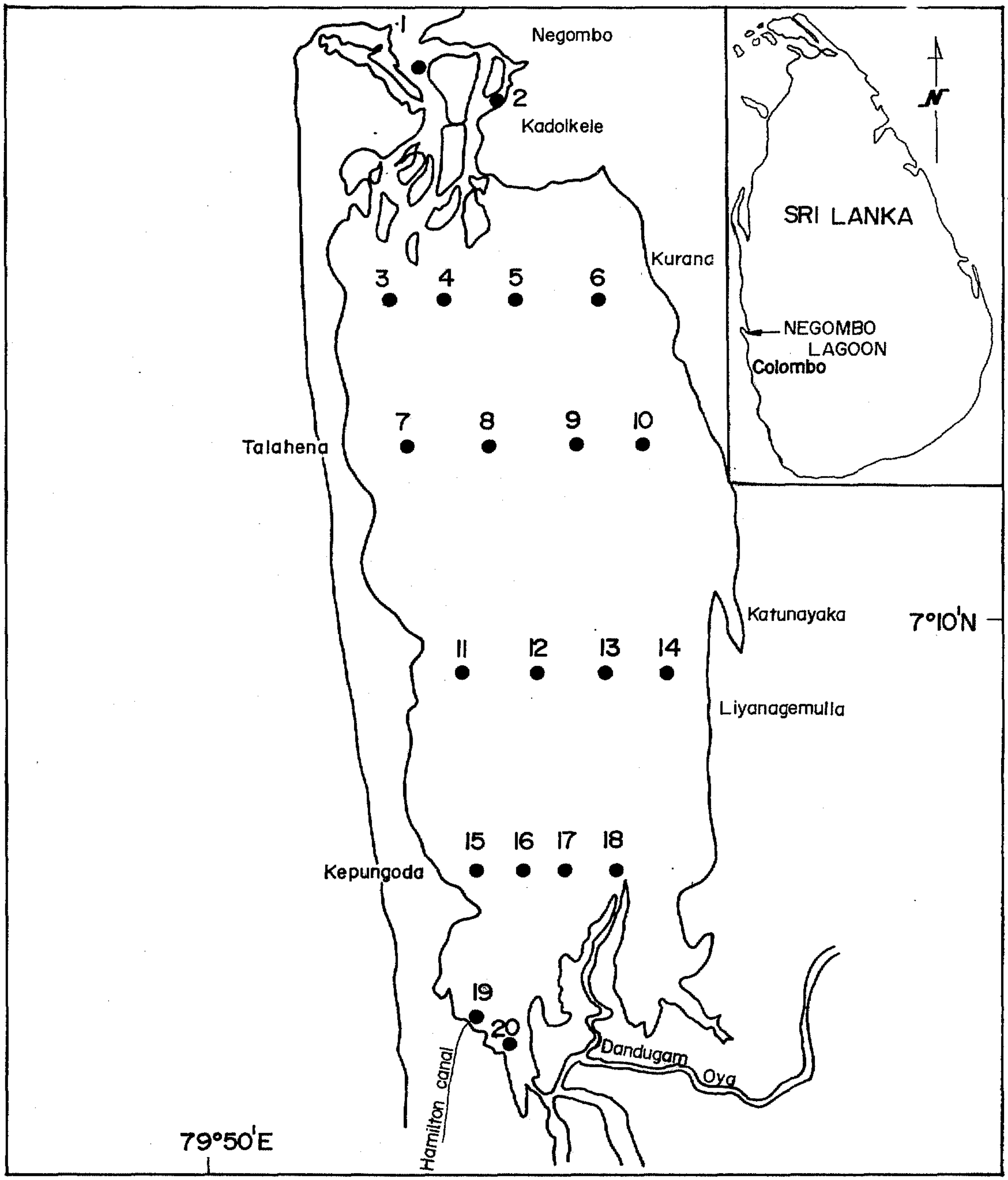

Figure 3.1 The Negombo Lagoon showing reference sampling points

an excess of rainfall. The highest excess of rainfall occured over evaporation in May and October, and the lowest in August. Accordingly, February, July and August are relatively dry months while September, October, November, April and June could be considered as relatively wet months of the year.

The highest mean daily air temperature occurs during March-April and the lowest during January-February. The highest day temperature generally occurs between 12.00 and 15.00 hours and the lowest between 05.00 and 06.00 hours. The daily maximum and minimum air temperature ranges from 19 °C to 35 °C and the highest daily fluctuation in temperature occurs from December to February according to several authors (Silva, 1981; NARA, 1992).

The daily wind speed can change irrespective of the month of the year. However, the wind direction shows a particular seasonal pattern in this area. The main wind direction from November through February is north to north-west, and the south-west direction dominates during the rest of the year. The eastwardly prevailing wind is experienced in April and March during evening hours.

The Negombo Lagoon has developed during the Holocene period on a Pleistocene landscape that existed after the last glacial period. The geological processes that led to the formation of the Negombo Lagoon with its only connection to the sea in the north and with the Dandugam Oya (and possibly the Kelani Ganga during floods) supplying freshwater have been explained by several authors (Cooray, 1984; Swan, 1983; Katupotha, 1988).

The peat formation started in the southern part of the lagoon during a period of low sea level, probably around 6000 years B.C. (Dissanayake, 1984). The acidic peat bog converts the metals to free ions which are adsorbed onto the clay complex. This governs the nutrient availability of the Negombo Lagoon and hence its productivity. The geochemical balance of the nutrient cycling between the Negombo Lagoon and the Muthurajawela Marsh is therefore of prime importance. Any disturbance of this balance will undoubtedly have adverse effects on the productivity of the lagoon (Dissanayake, 1990). The bog soils bordering the Negombo Lagoon and those situated on the western segment of the main marsh become saline because of the tidal influence.

The southern part of the Negombo Lagoon where the Dandugam Oya and the Ja Ela empty into the lagoon is in fact a swampy, brackish water tidal delta. In addition to the main stream flows, the swampy tidal delta also receives freshwater from rainfall and occasionally due to high floods of the Kalu Oya and the Kelani Ganga. The Muthurajawela Marsh also acts as a source of freshwater to the tidal delta and to the open lagoon. The open water between the swampy delta in the south, the high ground in the east, the dune ridge in the west and the flood delta of its inlet in the north, is fringed by a narrow strip of low land. Sea water enters the lagoon through its inlet with high tides, the salinity being balanced by the sources of freshwater (i.e. inflow from the Dandugam Oya, Muthurajawela Marsh and precipitation).

Freshwater enters into the Negombo Lagoon from the Attanagalu Oya (Dandugam Oya and Ja Ela) at a rate of 1.5 km^3y^{-1} and from precipitation (0.2 km^3y^{-1}). Occasional inflows could occur from the Kalu Oya and the Kelani Ganga during high floods. Evaporation and evapo-transpiration remove about 0.15 km^3 of water annually. The balance water flows into the sea, mainly via the inlet of the lagoon and for a lesser extent through the Hamilton Canal into the mouth of the Kelani Estuary. The inflow of saline water from the sea is estimated to be 1.1 km^3 per year through the inlet of the lagoon while a considerably lower quantity comes in through the Hamilton Canal.

Land Use: Human association with the Negombo Lagoon dates back to as early as the 15th century. Various development activities and dense human settlement in the catchment of the Negombo Lagoon may have effects on the hydrography and the water quality of the lagoon ecosystem. Certainly, the water budget and the hydrography of the lagoon have been affected by the construction of the canal system (i.e. the Old Dutch Canal and the Hamilton Canal). Apparently, a substantial amount of domestic sewage reaches the lagoon from the watershed which may enhance aquatic pollution. Seventeen industries generating industrial effluent in the Ekala Industrial Processing Factories discharge partially treated or untreated effluent into the freshwater inflow of the Negombo Lagoon directly or indirectly (Edirisinghe, 1993). These industries comprise of a tannery, several textile processing units and some other factories (e.g. chemical processing, battery manufacturing, distillery and fibre mill). In addition, Central Sewage Treatment Plant of the Katunayake Export Processing Zone treats the effluent of 76 industries which are also located in the vicinity of the Negombo Lagoon. It has been reported that the effluent discharged from all these industries except from the Katunayake Export Processing Zone is not within the relevant CEA tolerance limit specified for effluent discharged into surface water. Therefore, it is apparent that the untreated effluent discharged from the industries eventually reaches the Negombo Lagoon polluting the lagoon ecosystem. Although, a few tourist hotels are located around the lagoon, their impact on the water quality may not be significant.

Since its location is in the lower drainage basin of the Attanagalu Oya, the watershed of the Negombo Lagoon is also confined to the wet zone. Therefore, the watershed consists more or less of urbanized land. It is unlikely to see natural forest vegetation except mangroves in the watershed and most of the land is converted into coconut or paddy cultivation. In addition, home gardens are also a predominant type of land use in the watershed. Infrastructure development is so intense and transportation, telecommunication and electric power transmission networks are seen everywhere in the watershed. The Colombo air port is also located in Katunayake adjacent to the south-east part of the Negombo Lagoon. Recently, the Katunayake area has been developed further by the establishment of a large number of trade processing factories.

3.4 Water Quality

Samarakoon and Raphael (1972) recorded the salinity of the Negombo Lagoon at four locations for a period of one year (1969-1970) during the course of study on the availability of seeds of cultured shrimps. Ward and Wyman (1977) observed variations in salinity, temperature and pH in the north-western part of the lagoon near a small village called Talahena for a period of two months (July-August 1973) during their investigations on the ethology and ecology of two species of indigenous cichlids (i.e. *Etroplus suratensis* and *Etroplus maculatus*). Salinity, temperature and pH of the surface water near an islet close to the sea mouth were monitored monthly over a period of one year during the observations made on some ecological aspects of edible oysters associated with mangrove vegetation (Pinto & Wignarajah, 1980). De Silva and Silva (1979) determined the seasonal and diurnal variations of temperature, salinity, dissolved oxygen contents and pH in the brackish water fish ponds draining into the Negombo Lagoon. An extensive survey on the hydrography of the Negombo Lagoon was carried out over a period of one year from December 1976 to November 1977 (Silva, 1981). During this survey, the basic physico-chemical characteristics of surface and bottom waters were examined at eight locations covering the entire lagoon. Further, some physico-chemical characteristics of the lower and upper reaches of the Negombo Lagoon have been reported by the National Aquatic Resources Agency (NARA) in 1988 and this study has been carried out for a period of one year (August 1986- July 1987). In addition, the ranges of seven water quality parameters have been reported by NARA in its 1991 Status Report on Water Quality Aspects (De Alwis, 1991). A comprehensive study on some physical oceanographic characteristics of the Negombo Lagoon was carried out for a period of one year (March 1989-February 1990) by the Oceanographic Unit of NARA. During this study seven parameters were monitored at 20 locations covering the entire lagoon. A study concentrated on pollution indicative parameters such as BOD_3, COD, trace metals, micro-nutrients and bacteriological properties in 1991 during the survey on the Muthurajawela-Negombo Lagoon Wetland System (GCEC, 1991a,b). Apparently, the Negombo Lagoon has been subjected to several intermittent investigations for its physico-chemical characteristics from 1969 to 1991.

The results of the studies carried out from 1969 to 1991 (Samarakoon & Raphael, 1970; Silva, 1981; NARA, 1988; NARA, 1992) were diagnosed to analyse the spatial, seasonal and diurnal patterns of the physico-chemical characteristics of the Negombo Lagoon. In addition, information reported by the GCEC (1991a) was analysed to examine the pollution status with respect to organic waste and trace metals. During this comparative diagnosis of results, the sampling sites selected by NARA (1992), in its oceanographic survey of the Negombo Lagoon were selected as the reference sampling sites and compared with other studies (Fig. 3.1), because, NARA examined several basic physico-chemical characteristics (i.e. salinity, temperature, turbidity, pH, suspended solid, etc.,) at 20 stratified sampling sites.

Temperature in shallow water bodies in the tropics is always influenced by air temperature and thermal conditions which are often variable due to the mixing of water of varying temperatures and the diurnal and seasonal variations of total incoming radiation. The seasonal variations of the day temperature of the surface and bottom waters of the Negombo Lagoon at different locations were reported during most of the studies. In some instances, diurnal variations in temperature were also reported. In general, the difference between the surface and bottom waters were always less than 1 ^{0}C and the lagoon water becomes warmer from February to April. The water temperature dropped slightly in May with the onset of the south-west monsoonal rainfalls. The diurnal variation in temperature (surface and bottom) of the Negombo Lagoon had been reported by Silva (1981) for the spring and autumn equinoxes in 1977 for two locations (i.e. sea mouth and near Talahena).

The salinity levels of the Negombo Lagoon were reported by Samarakoon and Raphael (1972) for the first time. Since then several studies examined site-specific and time-bound changes in salinity in the Negombo Lagoon. The lagoon showed marked temporal and spatial variations in salinity. There was a uniform pattern in the seasonal variation of surface salinities at all locations of the lagoon (Table 3.1). Annual variation of salinity in the Negombo Lagoon reached a maximum during March-April and minimum during May-June and November-December. The salinity attained its maximum during the first intermonsoon (i.e. February-April) and it led to a condition where the lagoon converted almost into freshwater with the onset of the south-west monsoon (May-June). During the intermediate rainy season, a pronounced salinity gradient developed in the lagoon (i.e. January, July and December) with a range of salinity varying from 20-30 ppt at the mouth to less than 5-10 ppt at the head of the estuary. The salinity gradient was well established during August and September from the freshwater outfall to the sea mouth and vice versa. Relatively higher bottom salinities were reported in September 1989 (NARA, 1992). This pattern changed markedly once again with the onset of the second intermonsoon (i.e. October-November) combined with changing wind pattern. This resulted in converting the entire water body into freshwater again. The lower salinity values reported for November and December in the Negombo Lagoon could be attributed to strong northerly currents.

The lagoon water was alkaline during most of the year. However, the hydrogen ion concentration was not evenly distributed. In general, pH increased towards the sea mouth and the highest pH was recorded during the driest months of the year (Table 3.2). Slightly acidic conditions, mainly towards the freshwater inflows were reported in all studies during rainy months (May, June, October, November).

Table 3.1 Seasonal and spatial changes in salinity (ppt) in the Negombo Lagoon from 1969 to 1989 (extracted from several authors)

Year	St 1	St 2	St 3	St 4	St 5	St 6	St 7	St 8	St 9	St 10	St 11	St 12	St 13	St 14	St 15	St 16	St 17	St 18	St 19	St 20
Mar																				
1970	23.8	--	--	20.5	--	--	17.0	--	--	--	--	--	--	5.8	--	--	--	--	--	--
1977	--	--	--	31.2	--	--	18.0	18.0	18.0	--	15.0	--	--	15.0	15.0	--	--	14.2	--	--
1987	--	--	--	--	36	--	--	--	--	--	34	--	--	--	33	--	--	--	--	22
1989	34.8	33.4	34.6	34.2	35.2	34.5	32.4	31.2	29.5	30.2	30.6	27.4	28.2	26.5	30.2	17.2	28.1	27.4	20.2	21.4
Apr																				
1970	18.8	--	--	16.0	--	--	18	--	--	--	--	--	--	7.5	--	--	--	--	--	--
1977	--	--	--	22.8	--	--	19.2	22.2	22.2	--	19.8	--	--	18.6	18.0	--	--	13.8	--	--
1986	--	--	--	--	22	--	--	--	--	--	18	--	--	20	--	--	--	--	--	6.0
1989	27.3	28.3	28.0	27.8	27.8	28.0	25.6	26.7	22.0	26.5	24.5	25.6	20.3	22.3	20.1	19.0	14.1	12.5	12.7	13.7
May																				
1970	17.0	--	--	15.0	--	--	12.5	--	--	--	--	--	--	10.8	--	--	--	--	--	--
1977	--	--	--	1.8	--	--	1.2	0.4	1.2	--	2.4	--	--	0.6	0.6	--	--	0.4	--	--
1987	--	--	--	--	20	--	--	--	--	--	19	--	--	18	--	--	--	--	--	5.0
1989	5.3	5.7	4.3	4.2	4.0	3.8	1.9	2.2	1.4	1.9	1.6	1.3	1.5	1.1	0.7	1.4	1.2	0.6	0.9	1.4
Jun																				
1970	20.0	--	--	20.0	--	--	16.5	--	--	--	--	--	--	10.8	--	--	--	--	--	--
1977	--	--	--	8.4	--	--	7.2	3.0	6.0	--	7.8	--	--	6.0	7.2	--	--	2.4	--	--
1987	--	--	--	--	11	--	--	--	--	--	14	--	--	6.0	--	--	--	--	--	8.5
1989	4.5	4.6	4.1	3.8	3.1	2.7	2.5	2.3	2.0	1.6	1.5	1.6	1.7	1.2	0.9	0.8	0.7	0.5	1.3	1.2
Jul																				
1970	23.5	--	--	17.5	--	--	15.0	--	--	--	--	--	--	10.0	--	--	--	--	--	--
1977	--	--	--	21.0	--	--	19.2	8.4	21.0	--	19.8	--	--	17.4	16.8	--	--	13.2	--	--
1987	--	--	--	--	28	--	--	--	--	--	25	--	--	21	--	--	--	--	--	19
1989	27.5	26.2	22.5	20.4	18.8	9.8	14.9	12.8	14.2	7.5	13.1	11.5	9.2	8.2	3.4	8.9	8.2	6.2	--	--
Aug																				
1969	33.8	--	--	30.5	--	--	35.5	--	--	--	--	--	--	12.6	--	--	--	--	--	--
1977	--	--	--	31.2	--	--	28.8	13.8	28.8	--	28.2	--	--	27.0	27.0	--	--	22.2	--	--
1986	--	--	--	--	17	--	--	--	--	--	15	--	--	25	--	--	--	--	--	8.0
1989	30.1	30.3	23.5	31.4	30.5	31.4	20.6	20.4	20.3	18.5	15.6	16.2	17.5	14.2	14.5	15.2	16.2	5.2	12.2	11.4

Table 3.1 Contd.,

Sep																				
1969	30.8	--	--	24.8	--	--	22.0	--	--	--	--	--	--	9.0	--	--	--	--	--	--
1977	--	--	--	19.8	--	--	28.2	19.2	20.4	--	30.0	--	--	15.6	18.0	--	--	14.4	--	--
1986	--	--	--	--	18	--	--	--	--	--	20	--	--	18	--	--	--	--	--	21
1989	28.3	22.4	30.2	30.4	24.9	22.4	24.2	24.8	22.2	20.0	22.4	20.8	20.9	18.8	20.4	15.8	13.6	14.2	14.9	15.2
Oct																				
1969	23.5	--	--	17.9	--	--	15.0	--	--	--	--	--	--	6.1	--	--	--	--	--	--
1977	--	--	--	0.5	--	--	0.6	2.4	0.2	--	0.6	--	--	0.4	0.2	--	--	0.2	--	--
1986	--	--	--	--	5.0	--	--	--	--	--	00	--	--	30	--	--	--	--	--	00
1989	7.5	8.6	8.5	8.4	4.0	1.5	2.5	2.4	2.3	2.5	3.6	3.0	2.5	2.2	2.5	1.8	1.4	1.3	0.5	0.0
Nov																				
1969	21.5	--	--	13.0	--	--	10.9	--	--	--	--	--	--	1.0	--	--	--	--	--	--
1977	--	--	--	1.8	--	--	1.2	0.6	1.2	--	1.2	--	--	0.6	0.6	--	--	0.4	--	--
1986	--	--	--	--	22	--	--	--	--	--	20	--	--	28	--	--	--	--	--	30
1989	10.8	11.8	4.6	7.2	4.5	4.5	4.6	4.1	4.2	9.8	3.4	3.8	3.6	3.4	3.3	3.6	3.3	1.5	2.8	2.6
Dec																				
1969	20.8	--	--	12.8	--	--	9.5	--	--	--	--	--	--	0.8	--	--	--	--	--	--
1977	--	--	--	10.2	--	--	8.4	5.4	3.0	--	4.8	--	--	1.8	3.0	--	--	1.8	--	--
1986	--	--	--	--	19	--	--	--	--	--	20	--	--	29	--	--	--	--	--	18
1989	20.8	21.0	17.8	17.6	13.3	12.6	14.0	12.3	11.5	13.3	11.0	11.6	11.8	11.6	9.3	7.7	7.1	5.5	--	--
Jan																				
1969	22.5	--	--	17.2	--	--	11.0	--	--	--	--	--	--	2.5	--	--	--	--	--	--
1977	--	--	--	23.4	--	--	21.6	15.0	9.6	--	15.0	--	--	8.4	13.8	--	--	6.6	--	--
1986	--	--	--	--	32	--	--	--	--	--	28	--	--	30	--	--	--	--	--	31
1989	22.7	16.6	16.0	15.1	18.7	11.3	10.4	12.5	13.6	8.8	8.8	11.2	1.2	3.5	5.0	1.3	0.0	0.5	0.0	0.5
1990	--	--	--	27.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	22.1
Feb																				
1970	23.8	--	--	19.0	--	--	15.5	--	--	--	--	--	--	5.3	--	--	--	--	--	--
1977	--	--	--	25.8	--	--	26.4	16.2	13.2	--	24.6	--	--	12.0	21.6	--	--	10.6	--	--
1986	--	--	--	--	36	--	--	--	--	--	30	--	--	31	--	--	--	--	--	32
1990	30.4	29.1	28.1	28.4	27.6	30.1	25.1	26.0	25.4	26.3	24.9	25.2	25.2	25.5	14.5	22.0	22.2	23.2	--	--

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Table 3.2 Seasonal and spatial changes in pH in the Negombo Lagoon from 1977 to 1989 (extracted from several authors)

Year	St 1	St 2	St 3	St 4	St 5	St 6	St 7	St 8	St 9	St 10	St 11	St 12	St 13	St 14	St 15	St 16	St 17	St 18	St 19	St 20
Mar																				
1977	--	--	--	8.31	-	--	8.14	8.09	8.26	--	8.59	--	--	.77	7.98	--	--	8.09	--	--
1987	--	--	--	--	8.1	--		--	--	--	8.0	--	--	8.1	--	--	--	--	--	7.5
1989	8.1	8.1	7.6	8.1	8.2	8.2	8.1	8.1	8.2	8.2	8.1	8.1	8.2	8.2	8.1	8.1	8.1	8.1	8.1	8.1
Apr																				
1977	--	--	--	8.92	--	--	7.87	8.48	8.31	--	7.3	--	--	7.70	7.77	--	--	7.92	--	--
1987	--	--	--	--	7.2	--	--	--	--	--	7.3	--	--	8.0	--	--	--	--	--	7.0
1989	8.1	8.1	8.2	8.1	7.7	8.1	7.6	7.9	8.1	7.9	7.6	8.1	8.2	7.9	7.6	7.6	8.1	7.9	7.6	7.6
May																				
1977	--	--	--	7.49	--	--	7.38	7.59	7.59	--	7.3	--	--	6.94	6.9	--	--	6.49	--	--
1987	--	--	--	--	8.4	--	--	--	--	--	7.3	--	--	8.0	--	--	--	--	--	7.0
1989	7.7	7.7	8.6	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.7	7.7	7.6	7.6	7.7	7.7	7.7	7.7	8.1
Jun																				
1977	--	--	--	8.14	--	--	8.26	7.66	8.03	--	7.2	--	--	7.48	7.6	--	--	6.66	--	--
1987	--	--	--	--	7.2	--	--	--	--	--	7.2	--	--	7.8	--	--	--	--	--	7.1
1989	8.1	8.1	8.2	8.1	7.7	7.7	8.1	8.1	8.1	8.1	8.1	7.7	7.7	7.4	7.6	7.6	7.9	7.6	7.6	7.6
Jul																				
1977	--	--	--	8.33	--	--	8.2	8.20	8.37	--	7.5	--	--	8.37	7.92	--	--	7.6	--	--
1987	--	--	--	--	6.5	--	--	--	--	--	6.5	--	--	7.7	--	--	--	--	--	6.8
1989	8.2	8.2	8.2	8.2	8.2	8.2	8.1	8.2	8.1	8.1	7.9	8.1	8.2	8.1	8.1	7.6	7.6	7.6	7.6	7.6
Aug																				
1977	--	--	--	8.75	--	--	8.0	8.80	8.85	--	7.6	--	--	9.2	8.37	--	--	8.59	--	--
1987	--	--	--	--	7.2	--	--	--	--	--	7.6	--	--	6.5	--	--	--	--	--	6.7
1989	7.6	7.6	8.1	8.1	8.1	8.1	8.1	8.1	8.1	7.9	7.9	7.9	8.1	7.9	7.9	7.9	7.7	7.7	7.7	7.7

Table 3.2 Contd.,

Sep																				
1977	--	--	--	7.92	--	--	7.98	8.2	8.65	--	7.2	--	--	8.75	8.69	--	--	8.47	--	--
1987	--	--	--	--	7.7	--	--	--	--	--	7.2	--	--	6.8	--	--	--	--	--	7.1
1989	7.6	7.6	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8.1	8.2	8.2
Oct																				
1977	--	--	--	6.72	--	--	7.1	7.10	6.83	--	7.6	--	--	6.28	6.84	--	--	6.27	--	--
1987	--	--	--	--	6.2	--	--	--	--	--	5.6	--	--	6.3	--	--	--	--	--	6.1
1989	8.1	8.1	8.1	8.1	7.9	8.2	7.9	7.9	7.7	7.9	7.9	7.9	7.7	7.9	7.9	7.9	7.7	7.7	7.7	7.7
Nov																				
1977	--	--	--	7.37	--	--	8.2	6.98	6.96	--	6.5	--	--	6.90	7.05	--	--	6.32	--	--
1987	--	--	--	--	6.5	--	--	--	--	--	6.5	--	--	8.5	--	--	--	--	--	7.0
1989	7.7	7.7	7.1	7.7	8.1	7.6	7.9	8.2	7.7	7.6	7.7	7.6	7.6	7.7	7.9	7.6	7.6	7.6	7.1	7.7
Dec																				
1977	--	--	--	8.03	--	--	7.90	7.92	7.59	--	7.6	--	--	7.48	7.82	--	--	7.69	--	--
1987	--	--	--	--	6.0	--	--	--	--	--	7.6	--	--	6.2	--	--	--	--	--	7.7
1989	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.7	7.7	7.9	7.7	7.7	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Jan																				
1977	--	--	--	8.00	--	--	8.01	8.09	7.44	--	7.6	--	--	7.93	8.09	--	--	7.92	--	--
1987	--	--	--	--	7.6	--	--	--	--	--	7.6	--	--	6.0	--	--	--	--	--	6.5
1989	8.1	7.9	7.9	8.1	8.1	8.1	8.1	7.9	7.9	8.1	7.6	7.6	7.6	7.6	7.7	7.7	7.6	7.6	7.6	7.6
Feb																				
1977	--	--	--	9.25	--	--	8.09	8.03	7.92	--	6.5	--	--	7.90	7.82	--	--	8.0	--	--
1987	--	--	--	--	7.1	--	--	--	--	--	6.5	--	--	6.5	--	--	--	--	--	6.5
1989	8.1	8.1	8.1	8.1	7.9	8.1	8.1	7.9	8.1	8.1	7.9	7.9	7.9	8.1	7.7	7.7	7.7	7.6	7.6	7.6

In general, the distribution pattern of hydrographic parameters (e.g. salinity, pH etc.,) is always determined by sea water intrusion resulting from tidal fluctuation and amplitude in freshwater inflow. Therefore, it is extremely difficult to compare the different results on a seasonal or spatial basis. The seasonal changes in dissolved oxygen (DO) had been reported by Silva (1981) for eight locations (Table 3.3). In this case also, it was difficult to identify a particular time-bound pattern in the distribution of dissolved oxygen in the Negombo lagoon. The reported DO values for the surface water varied from 5.54 mgO_2l^{-1} to 9.24 mgO_2l^{-1} and the wide range attributed to sampling time, photosynthetic activity and local temperature as well as to the mixing of sea water and freshwater. The dissolved oxygen concentrations found by Silva (1981) were well within the permissible values for natural surface water.

Table 3.3 Seasonal and spatial changes in dissolved oxygen (mgO_2l^{-1}) in the Negombo Lagoon from Dec.1977 to Nov.1978 (extracted from Silva, 1981)

Month	Stn 4	Stn 7	Stn 8	Stn 9	Stn 11	Stn 14	Stn 15	Stn 18
Dec	6.20	7.08	8.20	7.88	7.40	8.04	7.72	8.12
Jan	5.88	6.60	7.08	7.24	6.92	6.16	7.24	7.16
Feb	6.28	6.28	6.86	6.92	6.36	6.20	6.68	7.08
Mar	6.52	7.08	6.84	6.84	6.92	7.00	7.16	7.24
Apr	6.60	7.28	7.16	7.32	6.60	7.32	7.00	8.18
May	7.24	7.32	6.76	6.92	7.00	7.40	7.24	6.76
Jun	6.92	7.32	7.32	7.24	8.12	7.32	7.08	7.08
Jul	6.44	6.52	7.24	6.68	7.00	6.60	6.28	6.60
Aug	5.96	5.80	7.16	6.20	6.20	6.20	5.54	6.28
Sep	7.24	6.92	7.20	6.84	7.32	7.08	6.92	7.16
Oct	8.68	8.60	7.20	8.52	8.36	7.96	8.84	7.48
Nov	8.36	8.20	8.76	9.24	8.52	9.16	7.72	7.16

Turbidity of the water which is a function of suspended matter indicates both the sediment loading (i.e. suspended and particulate) and the turbulent mixing in the lagoon. Seasonal and spatial distribution of turbidity (Table 3.4) and suspended solid (Table 3.5) are directly associated with the freshwater inflow and the annual rainfall pattern. In general, the contents of suspended matter and the turbidity in the Negombo Lagoon showed an increasing trend towards the river inflow. The highest values of both parameters were recorded in May-June and October-November (Tables 3.4, 3.5). The highest turbidity recorded in the Negombo Lagoon was 1211 NTU in May at station 18 and the lowest was 3.5 NTU in March at station 6 (Tables 3.4, 3.5).

Table 3.4 Seasonal and spatial changes in turbidity (NTU) in the Negombo Lagoon (extracted from NARA, 1992)

Month	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7	Stn 8	Stn 9	Stn 10	Stn 11	Stn 12	Stn 13	Stn 14	Stn 15	Stn 16	Stn 17	Stn 18	Stn 19	Stn 20
Dec	7.0	6	8	9.25	12	5.5	13.5	11.75	15.25	15.25	26	22.75	25	29.75	28	28	36.75	39.0	26.0	27.573
Jan	10.4	10.15	15.5	14.85	8.35	9.25	6.75	12.6	10.5	5.8	5.9	11.85	11.4	11.3	7.25	8.6	17.15	16.75	16.4	13.75
Feb	9.5	10.5	13.5	12.5	7.0	9.0	9.0	11.5	12.0	7.5	7.0	11.0	9.5	5.5	6.5	8.5	17.0	14.5	13.5	16
Mar	10.5	7.25	7.5	8.0	10.5	3.5	13.25	12.35	12.0	7.0	13.0	10.5	15.25	9.25	10.0	10.75	14.0	17.0	13.5	--
Apr	13.0	11.0	9.0	14.65	14.0	3.5	12.5	13.5	30.0	19.5	16.0	9.6	13.5	10.5	11.0	15.0	20.0	19.5	15.5	–
May	13.17	17.37	12.37	13.72	18.02	9.67	24.52	104.17	63.22	18.52	106.0	186.35	689.75	329.5	34.23	66.02	891.42	1211.82	26.46	–
Jun	27.0	15.28	10.69	11.5	12.5	14.05	16.1	16.5	32.75	39.0	49.0	34.5	72.5	80.5	59.0	73.5	114.75	176.91	34.25	--
Jul	17.0	17.25	11.12	14.12	20.0	46.5	27.25	21.25	24.5	46.0	34.25	17.5	31.12	72.0	26.55	26.5	43.0	45.0	78.5	–
Aug	22.5	16.75	15.0	14.5	21.5	13.0	73.0	60.5	16.5	34.0	84.0	135.0	28.0	143.0	21.5	39.5	60.0	27.0	24.0	23.5
Sep	8.62	7.5	9.10	10.22	10.76	5.87	32.0	25.26	22.83	10.18	25.04	13.27	8.12	13.35	12.9	16.79	18.45	14.85	12.85	14.99
Oct	6.75	5.62	6.62	5.42	6.5	5.87	12.75	9.5	7.12	13.5	13.75	11.65	28.62	68.5	22.5	39.25	30.0	14.0	31.12	9.62
Nov	11.56	15.7	14.85	22.10	14.35	11.15	27.15	29.52	29.25	27.75	50.6	37.15	44.25	39.87	126.25	142.05	84.71	48.9	24.25	18.5

Table 3.5 Seasonal and spatial changes in suspended solid (mgl^{-1}) in the Negombo Lagoon (extracted from NARA, 1992)

Month	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7	Stn 8	Stn 9	Stn 10	Stn 11	Stn 12	Stn 13	Stn 14	Stn 15	Stn 16	Stn 17	Stn 18	Stn 19	Stn 20
Mar	16.93	11.6	36.57	37.65	40.94	20.52	14.26	23.38	21.51	27.29	13.38	13.5	16.76	20.96	23.47	30.16	31.16	35.9	31.62	32.74
Apr	15.41	17.54	45.45	39.97	32.22	32.6	12.8	16.25	22.2	31.24	20.76	17.81	27.51	37.47	13.57	23.43	50.99	65.96	49.2	38.51
May	24.54	21.16	56.67	55.22	47.69	17.04	24.44	48.67	44.09	69.83	26.92	45.72	67.72	84.51	25.00	49.68	99.52	114.17	76.33	73.74
Jun	49.64	38.33	58.42	70.53	66.42	46.29	25.99	55.86	65.42	59.38	33.96	41.41	114.36	109.86	37.89	49.36	116.96	125.17	98.2	85.30
Jul	28.21	19.46	24.58	29.18	20.12	15.27	10.48	15.04	15.93	11.36	12.29	16.38	18.32	22.45	7.89	12.72	8.21	9.92	14.24	11.71
Aug	10.24	5.61	8.23	15.65	12.32	10.62	5.27	8.34	6.56	19.36	12.44	6.77	10.32	14.28	10.32	6.21	14.24	27.45	10.24	12.66
Sep	6.35	2.82	10.43	12.67	9.85	5.35	6.50	7.51	16.30	13.28	6.01	8.00	7.60	13.57	6.66	6.25	11.97	13.37	9.55	7.42
Oct	18.66	14.81	24.74	13.27	23.45	7.52	11.50	14.73	28.66	24.80	11.07	13.50	39.69	48.42	17.1	30.4	52.99	73.56	29.10	29.83
Nov	19.28	18.62	41.96	40.30	39.60	16.61	10.6	20.64	29.70	39.41	9.25	23.00	65.75	62.51	12.31	18.41	50.78	83.93	33.82	37.77
Dec	38.46	22.69	34.78	49.26	30.06	22.69	13.57	12.45	49.68	54.35	8.53	10.32	78.31	104.37	16.37	29.46	80.52	113.27	34.27	37.25
Jan	7.52	9.64	22.47	28.32	14.65	12.34	7.42	4.26	14.79	20.36	8.25	11.42	14.61	28.31	7.34	8.75	12.35	29.56	12.36	9.38
Feb	10.08	8.64	10.39	22.45	10.23	8.19	9.65	7.98	8.51	15.99	4.55	7.24	19.36	20.46	3.29	6.73	9.28	10.08	3.98	2.24

In the case of suspended solid, the highest was 125.2 mgl^{-1} in June at station 18 and the lowest was 5.35 mgl^{-1} in September at station 6 (Table 3.5). The concentrations of micro nutrients in the Negombo Lagoon were reported only for one seasonal cycle for its lower and upper reaches (NARA, 1988). The concentrations of NO_3-N, NO_2-N and PO_4^{-3} are included in Table 3.6 together with the temperature and turbidity reported during the same study. The concentrations of reported micro-nutrients (i.e. NO_3-N, NO_2-N and PO_4^{-3}) did not show seasonal variations and the values are acceptable for natural brackish water. The nitrate concentration ranged from non-detectable level to 410 μgl^{-1}. The concentrations of NO_2-N and PO_4^{-3} ranged from non-detectable level to 9.3 μgl^{-1} and from non-detectable level to 300 μgl^{-1} respectively. Non-detectable levels may be attributed to poor analytical techniques and extremely high turn over rate. Therefore, it is necessary to improve the analytical techniques for micro-nutrients. The physico-chemical and bacteriological characteristics reported by GCEC (1991a) are included in Table 3.7. Table 3.7 also contains information on pollution indicative parameters (e.g. heavy metals and coliform bacteria). The results were not subjected to a detailed diagnosis because the field techniques and analytical methods had not been stated and the reported concentrations of several heavy metals were not detectable under the facilities available in Sri Lanka. Nevertheless, the results indicated that the Negombo Lagoon was polluted with respect to both bacteriological properties and heavy metal concentrations.

Diurnal Changes: Two studies reported the diurnal changes in some physico-chemical parameters (Silva, 1981; NARA, 1988). Silva (1981) examined diurnal variations in temperature, salinity, dissolved oxygen and pH at stations 4 and 7 on the spring and autumn equinoxes (Table 3.8) while NARA (1988) examined temperature, turbidity, salinity, pH, dissolved oxygen and NO_3^- at the lower and upper reaches of the Negombo Lagoon (Table 3.9). According to the results, hydrographic parameters, pH and dissolved oxygen showed marked diurnal patterns reflecting the location, tidal influence and the diurnal weather cycle. The diurnal changes in salinity were directly associated with the tidal rhythm which also changes the pH and the DO. In addition, diurnal changes in pH and DO may be attributed to temperature, photosynthetic activity and the mixing of freshwater and sea water. It is important to note that NARA (1988) reported a relatively low dissolved oxygen concentration (1.2 mgl^{-1}) at 5.00 a.m. for the lower reach of the lagoon. However, there was no marked diurnal variation in turbidity at both the lower and upper reaches of the lagoon (Table 3.9).

Table 3.6 Seasonal changes of turbidity, nitrate, nitrite and phosphate in the lower and upper reaches of the Negombo Lagoon (extracted from NARA, 1988)

Parameter	Reach	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Temperature (C^0)	Lower	27	26	28	32	29	30	31	30.5	30.5	34	28	25	25
	Upper	30	32	28	32.5	30	32	29	32	36	37	32	26	29
Turbidity (NTU)	Lower	7.6	8.8	7.4	2.8	6.9	3.4	2.6	4.0	3.6	4.0	5.6	3.4	3.6
	Upper	7.6	7.6	7.4	2.4	2.8	3.6	2.2	4.0	2.0	2.0	3.8	4.8	7.2
NO_3 (μgl^{-1})	Lower	0.4	0.3	0.4	0.0	0.41	0.14	0.17	0.08	0.15	0.11	0.0	0.0	0.38
	Upper	0.08	0.03	0.3	0.05	0.4	0.1	0.17	0.11	0.27	0.0	0.4	0.38	0.11
NO_2 (μgl^{-1})	Lower	3.0	3.0	0.0	5.0	0.0	0.2	9.0	0.0	2.8	9.3	0.0	0.3	6.0
	Upper	5.1	0.1	0.0	4.9	0.0	0.1	5.7	0.0	0.0	7.8	0.0	2.0	5.8
PO_4^{-3} (μgl^{-1})	Lower	0.0	20.0	0.0	22.0	0.0	300	25.0	180	0.0	0.0	0.0	0.0	200
	Upper	30.0	32.0	5.0	20.0	25.0	25.0	5.0	250	55.0	30.0	0.0	30.0	29.0

Table 3.7 Water quality characteristics reported for three reference sites (2, 6 and 10) by GCEC, 1991a

Parameter	Site 2	Site 6	Site 10
pH	7.1-7.9	7.1-8.6	6.4-8.1
Turbidity (NTU)	3.0-20	3.0-13	3.0-24
Conductivity (μ^0S)	22.2	31.7-32	11.9-38.8
Salinity (ppt)	43	35	13.0-40
Total coliform (per ml)	11200	6000	4510
Faecal coliform (per 100 ml)	2500	90-2510	1500
BOD_5 at 30 °C	18-40	10-38	6-35
Total Phosphate (mgl^{-1})	0.01-0.28	0.03-0.24	0.06-0.56
Zinc (mgl^{-1})	0.01	0.01	0.01
Chromium (mgl^{-1})	<0.01	<0.01	<0.01
Copper (mgl^{-1})	0.02	0.01	<0.01
Ammonia (mgl^{-1})	<1.0	<1.0	<1.0
Nitrate (mgl^{-1})	0.06	0.12	0.10
Nitrite (mgl^{-1})	0.002	0.001	0.002
Cadmium (mgl^{-1})	0.02	0.01	0.01
Mercury (mgl^{-1})	<0.02	<0.02	<0.02

Table 3.8 Diurnal variation of surface and bottom salinity, temperature, dissolved oxygen and pH at stations 4 and 7 of the Negombo Lagoon on spring and autumn equinoxes (extracted from Silva, 1981)

Equinox	St	Time	Salinity		Temp		DO		pH	
			Sur	Bot	Sur	Bot	Sur	Bot	Sur	Bot
SPRING	4	14.00	30.8	33.0	31.2	31.0	6.4	6.8	--	--
		18.00	28.5	33.0	31.9	31.7	6.5	6.0	--	--
		22.00	22.2	28.0	30.2	30.6	7.2	7.0	--	--
		02.00	18.5	33.5	29.2	29.7	7.1	6.2	--	--
		06.00	22.0	24.5	29.2	29.3	6.2	6.1	--	--
		10.00	20.0	31.0	29.8	30.1	6.0	6.4	--	--
	7	14.00	15.2	25.1	32.2	33.2	7.1	6.5	--	--
		18.00	16.5	25.2	32.3	33.1	7.0	6.2	--	--
		22.00	17.6	25.3	30.2	31.3	7.4	7.2	--	--
		02.00	16.0	25.1	30.1	32.1	7.3	7.1	--	--
		06.00	18.0	19.3	29.7	30.2	6.8	6.2	--	--
		10.00	16.2	18.5	30.5	30.0	6.5	6.4	--	--
AUTUMN	4	10.00	26.0	32.0	29.8	30.1	6.7	6.5	7.7	7.8
		13.00	30.0	33.0	32.2	31.8	7.2	6.8	8.7	8.7
		17.00	35.2	35.0	30.5	30.4	7.6	7.2	8.4	8.5
		20.00	31.2	30.1	30.9	30.5	7.8	7.5	8.3	8.7
		24.00	27.0	26.1	30.2	30.2	7.2	6.7	8.2	8.4
		04.00	31.8	35.0	29.3	29.2	6.4	5.6	7.8	7.8
		07.00	35.2	35.2	29.7	29.8	6.4	6.0	8.3	8.4
	7	10.00	30.5	32.5	30.5	30.5	7.1	6.0	8.5	8.1
		13.00	23.5	26.5	31.7	32.4	7.8	6.4	8.2	8.0
		17.00	25.1	28.5	32.2	32.9	7.6	5.6	7.8	8.0
		20.00	26.0	27.0	31.5	31.5	7.1	7.0	8.1	8.0
		24.00	26.5	27.5	30.5	31.0	7.1	6.4	7.7	8.3
		04.00	27.0	28.0	29.6	31.1	6.6	5.6	8.1	8.2
		07.00	29.1	30.1	30.0	30.5	6.3	5.6	8.0	8.1

Table 3.9 Diurnal variation of temperature, turbidity, salinity, pH, dissolved oxygen, nitrate and phosphate at lower and upper reaches of the Negombo Lagoon (extracted from NARA, 1988)

Parameter	Reach	9.00 h	13.00 h	17.00 h	21.00 h	1.00 h	5.00 h	9.00 h
Temperature (°C)	Lower	31.5	31.9	29.9	28.4	28.4	27.1	30.7
	Upper	32.5	33.9	31.5	29.0	39.5	25.8	32.4
Turbidity (NTU)	Lower	27.0	6.2	13.0	11.0	26.0	32.0	9.0
	Upper	5.0	8.5	4.5	6.0	7.8	6.5	5.5
Salinity (ppt)	Lower	25	23	34	26	27	38	27
	Upper	20	25	18	15	17	20	23
pH	Lower	8.60	8.62	8.50	8.20	8.26	8.18	8.25
	Upper	8.31	8.37	8.50	8.62	8.50	8.50	8.12
DO (mgl^{-1})	Lower	3.5	5.5	3.8	4.0	3.5	1.2	4.2
	Upper	5.0	5.2	5.8	4.5	2.5	4.2	3.2
NO_3 (mgl^{-1})	Lower	0.05	0.07	0.05	0.07	0.1	0.07	--
	Upper	0.05	0.05	0.05	0.08	0.04	0.07	--
PO_4^{-3} (μgl^{-1})	Lower	10.0	40.0	44.0	0.0	20.0	21.0	--
	Upper	20.0	20.0	0.0	0.0	20.0	0.0	--

3.5 Trends in Pollution

The diagnosis of intermittently and irregularly reported information on hydrography (e.g. salinity, temperature, pH, etc.,) from 1969 to 1991 revealed that there were no significant changes in these water quality parameters, but there were prominent seasonal and spatial variations associated with a combination of natural factors (e.g. climatic and weather). However, the magnitude of salinity intrusion towards the freshwater inflow could not be assessed for a long period since appropriate data was not available. Heavy sediment loading (especially suspended) into the lagoon was apparent. This will certainly enhance the siltation of the lagoon bed and will also decrease the primary productivity due to decrease in the euphotic zone. The decrease in oxygen concentration during early morning hours reported during the diurnal survey conducted by NARA (1988), signals eutrophic condition of the lagoon. More emphasis should be placed on this aspect because such anoxic conditions were not observed during the diurnal surveys carried out by Silva (1981) on the spring and autumn equinoxes of 1977.

In the case of micro-nutrients, the Negombo Lagoon did not show a marked enrichment by nitrogen and phosphorous compounds. Conclusive evidence cannot be drawn with respect to the present status and future trends of nutrient enrichment in the Negombo Lagoon since the available data is insufficient. However, there may be a gradual increase in nutrient loading into the lagoon through the main inflows resulting from land based human activities in the watershed. A more or less similar assumption can be made on the present status of heavy metal concentration and trends in heavy metal pollution. The reported values for the coliform counts (i.e. total coliform and faecal coliform) and BOD_5 levels are also substantially high for a natural brackish water body. Accordingly, the Negombo Lagoon has been subjected to organic pollution. This situation may be further aggravated due to ongoing human activities and anticipated developments in its immediate watershed. It is not certain that the Central Waste Treatment Plant established in the Katunayake Free Trade Zone is efficient enough to treat both human waste and industrial effluent originating from this massive industrial complex. In addition, it has been reported that most of the effluent from the Ekala Trade Processing Zone, which is not properly treated discharges directly or indirectly into the major freshwater inflows (Dandugam Oya and Ja Ela).

The Environmental Department of GCEC reported seventeen water quality parameters (e.g. physical, chemical and bacteriological) at nine locations of the Negombo Lagoon including the main freshwater inflow (Table 3.7). During this study, sampling was carried out only for the surface water but the sampling frequency, study period and analytical methods were not stated. However, they have reported several pollution indicative water quality parameters (e.g. BOD_5, COD, coliform bacteria, heavy metals, etc.,). The hydrographic characteristics reported by GCEC were more or less similar to those reported in previous studies for similar localities. The levels of coliform bacteria were extremely high at all locations, whereas defaecation near the water or in the vicinity makes contamination possible. The levels of heavy metals reported in this study should be further investigated by more refined analysis using appropriate instruments (e.g. Atomic Absorption Spectrophotometer). Fish mortality observed in October 1990, in the Ja Ela has been attributed to discharge of waste water from a Gherkin Processing Factory into the canal. In addition, attempts have been made to correlate the high levels of heavy metals (e.g. chromium) to the discharge of industrial effluent into the freshwater inflows by the Ekala Industrial Estate. Evidently, the watershed of the Negombo Lagoon has been subjected to a variety of human activities which may result in deleterious changes in the water quality of the lagoon. However, the available data on the water quality of the Negombo Lagoon is neither sufficient nor systematic enough to interpret the status and future trends in the water quality.

3.6 Recommendations

- Priority should be given to launching a systematic study on pollution indicative water quality assessment in the lagoon for an appropriate period.

- This preliminary survey should be further extended to establish a systematic monitoring programme in the Negombo Lagoon in order to identify the trends in the water quality with a view to implementing appropriate regulatory measures and mitigation plans.

- Appropriate sanitary facilities should be provided to the poor families living (e.g. fisher folk) around the lagoon.

- Necessary management strategies should be implemented to minimize the silt load and to remove the excess freshwater that empties into the lagoon during high floods.

- Periodic investigations should be conducted to determine the availability of pesticides in the Negombo Lagoon.

- Preliminary investigations should also be carried out to determine whether coir and saw mills and boat manufacturing industries located along the shoreline of the lagoon have significant impacts on the water quality.

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CHAPTER 4: BOLGODA LAKE

4.1 Introduction

Of the 45 basin and riverine estuaries located along the coast of Sri Lanka (CCD, 1990), Bolgoda Lake is popularly known as an aesthetic coastal water body. The Bolgoda Lake is a basin estuary, but it is called a lake because some natural brackish water bodies are referred to as coastal lakes in some instances. This shallow dual basin estuary is mainly fed by monsoonal rain in addition to minor inflows which are exclusively confined to the first peneplain in the wet zone. Since, the Bolgoda Lake is not connected to the sea throughout the year via the Panadura Estuary, it could be considered as a semi-closed lagoon. As in the case of several other estuaries or lagoons in Sri Lanka (e.g. Kelani Estuary, Negombo Lagoon) the Bolgoda Lake is also closely linked with major urban centers located on the Galle bound main road. Its location close to the capital of the country, and relatively high population density in the watershed with urban expansions may have negative environmental impacts on this aesthetic water body. This may affect the utilization of the estuary for several human requirements by the people living in the area.

In general, ecological stability of these brackish water bodies is largely determined by the sea water and freshwater influx into the estuary and the mixing processes therein, providing sufficient renewal of essential nutrients, organic matter and dissolved gases. The ecological processes in these estuarine systems can be disturbed in many instances directly or indirectly due to land based human activities. Effluent discharge from industries, waste disposed by people living in the vicinity, intense recreational activities and improper land use in the upper watershed are among the most commonly found human activities that could deteriorate the estuarine habitat. In the case of the Bolgoda Lake the above mentioned activities may deteriorate the natural beauty or the aesthetic value of the water body and handicap the present uses of it (e.g. fishing and recreation). Therefore, it is important to examine the impacts of such man-made activities on the lagoon ecosystem and to maintain a regular recording on ecological characteristics of the water body (i.e. water quality, flora and fauna).

4.2 Study Site

The Bolgoda Lake (6^0 40'-49' N; 79^0 54'-58' E), a shallow brackish water body in the Bolgoda watershed, is located between the southern border of the Kalu Ganga basin and the northern border of the Kelani Ganga basin in the wet zone of the country. The Bolgoda Lake has two major basins (North Lake and South Lake) connected by a narrow stream known as the Bolgoda Ganga (Fig. 4.1). North Lake opens to the Indian Ocean at Panadura via the Panadura Estuary. South Lake is also connected with the sea at Pinwatte through a narrow artificial canal known as the Talpitiya Canal, but sea water intrusion through this canal is negligible. North Lake has extended upto Ratmalana (near Colombo Air Port) and its extreme north is called the Weras Ganga. The Weras Ganga is connected with the

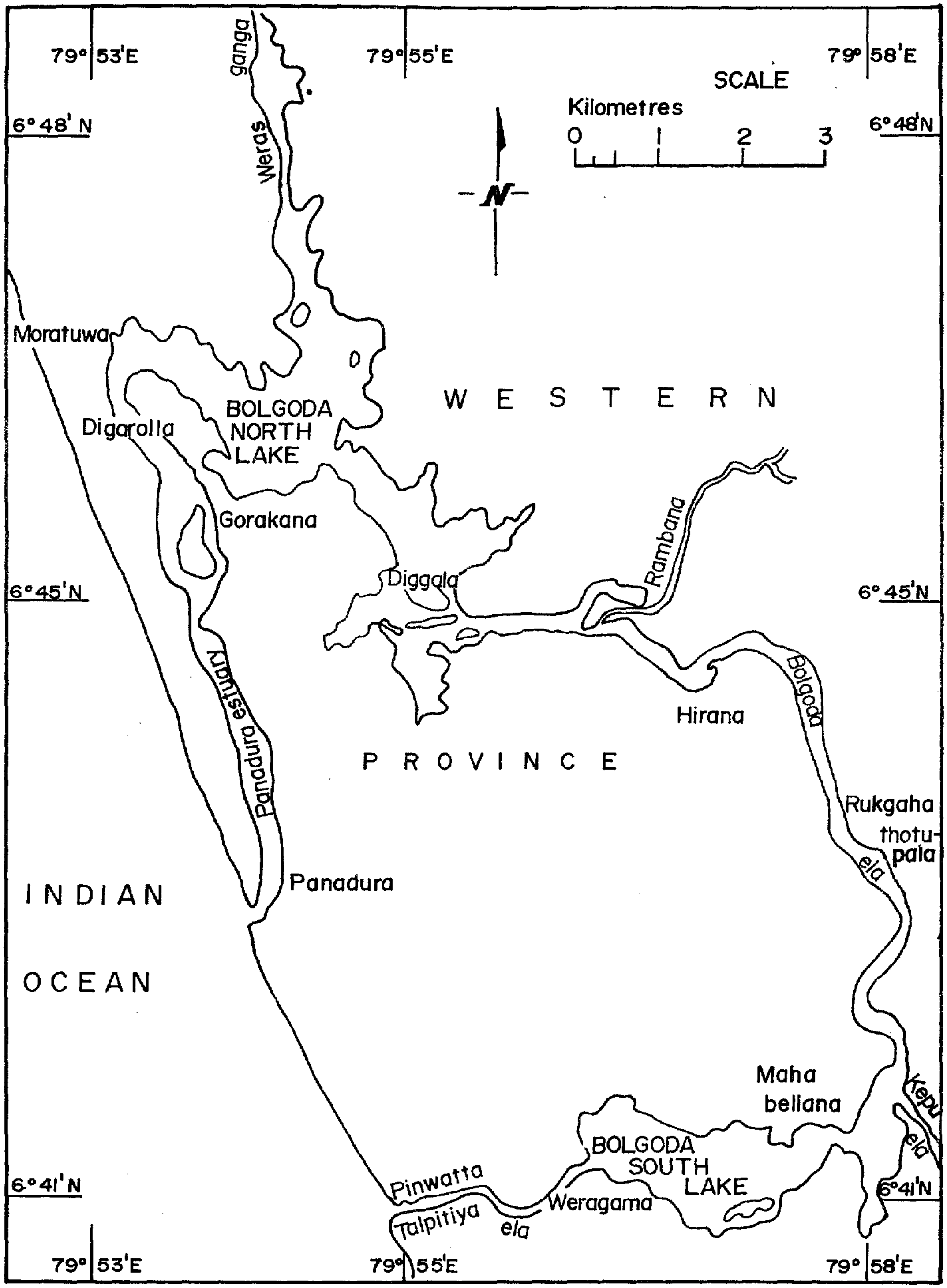

Figure 4.1 The Bolgoda Lake

Dehiwela-Wellawatte Canal System at its northern end. North Lake has an irregular shoreline and it looks like two closely inter-connected basins linked by a narrow stream. The Maha Oya (the major freshwater inflow of North Lake) connects with North Lake at its extreme south end where the Bolgoda Ganga shows a southward flow and connects with South Lake from its north-eastern end. The Panape Ela and Kepu Ela, the major freshwater inflows of South Lake join together and empty into the Bolgoda Ganga. In addition, the Maha Ela and an irrigation canal connect with South Lake from its southern end via two small basins known as the Madubokka Ganga and Hungurilla Ganga.

The Bolgoda Lake has an average depth of about 2 m and both basins cover an area of 1,245 ha including the Bolgoda Ganga. The bank of the Lake is steep, and as a result, two basins have hardly any area less than 1 m in depth. The tidal amplitude of the Lake varies between 1 cm and 75 cm and the average daily variation changes from 1 cm to 6.2 cm near Weragama, a small village adjacent to the north of the Panadura Estuary (Siriwardena & Perera, 1986). The substratum of the Bolgoda Lake is quite different from several other lagoons such as the Puttlam, Nathikadal, Nayarum and Jaffna lagoon because of its high percentage of clay and silt (Siriwardena & Perera, 1986). The bottom of North Lake is more or less irregular while there is a gentle gradient in South Lake.

More or less complete closure of the Lake opening into the sea at Pinwatte prevents sea water intrusion into South Lake via the Talpitiya Canal. However, the Bolgoda Ganga flows from North Lake to South Lake because of elevational differences. South Lake receives freshwater from its own catchment whereas sea water pushes through the Panadura Estuary to North Lake during high tides. Besides the freshwater inflow to North Lake from its own catchment, the water from the Sea Water Elimination Scheme at Attidiya flows into the same basin via the Weras Ganga. In addition, several surface drains discharge into the Bolgoda Lake from its entire periphery perhaps, carrying considerably high amounts of silt into the Lake.

4.3 Watershed

The entire watershed of the Bolgoda Lake is about 6000 ha and the natural vegetation has been mainly substituted by two major crops (i.e. paddy and rubber) and village gardens (Fig. 4.2). Several densely populated townships (e.g. Mount Lavinia, Ratmalana, Moratuwa, Panadura and Wadduwa) are located along the coastal boundary of the watershed. The impact of these townships on the Lake may not be significant since they are located downstream. A few factories are also located on either side of the Weras Ganga from Kaudana to Katubedda. The major townships in the upstream watershed of the Bolgoda Lake are Horana and Bandaragama. Except for major land use, the entire watershed is subjected to infrastructure development (e.g. transportation, telecommunication, transmission of electricity) and establishment of other amenities such as schools, hospitals, etc.,.

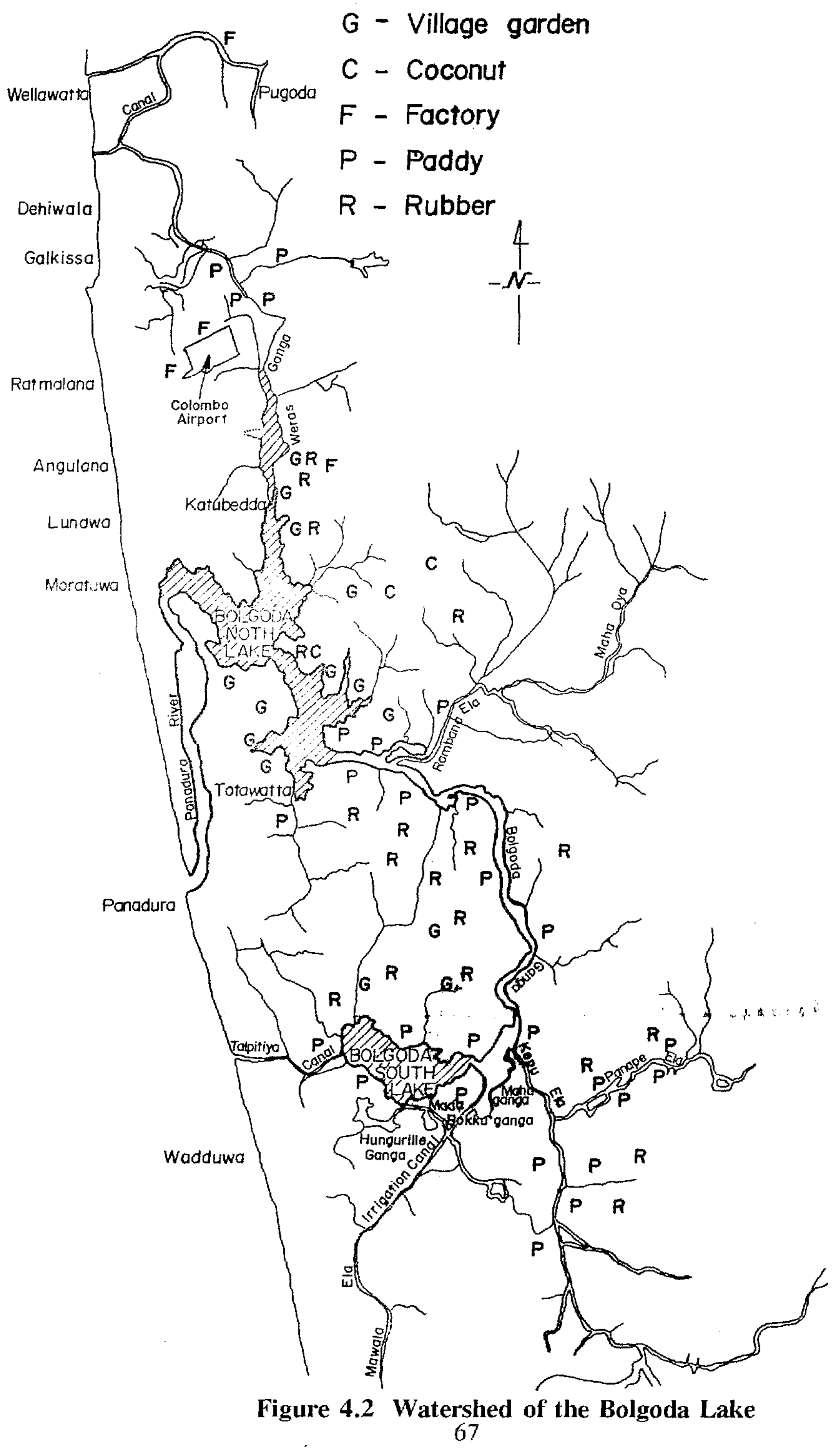

Figure 4.2 Watershed of the Bolgoda Lake

The Lake water is being used to irrigate the neighbouring paddy-fields. In addition, water is also used by people living in the area for several domestic purposes including drinking. Fishing in the Lake is a common practice. The industrial effluent from textile factories and printers enters the Weras Ganga. Since the main east-west shipping routes lie along the southern coast, maritime waste may also enter the Lake via the Panadura Estuary. Agriculture practices are so intense in the watershed such that there is a great potential to contaminate the Lake with pesticides and eutrophicate by fertilizer. Further, domestic waste may also reach the Lake directly or indirectly.

4.4 Water Quality

Some aspects of the physical characteristics (i.e. temperature, turbidity and transparency) of South Lake were examined during a survey conducted on the composition and seasonal fluctuation of zooplankton in the Bolgoda Lake from October 1980 to September 1981 (Wignarajah & Amarasiriwardena, 1983). Six locations of the Bolgoda Lake were examined during two consecutive years (February 1984-March 1986) for seasonal and diurnal changes in some physico-chemical parameters (i.e. temperature, transparency, dissolved oxygen, total alkalinity, pH, salinity and conductivity) by the National Aquatic Resources Agency (NARA) (Siriwardena & Tissa, 1988). NARA also conducted a survey on several physico-chemical parameters (i.e. hardness, Ca^{2+}, Mg^{2+}, conductivity, Cl^{-}) and pollution indicative parameters (i.e. DO, BOD_5, permanganate value, total coliform, faecal coliform, and NH_3-N) to determine the salinity intrusion and organic pollution respectively (Dassanayake *et al.*, 1991). During this survey they examined the above parameters at three sites located at 1 km intervals upstream of the Panadura Estuary during low and high tides at both neap and spring tides in the surface and bottom waters.

During the studies conducted by Wignarajah and Amarasiriwardena (1983), the mean temperature of South Lake changed from 29 °C to 32 °C (October 1980-September 1981) and slightly higher temperatures were reported for the dry months (Table 4.1). The water turbidity ranged from 0.9 to 9.6 NTU throughout the study period demonstrating a moderate seasonality. The high turbidity found in South Lake during the north-east monsoon was attributed to the corresponding rainfall (Wignarajah & Amarasiriwardena, 1983) but the turbidity was relatively low from April to June with the onset of the south-west monsoonal rainfall (Table 4.1).

The water transparency (Secchi depth) reported for South Lake during this survey was relatively high for a shallow water body. Nevertheless the relationship between the Secchi depth and the turbidity was statistically significant.

Table 4.1 Monthly mean values (±SD) of depth, temperature, turbidity, transparency and total monthly rainfall at South Lake during 1980-1981 (extracted from Wignarajah & Amarasiriwardena, 1983)

Month	Turbidity (NTU)	Depth (m)	Transparency (m)	Temperature (°C)	Rainfall (mm)
Oct	9.60±2.73	2.24±0.13	1.39±0.13	29.90±0.27	370.3
Nov	5.41±3.36	1.83±0.13	1.44±0.03	29.70±0.27	333.5
Dec	8.51±3.46	1.94±0.18	1.54±0.37	28.51±0.13	211.1
Jan	2.42±0.72	1.91±0.09	1.66±0.11	29.26±0.49	155.2
Feb	0.97±1.03	1.98±0.057	1.67±0.20	29.86±0.42	83.3
Mar	2.47±1.14	1.86±0.14	1.35±0.24	32.08±0.27	69.4
Apr	2.66±0.62	2.06±0.06	1.38±0.19	31.93±0.34	268.6
May	2.17±0.33	1.93±0.10	1.54±0.11	31.25±0.37	528.9
Jun	3.00±0.36	2.11±0.07	1.61±0.09	28.59±0.48	187.6
Jul	2.63±1.53	1.76±0.09	1 49±0.09	28.67±0.37	19.6
Aug	2.06±0.26	1.77±0.15	1.59±0.15	29.46±0.26	97.7
Sep	2.34±0.48	1.73±0.04	1.50±0.08	29.98±0.40	144.5
Avg.	3.68	1.92	1.51	29.92	--

The raw data reported on five physico-chemical characteristics of the Bolgoda Lake for a period of two years by Siriwardena and Tissa (1988) was subjected to a one-way ANOVA to determine whether these parameters show significant spatial and seasonal variations (Table 4.2). The computed mean values and their ranges for seasonal and spatial variations of physical and chemical parameters (i.e. temperature, pH, salinity, alkalinity and dissolved oxygen) were well within the ranges reported for a natural brackish water body influenced by both tidal influxes and freshwater inflows except in a few cases. For example, the maximum value reported for dissolved oxygen (21.5 ppm) was remarkably high for a natural surface water body and indicated either extremely high photosynthetic rate of the water body resulting from hyper-eutrophication or analytical error. The salinity of the Lake was directly influenced by both freshwater inflow and sea water intrusion. The physical and chemical parameters determined during this study showed a statistically significant seasonal variability (Table 4.2). In contrast, only the temperature and salinity showed statistically significant site-specific variation (Table 4.2). Significantly different inter-site variability in salinity is usual in brackish water bodies while a significant variability in temperature for a small water body is unusual in the tropics. Statistically significant site-specific variation in the temperature may be attributed to differential sampling time.

Table 4.2 Results of the one-way ANOVA for physico-chemical parameters (spatial and seasonal) extracted from Siriwardena and Tissa (1988)

Parameter	Range	Mean		F Value	Pr > F
Temperature (°C)	27.25-32.75	30.35	Inter-site	3.50	0.0054
			Seasonal	4.73	0.0001
pH	6-8.2	6.91	Inter-site	1.70	0.1381
			Seasonal	1.90	0.0446
Salinity (ppt)	0-15	1.42	Inter-site	11.5	0.0001
			Seasonal	2.92	0.0018
Alkalinity (ppm)	12.5-140.62	42.21	Inter-site	2.08	0.0716
			Seasonal	2.27	0.0146
Dissolved Oxygen (mgl^{-1})	5.5-21.5	9.15	Inter-site	0.37	0.8674
			Seasonal	6.37	0.0001

The log-transformed data extracted from bar charts have been plotted in log scale to show the salinity intrusion and organic pollution in the Panadura estuarine section of the Bolgoda Lake by Dassanayake *et al.*, (1991) during low and high tides at both neap and spring tides. This data was re-transformed into linear scale and electrical conductivity was considered as a determinant of salinity intrusion, while BOD_5 and total coliform were treated as organic pollution indicative parameters. According to the authors (Dassanayake *et al.*, 1991) a conductivity gradient developed towards the estuarine mouth within a 3 km distance in the surface water during high and low tides at both neap and spring tides. Such a conductivity or salinity gradient should be prominent in any brackish water body connected to the sea but there was no any significant pattern with respect to the other parameters (Table 4.3).

The same study showed significant differences in BOD_5 during low and high tides at both neap and spring tides in surface and bottom waters of the Bolgoda Lake. The reported values were extremely high in some instances for a shallow estuarine water body. For example, the reported BOD_5 for the surface was 4.46 mgO_2l^{-1} during low tide period at neap tide while it was 17.8 mgO_2l^{-1} under the same tidal condition for the bottom water (Table 4.4) indicating severe organic pollution. Extremely high BOD_5 values ranging from 63.1 mgO_2l^{-1} to 501.2 mgO_2l^{-1} were reported for both surface and bottom waters during low and high tides at spring tide (Table 4.4). These values however, are inconsistent or irregular and do not lead to any meaningful interpretation. More or less similar results were reported for the total coliform and *E. coli* during low and high tides at spring tide (Table 4.4).

Table 4.3 Variation in electrical conductivity, total hardness, chloride, Ca^{2+} and Mg^{2+} at Stations 1, 2 and 3 during low and high tides at neap and spring tides (Source: Dassanayake *et al.*, 1991)

	Neap Tide				Spring Tide			
	Low Tide		High Tide		Low Tide		High Tide	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
EC (μ"S)								
Stn 1	3981.07	6309.57	5623.41	6309.57	12589.25	11220.18	10715.19	11748.76
Stn 2	3548.13	ND	3548.13	3548.13	10000	14125.37	11481.53	11748.97
Stn 3	2511.88	14125.37	2511.88	6309.57	11220.18	15848.93	11481.53	11748.76
TH (ppm)								
Stn 1	141.25	316.22	141.25	316.22	177.82	141.25	141.25	56.23
Stn 2	177.82	199.52	186.20	177.82	100	141.25	125.89	112.20
Stn 3	63.09	398.10	112.20	3162.27	79.43	79.43	112.50	177.82
Cl^- (ppm)								
Stn 1	1995.26	1905.46	1995.26	1995.26	44668.35	41686.93	31622.77	39810.71
Stn 2	1995.26	2511.88	1258.92	1905.46	44668.35	15848.93	31622.77	19952.62
Stn 3	2511.88	5011.87	2511.88	3162.27	11481.53	31622.77	11220.18	17782.79
Ca^{2+} (ppm)								
Stn 1	100	63.09	22.38	56.23	177.82	141.25	141.25	56.23
Stn 2	39.81	50.11	70.79	70.79	100	141.25	125.89	112.20
Stn 3	39.89	56.23	89.12	56.23	79.43	79.43	112.20	177.82
Mg^{2+} (ppm)								
Stn 1	56.23	31.62	19.95	56.23	316.22	251.18	131.82	199.52
Stn 2	31.62	56.23	10	17.78	125.89	141.25	125.89	125.89
Stn 3	17.78	177.82	11.22	63.09	112.20	199.52	70.79	141.25

Table 4.4 Variations in BOD_5 mgO_2l^{-1}, DO mgl^{-1}, Faecal coliform (FC, counts per 100 ml) and Total coliform (TC, counts per 100 ml) at Stations 1, 2 and 3 during low and high tides at neap and spring tides (Source: Dassanayake *et al.*, 1991)

	Neap Tide				Spring Tide			
	Low Tide		High Tide		Low Tide		High Tide	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
BOD_5								
Stn 1	4.4	17.7	6.3	12.5	501.1	100	199.5	63.0
Stn 2	3.1	3.9	ND	3.1	5.6	15.8	15.8	630.9
Stn 3	19.9	3.1	1.9	2.5	39.8	39.8	17.7	100
DO								
Stn 1	4.4	6.3	5.6	6.3				
Stn 2	5.6	6.3	7.0	7.0				
Stn 3	7.9	6.3	6.3	7.9				
FC								
Stn 1					56	11	794	ND
Stn 2					125	40	11	45
Stn 3					ND	ND	562	40
TC								
Stn 1					32	18	1000	100
Stn 2					316	20	ND	23
Stn 3					100	32	1778	126

4.5 Trends in Pollution

According to the available data on physico-chemical and biological parameters for different locations of the Bolgoda Lake, it is apparent that high values have been reported for organic pollution indicative parameters (e.g. BOD_5) in the Panadura Estuarine segment during low and high tide periods at spring tide. However, the total and faecal coliform values reported for the same sites during the same tidal regime were within the permissible levels for natural brackish water. In addition, levels of some physico-chemical parameters (e.g. turbidity and transparency) indicated that the Bolgoda Lake had fairly clean water which had not been affected by sediment loading. The seasonal and spatial patterns of the variation in the basic physico-chemical characteristics (e.g. temperature, pH, salinity, alkalinity, dissolved oxygen) were quite acceptable for a shallow basin estuary which connects with the sea intermittently. The salinity and pH of the Bolgoda Lake exhibited a euryhaline nature because of its partial connection with the sea. The formation of a temporary sand bar indicated that the estuary was not completely flushed by the freshwater inflow. Therefore, salinity profiles (vertical and horizontal) should be fairly moderated, compared to the Negombo Lagoon.

It is too early to speculate that the northward extreme of North Lake has been subjected to technogenic pollution since appropriate information is not available. The water quality could deteriorate up to a certain extent since this region of the Lake receives untreated industrial effluent.

4.6 Recommendations

- A monitoring programme for water quality assessment of the Bolgoda Lake should be established simultaneously with the Negombo Lagoon and the Kelani Estuary.

- More emphasis should be placed on technogenic pollution at the upper reaches of North Lake.

- Since extremely high dissolved oxygen has been reported during certain instances, it is worthwhile to pay more attention to the parameters which indicate hyper-eutrophication.

- It is also important to carry out periodic investigations on pesticides, as the fishery in the lagoon is a traditional practice.

- A small laboratory equipped for water analysis should be established at the Lake site.

4.7 References

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CHAPTER 5: KOGGALA LAGOON

5.1 Introduction

Sri Lanka has 45 riverine estuaries and lagoons (basin estuaries). Of these, 17 are located in the southern segment of the island from Bentota to Palatupana. Many of the riverine estuaries and lagoons are closely linked with the major urban centers along the coast. Most of the basin estuaries (lagoons) in the southern coast of Sri Lanka remain closed for a good part of the year. These lagoons support subsistence fin fish and shellfish fisheries and provide a land-water interface which acts as a buffer zone against the erosional forces of the sea. The physical and ecological characteristics of many of these coastal lagoons make them specially susceptible for degradation. The estuaries and lagoon ecosystems found along the southern coast of Sri Lanka are relatively small in size, lack resistance, and have a low threshold for irreversible changes.

With the rise in human population and urban expansion, these coastal water bodies, in addition to their natural functions, are required to support a variety of human activities which take place within the lagoons and in their watersheds. The activities that occur in the watersheds often have an overriding impact on the respective coastal habitats. The ongoing coastal development activities such as tourism, housing and infrastructure development as well as aquaculture practices would therefore have significant negative impacts on estuaries and lagoons. In addition, development of river basins also have resulted in significant negative impacts on coastal habitats.

Of the southern coastal water bodies, the Koggala Lagoon is now considered as an important basin estuary because of its location close to the newly proclaimed Trade Processing Zone (TPZ) of the country. Therefore, it is reasonable to be of the opinion that the Koggala Lagoon would certainly become a potential site which could be affected by the industrial development of the Koggala TPZ if appropriate remedial measures are not implemented. In this chapter, the available water quality data of the Koggala Lagoon is presented as a prerequisite to implementing a systematic water quality assessment programme.

5.2 Study Site

The Koggala Lagoon (6° 1' N; 80° 18' E), a basin estuary, could also be considered a coastal lake. The lagoon is situated about 130 km south of Colombo and separated from the Indian Ocean by a narrow sand bar during most of the year. The sand bar develops near Katoluwa, where the lagoon opens to the sea, 2 km south of the Koggala township (Fig. 5.1). The lagoon has a relatively deeper basin and a larger surface area with respect to the other coastal water bodies in the southern coast. The lagoon covers an area of 645 ha in its 6400 ha watershed. The volume of the lagoon is 127×10^6 m^3 and the maximum depth is about 4 m. The shoreline is irregular, and a few islets which are mainly forested with mangroves and other terrestrial shrubs are found in the open water. The largest islet is located in the south-east corner of the lagoon near Gurukanda Temple (Fig. 5.1). The Koggala Lagoon is essentially a rain fed coastal lake. A perennial stream which drains the north-west portion of the watershed empties into the lagoon via the village called Godawatte (Fig. 5.1). The entire shoreline of the lagoon is bordered with village gardens or minor plantation crops (e.g. cinnamon). A few paddy-fields are also located adjacent to the shoreline bordering the stream inflow. The area bordered by the Colombo-Matara main road and the south-west shoreline of the lagoon has now been proclaimed as the Koggala Trade Processing Zone.

5.3 Watershed

The watershed of the Koggala Lagoon is confined to the wet zone in the south-west coast of the island (Fig. 5.1). Being located in the south-west coastal margin, the lagoon experiences south-west monsoonal weather. The annual rainfall in the area varies between 2500-3250 mm with two prominent peaks. The first peak rain starts with the onset of the south-west monsoon and gradually decreases towards August. The second peak commences in September and the highest annual rainfall which is about 3250 mm occurs in October.

The main geological form of the area is garnet biotite gneiss of Precambrian origin. Dolomitic marble may also be found close to the beach. Three major types of soil, characteristic to the wet zone are found in the watershed. Red yellow podzolic, with soft or hard laterite soils are predominant in rolling and undulating terrain while bog and half bog soils are found in flat terrain. Regosols on recent beach sand are also found in between the lagoon and the beach.

Except mangroves and scrub jungles there is no natural forest vegetation in the watershed of the Koggala Lagoon. The main land use patterns in the watershed are paddy cultivation and village gardens. A few patches of coconut plantations are scattered mainly towards the seaward boundary and a fairly large area has been cultivated with cinnamon in the north-eastern part of the watershed bordering the lagoon. The infrastructure development in the watershed is minimum except at the Trade Processing Zone and establishment of a few tourist hotels along the beach.

The human interference with the watershed could be related mainly to agricultural activities. It is apparent that the water from the inflow area of the lagoon is being used for agricultural practices. Despite fishing in the lagoon, especially for fin fish, a few bird watchers visit the small islets. About 12 industries, most of which are garment processing factories have already been established in the Trade Processing Zone. It is anticipated to establish 20 more industries in the TPZ to produce mainly dry products. The industrial effluent and human waste originating in this area are discharged into the sea through a sea outfall after treatment.

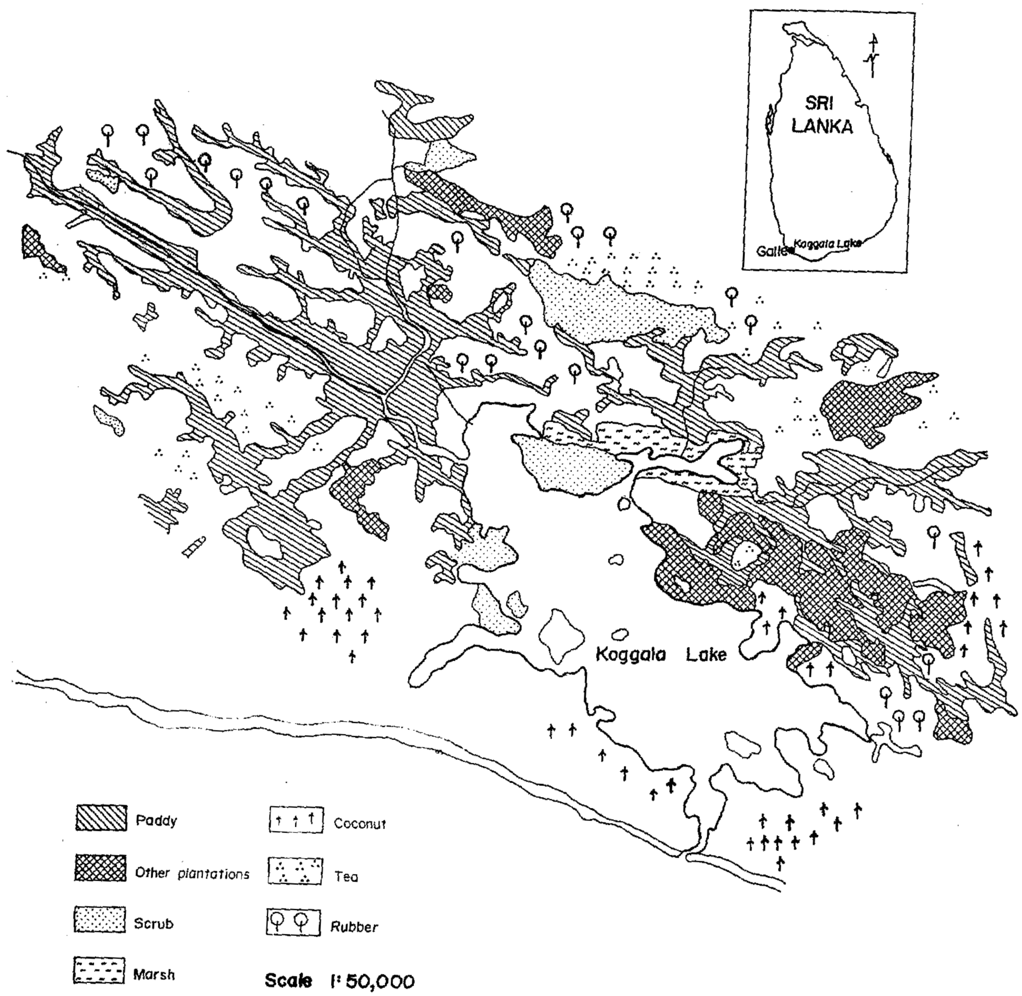

Figure 5.1 The Koggala Lagoon and its watershed

5.4 Water Quality

The first hydrobiological investigation on the Koggala Lagoon was carried out in 1981 by the Department of Zoology of the University of Ruhuna along with the survey conducted on the productivity of the southern lagoons in Sri Lanka (De Silva & Silva, 1982; Silva & Davies, 1986). Subsequently hydrographic characteristics of the Koggala Lagoon were examined monthly at four stations from the sea mouth to the freshwater inflow (Silva & De Silva, unpublished). The status of water quality of the Koggala Lagoon has been reported in the Environmental Impact Assessment (EIA) conducted on the Koggala Trade Processing Zone (Pemadasa & Senaratne, 1992). In 1994 March, several physico-chemical characteristics of the Koggala Lagoon were determined at the middle of the lagoon during a survey conducted to assess the buffer intensity of the surface water in Sri Lanka by the Institute of Fundamental Studies (Silva & Manuweera, in press). Most of these studies concentrated on the physico-chemical characteristics of the lagoon and in some cases on their seasonal and temporal variations. In addition, a survey on the Koggala Lagoon and its environs with special emphasis on the effects of human activities on socio-economic aspects of the people who utilized the lagoon as a resource for their livelihood was carried out during 1993-1994 by a research student attached to the University of London. Information however, is not available with respect to pollution indicative parameters such as BOD_5, COD, heavy metals, pesticides and coliform bacteria.

The results of the study carried out by Silva and De Silva (unpublished) on physico-chemical characteristics (e.g. temperature, salinity, alkalinity, pH and dissolved oxygen concentration) at four sites of the Koggala Lagoon, from April 1981 to March 1982 are summarized in Table 5.1. The annual variation in temperature was not significantly different among the study sites while there was a prominent salinity gradient in the Koggala Lagoon throughout the study period (Table 5.1). The salinity decreased from the sea mouth towards the freshwater inflow along the fetch of the lagoon and the highest mean salinity of 16.7 $\pm$ 3.2SD ppt was recorded in March 1981 while the second peak salinity of 16.2 $\pm$ 3.6SD ppt was found in August 1981. A similar pattern in the annual variation of salinity has been reported for the Koggala Lagoon by Pemadasa and Senaratne (1992). The surface water temperature of the Koggala Lagoon (April, 1981 to March, 1982) varied from 27.2 ^{0}C to 31.4 ^{0}C showing a slight seasonal trend (Table 5.1). The highest day temperature was found during the driest months of the year (i.e. February, March and April) and the lowest was in December and January. The salinity changes of the lagoon had direct bearings on the annual rainfall pattern. The salinity increased twice an year (i.e. March and August) to its peak value and dropped again during the corresponding peak rainfall (i.e. May-June and October-November). The highest salinity reported during this study was 18.0 ppt in March 1982 and the lowest was 0.5 ppt in November 1981.

Table 5.1 Annual ranges of salinity, temperature, pH, alkalinity and dissolved oxygen (DO) at four sites (Fig. 5.1) of the Koggala Lagoon from April 1981 to March 1982 (Source; Silva and De Silva, unpublished)

Parameter	Site 1	Site 2	Site 3	Site 4
Temp.(°C)	27.5-31.5	27.2-30.3	27.3-30.8	27.8-31.4
Salinity (ppt)	0.5-18.0	0.5-14.2	0.2-8.0	0.01-8.0
Alkalinity (ppm)	122-166	124-172	118-164	123-156
DO (ppm)	7.8-8.6	6.9-9.6	6.3-9.8	6.3-9.9
Secchi Depth (m)	0.8-1.4	0.8-1.5	0.7-1.6	0.7-1.5

With respect to pH and alkalinity, the lagoon water showed a more or less alkaline nature while the pH decreased with the onset of rainfall, during May-June and October-November. During the rainy season, the lagoon water became more or less neutral at the sea mouth and the middle, and slightly acidic towards the freshwater inflow. There was no statistically significant site-specific difference in dissolved oxygen concentration. Relatively higher oxygen values reported by the authors may be attributed to the sampling time which was around noon in most cases.

Table 5.2 Physico-chemical characteristics reported by Pemadasa and Senaratne in 1992 (Source; EIA report of the Koggala Trade Processing Zone)

Parameter	Value
Air Temperature (°C)	28.5
Water Temperature (°C)	30.5
Conductivity (milli mhos)	15.5
Salinity (ppt)	9.0%
pH	8.2
Dissolved oxygen content (ppm)	13.2
Total suspended matter (ppm)	55.5
Suspended organic matter (ppm)	28.4

The water transparency (Secchi depth) changed from 0.7 m to 1.6 m during the study period indicating low amounts of suspended and particulate matter (i.e. sediment, micro organism etc.,) in the water column. Apparently, some of the physico-chemical characteristics (i.e. salinity and pH) showed gradients from the sea mouth towards the direction of freshwater inflow. Although the coastal lagoons are generally amongst the most productive aquatic habitats with respect to primary production, a relatively low primary production has been estimated for the Koggala Lagoon (Silva & Davies, 1986). The details of the water quality data reported in the EIA exercise on the Koggala Trade Processing Zone are shown in Table 5.2. As shown in Table 5.2 a relatively higher concentration of dissolved oxygen (13.2 ppm) had been reported by Pemadasa and Senaratne (1992). The total suspended matter and suspended organic matter reported by the same authors were also relatively high for a coastal lagoon. During the study carried out by Silva and Manuweera (in press) in 1994 a buffer intensity of 3.93 x 10^{-4}moll^{-1} pH^{-1} was calculated for the Koggala Lagoon. The physico-chemical characteristics determined during the same study are given in Table 5.3.

Table 5.3 Physico-chemical characteristics at the middle of the Koggala Lagoon on 3rd March 1994.

Parameter	Value
Temperature (^{0}C)	31.0
pH	7.69
Salinity (ppt)	19.6
Alkalinity (ppm)	118
Cl^- (ppm)	19.1
SO_4^{-2} (ppm)	0.22
Ca^{+2}(ppm)	96.0
Mg^{+2} (ppm)	11.2
t-P (ppb)	10.0
d-P (ppb)	>1.0
NO_2^- (ppb)	4.0
NO_3^- (ppb)	21.0

"ND - Not Detectable, d-P - Dissolved Phosphorus, t-P - Total Phosphorus

In this study, the concentrations of micro-nutrients in the Koggala Lagoon were determined. The concentrations of the total phosphorus, dissolved phosphorus, nitrate and nitrite reported for the Koggala Lagoon are within the ambient limits recommended for unpolluted brackish water bodies (Table 5.3).

5.5 Trends in Pollution

Sufficient information is not available on pollution indicative water quality parameters (i.e. micro-nutrients, pesticide residues, COD, BOD_5 and coliform bacteria) of the Koggala

Lagoon. The available information did not permit either trend analysis in pollution or the expression of baseline levels of water quality characteristics. The general hydrographic characteristics of the Koggala Lagoon were mainly determined by the seasonal weather pattern and the influx of sea water and freshwater into the lagoon. Relatively low primary productivity values and concentrations of micro-nutrients of this brackish water body indicated that the lagoon was not enriched as yet with nitrogen and phosphorous compounds. There is only a slight possibility that this lagoon could be contaminated with trace metals since industrial effluents do not drain into the lagoon. On the other hand it is likely that pesticides or sediment could be found in the water since the watershed is heavily utilized for different crop cultivation. Contamination of the lagoon water with human excreta is also possible but it is premature to draw assumptions without having baseline information. It is also anticipated that the water quality of the Koggala Lagoon would be least affected by the establishment of the Trade Processing Zone. However, there is no information whether the effluent outfall of the Koggala TPZ would not have negative impacts on the lagoon.

5.6 Recommendations

- The present status of water quality of the Koggala Lagoon should be precisely determined with special reference to micro-nutrients, trace metals, microbial properties and organic residues.

- Regular monitoring programmes should be established along with the effluent discharged into the sea through the sea outfall to determine whether the effluent is carried back to the lagoon with the tidal floods when there is no sand bar between the lagoon mouth and the sea.

- A species spectrum of bio-indicators should be prepared and checked on a regular basis as a cost-effective method of pollution indication.

- The effects of the removal of the sand bar during the rainy seasons on salt water intrusion should be carefully assessed.

- It is worthwhile to establish a small laboratory at the Koggala Trade Processing Site for routine monitoring of basic water quality parameters.

5.7 References

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CHAPTER 6: KOTMALE RESERVOIR

6.1 Introduction

A recent event of increasing significance is the creation of artificial water bodies by man. However, human association with river basins and subsequent construction of artificial water bodies mainly for irrigation by damming or partial diversion of streams or rivers dates back to prehistoric time. Sri Lanka, an island which has no natural lakes is amongst the pioneer dam builders in the world, and its sophisticated network of ancient irrigation work is not well understood as yet.

At present, stream flow regulation for human benefit is cosmopolitan, mainly due to the increasing demand of water for irrigation, dry land farming, generation of hydroelectricity recreation and domestic uses. Certainly, the resulting anthropogenic ecosystems are quite different from natural ones with respect to structure and functioning. Such variations may partially be attributed to shorter duration time, non-stabilized equilibrium between aquatic and terrestrial ecotones and human interference with the water budget. Importance of managing man-made ecosystems is well understood because of increasing demand and parallel deterioration of natural resources. Indeed, a majority of inland water bodies are sinks for effluent resulting from unwarranted watershed management. This situation is more pronounced in the tropics where the greatest number of man-made water bodies are created and poor management strategies have been implemented due to lack of scientific know-how and technology. Therefore, establishment of routine quality monitoring programmes and implementation of remedial measures for the problems which are currently in existence are very necessary.

In Sri Lanka, two highland reservoirs, viz., Maussakelle and Castlereagh were constructed to generate hydroelectric power in the early 1960s by damming the headwater tributaries of the Kelani River. The Mahaweli Ganga Scheme, essentially a trans basin development project was designed later, not only to develop existing downstream reservoirs, but also to construct three major hydroelectric power reservoirs in the highland and two storage tanks downstream. The first phase of the Mahaweli Development Project was implemented in 1976 by partially diverting the Mahaweli water to the Kala Oya basin via the Polgolla-Bowatenna Scheme. Then, under the Accelerated Mahaweli Development Project, the trunk stream of the Mahaweli was dammed creating three hydroelectric power reservoirs, viz., Kotmale, Victoria and Randenigala-Rantambe in the central Mahaweli valley and partially diverted, inundating two storage reservoirs, viz., Maduru Oya and Ulhitiya Oya-Ratkinda in the lowland dry zone.

In general, it was assumed that deeper highland reservoirs are not eutrophic due to nutrient enrichment since their location is in the headwater. On the contrary, the Kotmale Reservoir was covered by a scum of algal bloom during the dry season of 1990 and the bloom disappeared gradually with increasing water level. This condition which is known as hyper-eutrophication affected the main function of the reservoir (i.e. hydroelectric power generation) but the causative factors inducing hyper-eutrophication have not been understood as yet fully. Therefore, it is worthwhile to focus more attention on highland reservoirs with respect to limnological characteristics and water quality.

6.2 Study Site

Kotmale, the deepest upstream hydroelectric reservoir (7° 3' N; 80° 37' E) situated 703 m above mean sea level was constructed under the Accelerated Mahaweli Programme by blocking the Kotmale Oya, by a rock fill dam at Kadadora village, about 6.6 km upstream of its confluence with the main stream of the Mahaweli River (Fig. 6.1). The Agra Oya, Dambagastâlawe Oya and Nanu Oya which are tributaries of the Kotmale Oya, drain the western slope of the highest region of the hill country at an elevation between 2000 m and 3000 m. The Agra Oya and Dambagastalawe Oya descend along steep gradients and join together at the Caledonia Estate and flow westward till Talawakelle, where the stream turns sharply northward before it merges with the Nanu Oya to form the Kotmale Oya proper. The Kotmale Oya, which is one of the major tributaries of the Mahaweli River at headwater, drains an area of 543 km^2 before meeting the Mahaweli River. Apart from the Kotmale Oya, Poona Oya, Pundalu Oya, Makandura Oya and the Gerandi Ella are the major inflows of the Kotmale Reservoir. The Kotmale Reservoir was sealed in 1985 and some important morphological and hydrological characteristics of the reservoir are summarized in Table 6.1.

Table 6.1 Some morphological and hydrological features of the Kotmale Reservoir

Hydrology	
Full supply level (a.s.l.)(m)	703.0
Extreme flood level (m)	704.3
Minimum operating level (m)	665.0
Catchment area (km^2)	550.0
Mean river flow ($m^3 sec.^{-1}$)	96.0
Morphometry	
Elevation (m)	703.0
Area (ha)	970.0
Volume at FSL ($x10^6 m^3$)	174.0
Maximum depth (m)	90.0
Mean depth (m)	26.8
Shoreline (km)	45.0
Shoreline development	4.9
Catchment area/lake area	55.8
Maximum length (km)	6.80
Maximum width (km)	1.41

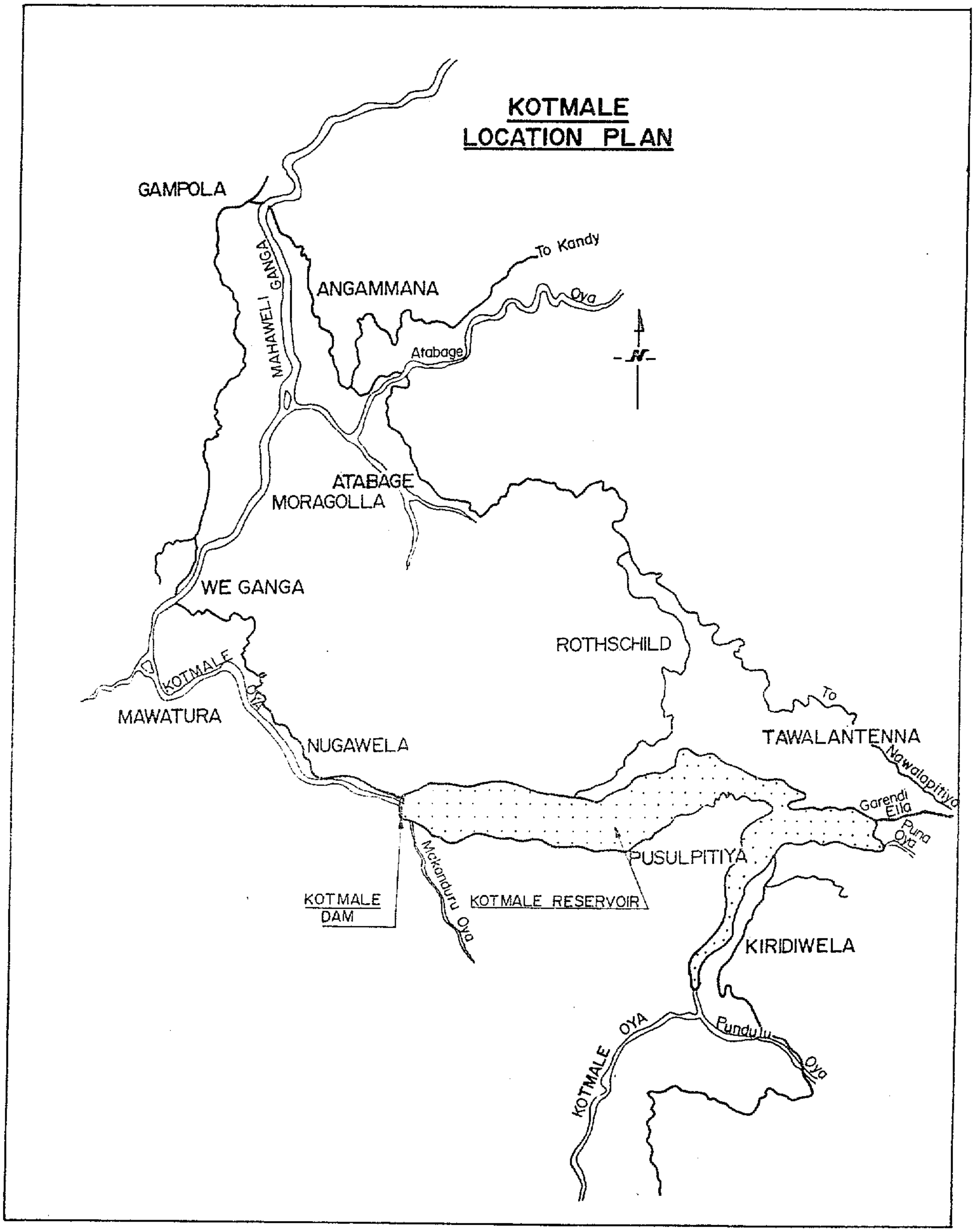

Figure 6.1. The Kotmale Reservoir

6.3 Watershed

The entire drainage basin of the Kotmale Reservoir is confined to the third peneplain in the central highland. A major portion of the highland of the island comprises of a charnokite-metasedimentary series of Precambrian origin. Therefore, the watershed of the Kotmale Reservoir is composed mainly of quartzite and gneiss. Soils in the watershed are tropical wet zone types (i.e. red-yellow podzolic soils). The Kotmale watershed receives 4000-5000 mm of annual rainfall and heavy rain occurs from May to October.

Catchment land use of the Kotmale watershed represents that of the upper catchment of the Mahaweli River. Changes in land use during the period from 1959 to 1979 are given in Table 6.2 (TAMS, 1980). Vegetable cultivation and subsequent use of agrochemicals have increased greatly during this period and application of fertilizer is one of the major contributory factors which may affect the nutrient levels of the reservoir.

Table 6.2 Land use (ha) changes in the upper catchment of the Mahaweli

Land use	1959	%	1979	%
Settlement	1,000	1	5,400	2.2
Homestead	20,000	12	24,300	10.1
Coconut	4,000	2	5,100	2.1
Cocoa	2,000	1	500	1.0
Tea	70,000	42	72,800	35.5
Orchard	--	--	2,000	1.0
Paddy	15,000	9	10,500	4.4
Perennial Dry Cropping	12,000	7	28,000	13.7
Chena	12,000	7	12,300	5.2
Tobacco	--	--	4,000	1.8
Grassland and Scrub	11,000	7	29,700	12.4
Natural Forest	18,000	11	29,300	12.3
Forest Plantation	1,000	1	3,500	1.5
Unused Land	--	--	900	1.0

Further, the watershed of the Kotmale Reservoir has been subjected to several other land use forms and the remaining natural vegetation has become insignificant. In addition to nutrient loading from tea plantations and vegetable fields, direct discharge of organic waste into the watercourse is common in densely populated areas. Above all, the Kotmale Oya received untreated effluent from the Kotmale Cheese Factory at Bogahawatte. The Cheese Factory effluent enriched the reservoir but the present status is unknown.

6.4 Water Quality

Since the reservoir was commissioned in 1985, a limnological investigation was carried out on a regular basis by the Department of Zoology of the University of Sri Jayawardenepura. This investigation focussed mainly on physical and chemical characteristics and on distribution of phytoplankton and zooplankton (Piyasiri, 1991, 1996). Further, six water quality parameters of the Kotmale Reservoir were determined by the Department of Zoology of the University of Peradeniya at ten randomly selected sites from January 1988 to December 1989 (De Silva, 1993). In addition, major inflows of the reservoir (i.e. Poona Oya, Pundalu Oya, Makandura Oya, Gerandi Ella and Kotmale Oya) and open water were examined on a monthly basis by the Institute of Fundamental Studies for micro-nutrients (nitrogen and phosphorous) following the occurrence of the algal bloom in 1991 (Silva, unpublished). The results of this investigation are not published as yet, and further investigations are in progress but the data already collected is summarized in this chapter.

Table 6.3 Some physical and chemical characteristics of the Kotmale Reservoir as reported by different authors

Parameter	Range	Mean	Reference
Temperature (°C)	24.03 - 27.59	25.61	De Silva (1993)
	--	21.00	Silva (1991)
	21.5 - 28.8	26.00	Piyasiri (1991)
pH	6.08 - 7.19	6.61	De Silva (1993)
	6.07 - 8.36	--	Piyasiri (1996, in press)
	--	6.7	Silva (1991)
Conductivity (μ^oS)	40 - 54	50.7	De Silva (1993)
	30 - 87	--	Piyasiri (1991)
	--	68.0	Silva (1991)
Total alkalinity (meq.l^{-1})	0.23 - 0.43	0.31	De Silva (1993)
Turbidity (NTU)	2.10 - 3.90	2.94	De Silva (1993)
Secchi Depth (m)	2.10 - 2.30	--	Piyasiri (1991)
Dissolved Oxygen (mgl^{-1})	4.75 - 7.50	--	Piyasiri (1991)
Sulphate (60 m depth, ppm)	--	3.40	Piyasiri (1996, in press)
Nitrite (ppb)	10 - 40	--	Piyasiri (1996, in press)
	1.0 - 11.8	3.97	Silva (unpublished)
Nitrate (ppb)	55 - 357.5	143.69	Silva (unpublished)
Dissolved Phosphorous (ppb)	1 - 55	10.55	Silva (unpublished)

On the other hand, pollution indicative parameters have not been examined except for micro-nutrients. The available information on water quality of the Kotmale Reservoir is summarized in Table 6.3.

During the studies carried out by Piyasiri (1991, 1996), the highest transparency occurred from January to March. Water transparency (Secchi depth) of the Kotmale Reservoir ranged from 2.10 m to 2.30 m (Table 6.3). De Silva (1993) reports the mean turbidity of the Kotmale Reservoir as 2.94 NTU with a range of 2.10-3.90 NTU (Table 6.3). The oxygen concentration of the Kotmale Reservoir ranged from 4.75 to 7.50 (Table 6.3) with a marked oxygen depletion observed where mixing of the surface water with the deeper layers was limited. The specific conductivity ranged from 30 μ^0S to 87 μ^0S (Table 6.3) with a marked seasonal fluctuation and the lowest values were recorded in February (Piyasiri, 1996). The pH of the reservoir varied from slightly acidic to alkaline (6.07-8.36) with an irregular fluctuation. Surface pH values were always higher than that of the deeper layers and the pH gradient was steep from the surface upto a 10 m depth. Below this depth, the pH remained more or less constant. Since the temperature was well above 4 ^{0}C with a rare circulation, the Kotmale Reservoir was classified as Oligomictic (Piyasiri, 1996). Unlike in temperate reservoirs, thermal stratification occurred throughout the year. The mean epilimnetic temperature often varied due to prevailing local weather conditions. Below 20 m, the temperature gradient of the Kotmale Reservoir decreased to 0.03 ^{0}C forming a sharp thermocline (Piyasiri, 1996). Daily density change in the upper 15-20 m strata resulted in re-location of these strata even during calm days, but such changes in the epilimnetic water did not disturb the thermocline. Release of water from the deeper layers for hydroelectric power generation resulted in periodic mixing of the oxygenated surface layers with the deeper layers.

According to the analysis made during the preliminary investigations (Piyasiri, 1996), the sulphate concentration showed a tendency to increase with increasing depth. The maximum sulphate concentration reported was 3.4 ppm (Table 6.3). The nitrite concentration also increased with increasing depth. The range of nitrite concentration reported by Piyasiri (1996) was 10-40 ppb while it was 1.0-11.8 ppb according to Silva (unpublished). The nitrate concentration varied from 55 ppb to 357.5 ppb with a mean value of 143.7 ppb (Table 6.3).

Table 6.4 summarizes some of the chemical constituents of major inflows determined from July 1992 to June 1993. The mean electrical conductivity of Kotmale Reservoir and its inflows varied from 20 μ^0S to 78 μ^0S during the study period (Table 6.4). Relatively high standard deviations of the mean values indicate a time-bound variability. Similar trends can be seen in the case of total alkalinity, pH and other cations (i.e. Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (i.e. SO_4^{2-} and Cl^-). Concentration ranges of the above mentioned chemical constituents of the Kotmale Reservoir and its inflows remained well within natural values reported elsewhere. With respect to influx of nutrients into the reservoir (i.e. PO_4^{3-}, NO_3^-), the total phosphorous in the reservoir ranged from 3 ppb to 230 ppb while it varied from 1 ppb to 460 ppb in the inflows with higher standard deviations than the mean values

Table 6.4 Physical and chemical parameters of the Kotmale Reservoir and its inflows during 1991 - 1992 (Silva, unpublished)

Parameters	Kotmale Reservoir		Makandura Oya		Gerandi Ella		Poona Oya		Pundalu Oya		Kotmale Oya	
	Mean ± STD	Range Mn-Mx	Mean ±STD	Range Mn-Mx	Mean±STD	Range Mn-Mx	Mean±STD	Range Mn-Mx	Mean±STD	Range Mn-Mx	Mean±STD	Range Mn-Mx
t-P (ppb)	35.4±78.7	3-230	47.0±137.0	20-460	16.5±32.2	2-111	17.8±32.4	2-111	17.9±32.7	2-111	27.27±64.17	1.0-220
NO_3 (ppb)	143.6±78.9	55-357.5	88.4±57.7	21-210	146.5±195.7	51-590	173.5±124.1	65-450	125.4±65.8	20-290	180.5±18.56	30-450
NO_2^- (ppb)	3.9±3.4	0-11.8	3.1±1.9	1-8	4.8±2.6	0.3-10	4.02±2.5	0.4-8.5	3.58±2.61	0.32-8	5.3±3.9	1-13
EC (μ^0S)	46.5±5.6	39-55	43.10±15.00	25-67	35.27±6.79	25-46	38.81±10.83	26-55	31.36±7.11	20-41	55.81±15.89	34-78
pH	7.28±0.32	6.65-7.64	7.22±0.79	6.3-8	7.4±0.75	6.56-8.7	7.03±0.54	6.24-8.19	6.98±0.50	6.32-7.86	7.19±0.62	6.43-8.54
Alkalinity (mgl^{-1})	16.77±4.92	10.76-23.75	14.78±4.2	7.30-21.3	18.6±14.47	7.9-60.9	13.33±5.74	4.26-23.14	13.45±3.48	9-18.87	17.58±6.72	9-25.57
Cl^- (mgl^{-1})	10.25±2.42	7.2-14	9.72±3.32	6.0-17	9.32±3.16	5-17	10.61±4.91	5.4-21	8.8±4.14	4.0-16.0	11.09±5.90	6.0-28.0
SO_4^{-2} (mgl^{-1})	1.57±2.18	0.1-6.0	1.80±1.50	0.2-5.0	3.11±3.37	0.1-8.3	1.24±0.91	0.1-3.0	1.69±1.39	0.35-5.1	1.57±1.17	0.2-4.3
Na^+ (ppm)	2.81±1.90	0.8-5.37	1.63±1.35	0.3-3	2.0±0.5	1.5-2.5	1.45±0.35	1.2-1.7	1.7±0.28	1.5-1.9	2.53±0.30	2.2-2.7
K^+ (ppm)	1.21±0.12	1.13-1.16	0.56±0.19	0.4-0.77	0.52±0.30	0.18-773	0.91±0.27	0.7-1.23	0.48±0.26	0.3-0.78	1.44±0.38	1.2-1.89
Ca^{+2} (ppm)	2.98±1.07	1.8-3.83	1.34-0.39	1.0-2.0	1.32±0.55	1.14-2.0	1.33±0.39	0.71-2.0	1.06±0.70	0.4-2.2	2.10±0.57	1.43-3.0
Mg^{+2} (ppm)	1.58±0.85	1.0-2.85	0.9±0.11	0.8-1.0	0.86±0.11	0.8-1.0	0.76±0.15	0.6-0.9	0.76±0.15	0.6-0.9	0.93±0.28	0.6-1.1

(Table 6.4). This indicates an irregularity of phosphorous loading into the reservoir as upper values are extremely high for headwater streams. A more or less similar trend was seen in the concentration of nitrate in the reservoir and its inflows (Table 6.4). The nitrate concentration of the reservoir ranged from 55 ppb to 357 ppb with a mean value of 143.6 ± 78.9SD ppb while the highest range for inflows was 51-590 ppb in the Gerandi Ella. Concentrations of nitrite in the reservoir and its inflows were relatively low and remained within the range of natural concentration (Table 6.4). Apparently, influx of micro-nutrients into the reservoir varied between different inflows over time.

6.5 Trends in pollution

Interest in pollution trends in the Kotmale Reservoir commenced in September 1991, when the Mahaweli Authority announced the presence of an algal bloom in the reservoir. The analysis of the Kotmale Reservoir water samples revealed hyper-eutrophication or over fertilization with nitrogen and phosphorous compounds. The planktonic algae responsible for this bloom was identified as *Microcystis aeruginosa*. This species may become poisonous, and troublesome in freshwater bodies where much organic matter is present. Hence, growth of this algae may lead to fish kills through suffocation.

The survey carried out by the Institute of Fundamental Studies on physico-chemical characteristics and nutrients of the major inflows of the Kotmale Reservoir since the occurrence of the algal bloom, found that total nitrogen and phosphorous were significantly higher in the Kotmale Oya than in the other inflows. Nevertheless, blooming of *Microcystis aeruginosa* was not observed during this period. As mentioned earlier the Kotmale Oya received untreated effluent of the Kotmale Cheese Factory at Bogahawatte and emptied that into the reservoir. The effluent of the Cheese Factory may be one of the causative factors for the Kotmale bloom in 1991.

No information is available to date on heavy metal concentrations, COD, BOD_5 levels and bacteriological counts in the Kotmale Reservoir. Therefore, it is necessary that a systematic monitoring of these parameters be carried out in order to implement proper management strategies because, the Mahaweli water downstream of the Kotmale Reservoir is tapped at Peradeniya and Getambe as a source of drinking water for the people living in the Kandy municipal area.

6.6 Recommendations

- Initiate systematic quality assessment on pollution trends of this reservoir (i.e. nutrients, COD and BOD_5 and bacteriological parameters).

- Treat effluent of the Bogahawatte Cheese Factory before it empties into the Kotmale Oya.

- Catchment land use, nutrient leaching from tea plantations and vegetable fields as well as direct discharge of human and other organic wastes into the watercourse should be monitored regularly.

- Regulate sediment loading into the reservoir via major inflows in order to control siltation.

- Appoint suitable personnel to implement viable management strategies based on above findings.

6.7 References

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CHAPTER 7: KALA WEWA AND RAJANGANA TANK

7.1 Introduction

Despite its favoured location in the humid tropics and the fact that it lies within the path of two monsoons, Sri Lanka exhibits excessive areas of water deficit. A major part of the island is vulnerable to dry spells lasting for several months. The source of surface water in Sri Lanka is essentially rivers, streams, creeks, brooks and waterfalls. Of the 103 river basins in Sri Lanka, the largest river (335 km long), the Mahaweli, is the only perennial river traversing the north-east dry zone. Therefore, careful husbanding of surface water in the dry zone over several centuries has resulted in an ingenious and elaborate network of water management. Apparently, there are 181 (102,719 ha) perennial water bodies over 40 ha which have inundated 1.57% of the island's surface area. Of these perennial tanks, 144 (67,634 ha) are located within 0-100 m contour, mainly in the dry zone. In general, the seasonal hydrological regime of man-made tanks in the dry zone reflects the monsoonal cycle and irrigation demand. In addition to irrigation, water is also used for drinking and other domestic purposes to a certain extent.

Irrigation water flows through reservoirs and canals and also through tunnels in some instances before it reaches the fields where crops are grown. During the course of flow, major cations and anions always dissolve and water may become saline. In the fields, water undergoes evapo-transpiration resulting in an accumulation of dissolved salts which would affect soil properties and subsequently, crop growth. Increased salinity or secondary salination has been reported in a majority of the surface water flowing in arid and semi-arid regions in the world. As a result, some intensively irrigated areas have been abandoned due to secondary salination and water logging.

Irrigation reservoirs are usually constructed in a form of cascades. Release of an upstream tank first reaches the respective command area, and surplus water is then collected in a downstream tank before it is conveyed to the next command area. Although, some attention has been focused on limnology of some dry zone reservoirs in Sri Lanka (Schiemer, 1981; Amarasinghe *et al.*, 1983; Silva & Davies, 1986, 1987), pollution indicative water quality parameters (i.e. agrochemicals, heavy metals, bacteriological properties) are poorly treated. Some aspects of water quality of the Kala Wewa-Balalu Wewa have been determined as a source of irrigation water (Gunawardhana & Adikari, 1981). In this chapter, the available data on water quality of two interconnected irrigation tanks, the Kala Wewa and the Rajangana Tank (fed by the Kala Oya in addition to the diverted water from the Mahaweli Ganga) is compiled and analyzed to identify the status of water quality and trends in pollution.

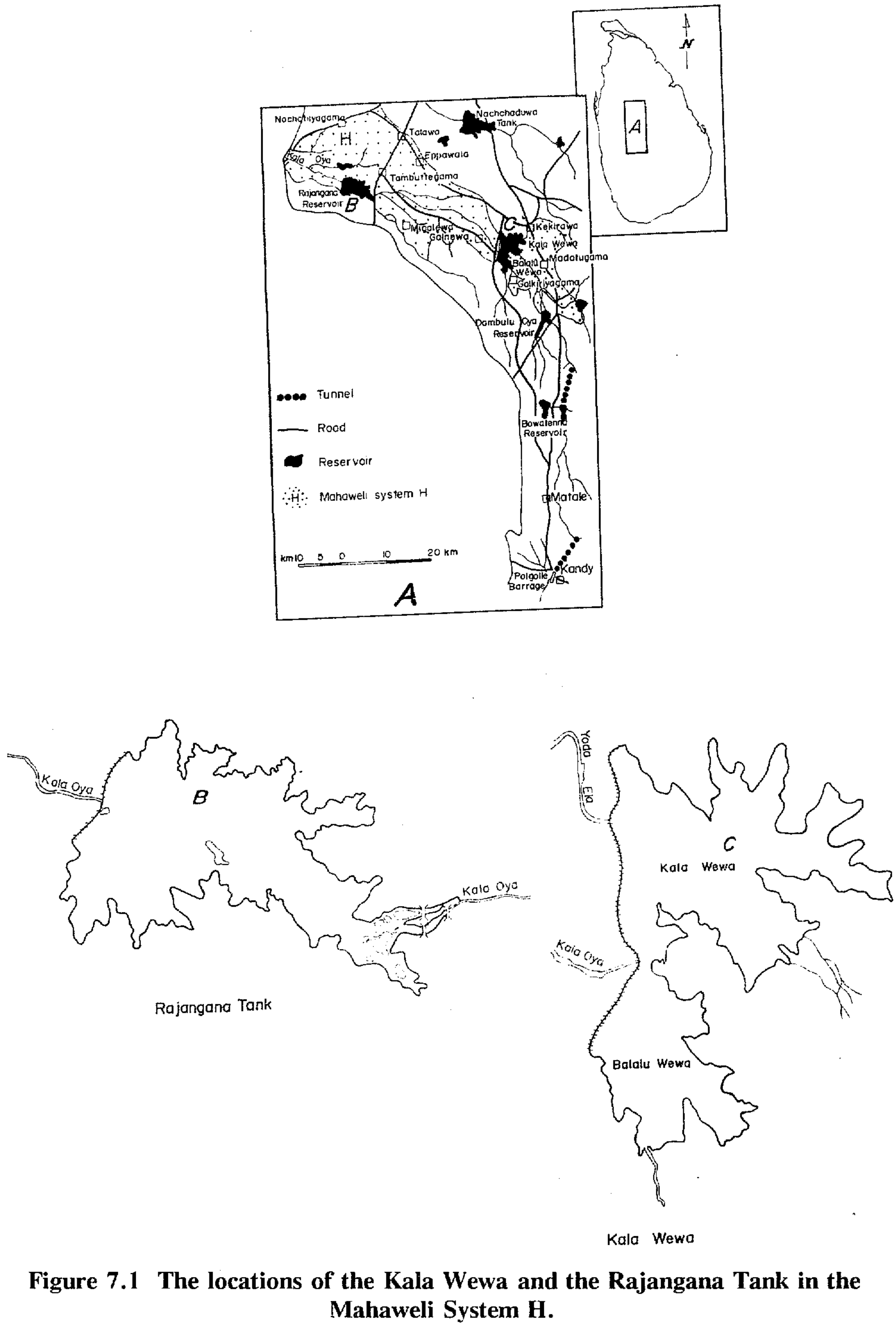

Figure 7.1 The locations of the Kala Wewa and the Rajangana Tank in the Mahaweli System H.

7.2 Study Sites

Kala Wewa : Kala Wewa (7° 59' N; 80° 33' E), historically known as the Kilavapi Tank, was constructed during the reign of King Dhatusena (459-477 AD) by damming the Kala Oya by an 8 km long earthen embankment of 20 ft. high, to impound the Dambulu Oya and the Heen Ela just below their confluence. The present tank was restored in 1887 and raised by about 2 m in 1939. Breaches were repaired in 1958 and the Kala Wewa and Balalu Wewa combined together to form one large irrigation reservoir. The Kala Wewa-Balalu Wewa is situated at an elevation of 130 m above mean sea level in the north-east dry zone (Fig.7.1). Outflow of the twin reservoir which is located near the confluence of the two reservoirs continues as the downstream of the Kala Oya and feeds the Rajangana Tank.

Since implementation of the first phase of the Mahaweli Development Project (i.e. trans basin diversion of the Mahaweli River and the Kala Oya via the Polgolla-Bowatenna Scheme) which was commissioned in 1976, the Kala Wewa and the Rajangana Tank receives the Mahaweli water through the Dambulu Oya, a main headwater tributary of the Kala Oya (Fig.7.1).

Table 7.1 Some morphological characteristics of the Kala Wewa and Rajangana Tank

Parameter	Kala Wewa	Rajangana Tank
Inflow	Kala Oya + Mahaweli + Heen Ela + Walamiti Oya	Kala Oya + Mahaweli
Location	System H (Mahaweli)	System H (Mahaweli)
Restoration	1887	1951
Storage (m^3)	8.806×10^7	9.8759×10^7
Area (ha)	2590	1619
Command Area (ha)	5140	7689
Catchment Area (ha)	8808	16,110
Elevation (m)	120	80
D-max (m)	9.2	10.6
D-mean (m)	3.4	6.1

Rajangana Tank: The Rajangana Tank (8° 7' N; 80° 15' E) is located about 30 km north-west of the Kala Wewa near the Tambuttegama railway station. The tank was built in 1951 by impounding water of the Kala Oya at the Kadigalla hill site. On the Kadigalla hills where the dam abuts into the rock are ruins of Maha May Ela Vihara built by the King Vankanasika Tissa (109-112 A.D.) on the banks of the Gona Nadi as the Kala Oya was then known. Basic morphometric characteristics of the Kala Wewa and the Rajangana Tank are given in Table 7.1. The right and left bank channel system provides water for about 12,000 ha in the command area. Overflow of the Rajangana Tank empties into the Dutch Bay of the Puttlam Lagoon.

7.3 Watershed

The Kala Wewa and the Rajangana Tank are situated in the Kala Oya watershed. The Kala Oya has its source near Nalanda and flows for 160 km in a north-westwardly direction passing Dambulla, Kalawewa and Rajanganaya. Upper reaches of the Kala Oya basin are fairly well utilized for development under the Kalawewa, Siyambalangamuwa, Rajanganaya, Angamuwa and several other major and minor irrigation schemes. Watershed of the Kala Wewa and the Rajangana Tank consists mainly of five land use forms (i.e. scrub, chena, home garden, paddy and coconut plantations). Natural forest is merely scrub jungle but the dry zone forest has been mainly substituted by other land use. Human settlements are scattered throughout the watershed. Infrastructure development is limited to road construction, power transmission and other amenities. Industries are not found in the Kala Wewa-Rajangana watershed except for a few garment processing factories established recently.

In general, association of peasants with irrigation tanks is very strong, from the historical past to date. The village tank which is a small rain fed seasonal pond is referred to as the finest item of the Sinhalese culture. Surface water forms such a precious commodity that Parakrama Bahu The Great, the 12th century ruler, reputed for his remarkable irrigation works exhorted "let not a single drop of water reach the sea without first serving man". In the present context, this concept is questionable with respect to environmental validity. Human interference with larger irrigation reservoirs and their impact on water quality may be insignificant since the population of a particular watershed is not so dense. However, care should be taken that irrigation tanks should not act as sinks for materials transported by their inflows because of low flushing rate and relatively high retention time of these water bodies. Since excessive amounts of agrochemicals (fertilizer and pesticides) are being used in command areas, the downstream can be contaminated substantially with organic residues and enriched with micro-nutrients. This situation may cause irrigation reservoirs to become eco-toxic and unacceptable eutrophic ecosystems. Apparently, some peasants living in the vicinity of these irrigation tanks utilize the tank's water for domestic uses including drinking. Drinking of untreated tank water may not exhibit recurrent health symptoms, but no one knows the chronic effects caused by consumption of such water. The irrigation water is certainly desirable for crop cultivation. Since the water may directly or indirectly affect the people living in the vicinity, it should be suitable for drinking and other domestic purposes as well.

7.4 Water Quality

The knowledge of the quality of irrigation water is important in judging its suitability for crop cultivation. Suitability of irrigation water is determined mainly by several factors reflected by the characteristics of water, soil, crops and climate. One of the most important indices of the physico-chemical characteristics of irrigation water is the relative proportion of sodium ions to other cations, which is known as the Sodium Absorption Ratio (SAR).

A study was carried out to determine water quality of the Kala Wewa (Gunawardhana & Adikari, 1981). In this study, authors examined the seasonal variation of the total salt concentration and the relative proportion of sodium to other cations and bicarbonate ions of the water collected from selected locations in the Kala Wewa and its command area. In addition, authors examined the total phosphorous, chloride and sulfate ion concentrations of the irrigation water during this study. Although attempts have been made to examine the seasonal changes in water quality with respect to its suitability for irrigation, the sampling frequency was slightly irregular due to unavoidable reasons according to the authors. Amarasinghe *et al.*, (1983) reports some physico-chemical characteristics of the Kala Wewa (i.e. temperature, conductivity, transparency, pH, dissolved oxygen and alkalinity) on a monthly basis from June 1980 to May 1981. Similar parameters were also examined in the Rajangana Tank during this study. Despite several physico-chemical characteristics reported by Amarasinghe *et al.*, (1983) during the survey on limnology and fish production potential of selected reservoirs in the Anuradhapura district, the Rajangana Tank was not subjected to a water quality assessment or a monitoring programme as such. In 1994, some physico-chemical characteristics of the Kala Wewa-Balalu Wewa and the Rajangana tank were determined by the Institute of Fundamental Studies during a survey carried out on the buffer intensity of surface water in Sri Lanka (Silva & Manuweera, in press). During this investigation some physico-chemical characteristics and concentrations of micro-nutrient (e.g. nitrate) were determined in both reservoirs.

Physico-chemical parameters reported by Gunawardhana and Adikari, (1981) for different sites of the Kala Wewa are summarized in Table 7.2. There were no significant differences in the seasonal variation in total dissolved salts in the Kala Wewa, its outflow and cultivated fields. A slight increase in total dissolved salts was found during the dry season (i.e. April) or at the end of the Maha harvest. However, this increase did not show a statistically significant difference and most probably, increased salt concentration was due to high evaporation. The content of total dissolved salts did not exceed 300 ppm during this survey (Table 7.2).

The concentrations of total phosphorous reported in this study for the Kala Wewa, its outflow canal and irrigation fields were extremely high (Table 7.2). Total phosphorous in the tank's water ranged from 8.38 ppm to 15.7 ppm while it varied from 4.89 ppm to 16.77 ppm and from 0.52 ppm to 16.07 ppm in the canal and in the irrigation field respectively. These values were extremely high compared to those reported for the Parakrama Samudra (Gunatilaka, 1981).

Table 7.2 Physico-chemical characteristics of the Kala Wewa (extracted from Gunawardhana & Adikari, 1981) FD=field, OF=outflow, KB=Kala Wewa-Balalu Wewa confluence

Time	Site	Ca^{2+} (meq dm^{-3})	Mg^{2+} (meq dm^{-3})	Na^{+} (meq dm^{-3})	K^{+} (meq dm^{-3})	HCO_3^- (meq dm^{-3})	CO_3^{2-} (meq dm^{-3})	PO_4^{3-} (meq dm^{-3})	Cl^- (meq dm^{-3})	SO_4^{2-} (meq dm^{-3})
May '78	FD	0.79	0.27	1.85	0.23	--	--	0.16	--	--
Jul '78	FD	0.23	0.15	2.55	0.05	1.16	0.19	0.04	--	--
Sep '78	FD	0.18	0.11	0.26	0.39	1.09	0.00	0.04	--	--
Oct '78	OF	0.21	0.23	0.17	0.04	--	--	--	--	--
Nov '78	FD	0.25	0.18	1.30	0.11	1.44	0.29	0.06	0.74	--
Jan '79	KB	0.29	0.22	1.39	0.09	1.66	0.27	0.04	0.59	--
	OF	0.29	0.22	1.04	0.10	1.79	0.27	0.02	0.65	--
	FD	0.29	0.31	1.13	0.12	2.11	0.09	0.002	0.75	--
Mar '79	KB	0.34	0.27	1.13	0.06	1.98	0.44	0.05	0.97	0.03
	OF	0.35	0.28	1.13	0.06	2.24	0.31	0.05	1.02	0.03
	FD	0.33	0.23	1.39	0.07	2.33	0.09	0.43	1.03	1.04
Apr '79	KB	0.36	0.29	1.83	0.09	2.35	0.31	0.07	1.13	0.39
	OF	0.38	0.31	1.87	0.09	2.53	0.30	0.08	1.18	0.03
	FD	0.35	0.29	2.09	0.13	2.43	0.26	0.07	1.22	0.03
May '79	KB	0.35	0.27	1.21	0.09	2.49	0.0	0.06	1.44	0.03
	OF	0.35	0.26	1.17	0.08	2.41	0.0	0.06	0.99	0.04
Jun '79	KB	0.26	0.23	0.8	0.06	1.99	0.0	0.03	0.67	0.03
	OF	0.32	0.25	1.11	0.07	2.26	0.0	0.04	0.83	0.03
	FD	0.30	0.24	1.30	0.08	2.17	0.0	0.04	0.86	0.06
Jul '79	KB	0.19	0.14	0.48	0.04	1.24	0.0	0.03	0.41	0.08
	OF	0.21	0.15	0.59	0.09	1.40	0.0	0.03	0.53	0.01
	FD	0.18	0.08	0.83	0.05	0.98	0.0	--	0.63	0.01
Aug '79	KB	0.20	0.10	0.48	0.04	1.19	0.0	0.04	0.38	0.01
	OF	0.21	0.14	0.61	0.04	1.36	0.0	0.04	0.46	--
Sep '79	KB	0.23	0.15	0.74	0.08	1.48	--	0.04	0.72	0.10

High concentrations of phosphate had been attributed partially to dissolution of minerals found in the area (Eppawela Apatite) and the application of fertilizer. The sodium ion concentration was relatively high in the irrigation water (Kala Wewa) compared to calcium and magnesium ions according to the results reported by Gunawardhana and Adikari (1981). However, in general the concentrations of calcium and magnesium were higher in the dry zone shallow irrigation tanks. With respect to major anions, HCO_3^- concentration was higher than Cl^- and SO_4^{-2} which is characteristic for dry zone shallow irrigation tanks. This study concluded that the water of the Kala Wewa and its outflow was suitable for irrigation purposes. Chemical characteristics reported for the Kala Wewa by Gunawardhana and Adikari, (1981) cannot be readily compared with physico-chemical parameters reported by Amarasinghe *et al.*, (1983) for the same water body because of incompatibility of the parameters monitored during two studies except for bicarbonate alkalinity.

As reported by Amarasinghe *et al.*, (1983) the surface water temperature of the Kala Wewa ranged from 27.0 °C to 32.0 °C (Table 7.3). Water transparency in terms of Secchi depth varied from 65 cm to 115 cm. The range of specific conductivity was 175-300 μ°S during this study. In addition, the tank's water was alkaline (pH, 7.5-8.5) throughout the study period. A relatively high dissolved oxygen concentration was reported for both surface (7.0-10.5 mgl^{-1}) and bottom (7.5-9.5 mgl^{-1}) waters indicating high photosynthetic activity. In the case of the Rajangana Tank, the day temperature varied from 27.2 ^{0}C in December to 30.5 ^{0}C in May. The transparency of the tank (i.e. Secchi depth) changed from 60 cm to 150 cm indicating availability of a fair amount of suspended and particulate matter in the water (Table 7.4). Since the tank's water was alkaline, the total alkalinity would mainly be due to the concentration of bicarbonate ions. A relatively high bicarbonate concentration (132-196 ppm) reported for the Rajangana Tank was directly proportionate to high specific conductivity of the tank's water which ranged from 450 μ^0S to 660 μ^0S. The dissolved oxygen concentration of surface water varied from 4.80 ppm to 9.60 ppm while it varied from 4.80 ppm to 8.80 ppm in bottom water (Table 7.4).

Table 7.3 Some physico-chemical characteristics of the Kala Wewa from June 1980 to May 1981 (extracted from Amarasinghe *et al.*, 1983)

Parameter	Jun	Jul	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Temp (°C)											
Air	31.0	31.5	30.0	30.0	31.0	30.0	30.5	31.0	31.0	32.0	31.5
Water	28.0	28.8	27.0	29.0	31.0	30.0	29.0	29.5	30.0	32.0	21.0
Secchi Depth (cm)	95.0	75.0	65.0	95.0	105.0	95.0	115.0	115.0	105.0	105.0	107.0
Conductivity (μ°S)	--	225.0	200.0	200.0	300.0	175.0	180.0	195.0	200.0	250.0	225.0
Alkalinity (as $CaCO_3$, ppm)	90.0	110.0	100.0	80.0	80.0	70.0	150.0	85.0	85.0	90.0	90.0
pH	8.01	8.04	8.05	8.0	7.5	8.1	8.5	8.4	8.0	8.1	8.2
DO (mgl^{-1})											
Surface	10.1	10.5	9.1	9.5	7.0	9.0	8.9	8.7	7.9	9.0	8.9
Bottom	9.0	9.5	8.5	9.0	7.5	8.2	9.0	8.5	8.0	8.1	8.5

Table 7.4 Some Physico-chemical Characteristics of the Rajangana Tank from June 1980 to May 1981 (extracted from Amarasinghe *et al.*, 1983)

Parameter	Jun	Jul	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Temp (°C)											
Air	31.5	31.4	30.4	30.8	28.2	27.6	28.0	29.2	31.5	32.4	32.5
Water	28.5	28.4	27.8	29.0	29.8	27.2	29.1	29.4	30.2	30.4	30.5
Secchi Depth (cm)	70.0	65.0	60.0	90.0	120.0	150.0	120.0	110.0	90.0	140.0	140.0
Conductivity (μ°S)	470.0	460.0	560.0	660.0	580.0	450.0	460.0	490.0	560.0	570.0	575.0
Alkalinity (as $CaCO_3$ ppm)	170.0	195.0	190.0	160.0	132.0	150.0	145.0	170.0	160.0	170.0	180.0
pH	8.5	8.8	8.7	8.4	7.8	8.0	8.7	8.1	8.6	8.4	8.2
DO (ppm)											
Surface	9.0	9.6	7.2	8.8	5.8	4.8	7.2	7.0	8.9	8.4	6.4
Bottom	8.5	8.8	7.0	7.4	5.7	4.8	7.0	6.9	8.1	8.3	6.3

Available information on some physico-chemical characteristics of the Rajangana Tank (Table 7.4) is not sufficient to assess the overall water quality. Apparently, this information reflects similar relationships between physico-chemical characteristics and monsoonal rainfall patterns. Usually, the pH decreases slightly during the rainy season in shallow dry zone reservoirs (Silva and Davies, 1987). The lowest value reported for dissolved oxygen (4.8 ppm) in the Rajangana Tank during the study carried out by Amarasinghe *et al.*, (1983) was substantially low for a eutrophic water body since photosynthetic activity is relatively high under day light. This indicates a possibility of extremely low concentration of dissolved oxygen during early morning hours because the high phytoplankton distribution reported during this survey indicates eutrophication.

There was no significant difference in the alkalinity in the Kala Wewa as reported in these studies (Gunawardhana & Adikari, 1981; Amarasinghe *et.al.*, 1983). Comparison of specific conductivity, a fundamental water quality parameter, between two irrigation tanks reveales that the mean conductivity of the upstream reservoir (Kala Wewa) was 225 ± 37.34SD and ranged from 175 μ^{0}S to 300 μ^{0}S while conductivity in the Rajangana Tank varied from 460 μ^{0}S to 660 μ^{0}S with a mean value of 530.4 ± 67.98SD. A significantly higher conductivity found in the Rajangana Tank may be attributed to the high concentration of bicarbonate ions compared to the Kala Wewa. In general, bicarbonate equilibrium in natural waters is determined by pH and photosynthetic activity.

Physico-chemical characteristics reported by Amarasinghe *et al.*, (1983) for the Kala Wewa and the Rajangana Tank are quite comparable with those reported by the Institute of Fundamental Studies during the survey carried out on buffer intensity (Table 7.5).

Table 7.5 Physico-chemical characteristics and nutrient concentrations of the Kala Wewa-Balalu Wewa and Rajangana Tank (source: Silva & Manuweera, in print)

Parameters	Kala Wewa	Balalu Wewa	Rajangana Tank
pH	7.76	7.64	8.01
EC (μ^{0}S)	250	195	345
Alkalinity (ppm)	62.12	65.13	137.02
Nitrate (ppb)	42	53	24
Nitrite (ppb)	10.5	12	13
Chloride (ppm)	50	20	30
Calcium (ppm)	5.4	5.2	6.6
Magnesium (ppm)	37.3	9.5	11.2

Comparison of pH values of both irrigation tanks showed that the Rajangana Tank was more alkaline than the Kala Wewa. Although these two reservoirs receive water from the same source and are also located in a more or less similar watershed their basic water quality characteristics are quite different to each other.

7.5 Trends in Pollution

Information on pollution indicative water quality characteristics of the Kala Wewa and the Rajangana Tank is not sufficient at all to make precise predictions on trends in pollution of these water bodies especially with respect to intended uses other than irrigation (e.g. drinking). The available information on water quality is limited only to a few physico-chemical characteristics. A complete spectrum of water quality data (physico-chemical and bacteriological) is needed to describe and understand the status of water quality. This would provide some clues as to how it may be altered.

Determinations of thermal stratification even in shallow irrigation tanks are needed to understand the distribution of chemical and biological characteristics. Water transparency determined by means of Secchi depth is one of the meaningful indicators of water quality. Transparency is an indirect measure of concentration of suspended and particulate matter. Thus, low Secchi depth values recorded in the Kala Wewa and the Rajangana Tank indirectly indicate the sediment loading and the growth of planktonic organisms. Dissolved oxygen concentrations of these shallow irrigation tanks clearly illustrate the eutrophic status with subsequent oxygen loss and super saturation. However, it highlights the need to determine oxygen stratification and diurnal variation of dissolved oxygen.

Since time series data on water quality (physical, chemical and biological) is not available, it is quite impossible to shed light on trend analysis. Evidently, these shallow irrigation tanks are eutrophic and could be contaminated with toxic agrochemicals. Despite the fact that the tank's water is used for a variety of purposes other than irrigation (e.g. washing, bathing, drinking, wildlife propagation etc.,) the following recommendations should be taken into consideration during the implementation of a systematic water quality assessment. In conclusion two reservoirs located in the same watershed and also fed by the same inflows exhibit marked differences in basic water quality characteristics which should be studied in detail.

7.6 Recommendations

- Water quality of these shallow irrigation tanks should be examined on a seasonal and diurnal basis with respect to the water budget of the tanks (e.g. inflow, release, retention time etc.,)

- More emphasis should be placed on bacteriological characteristics and the distribution of toxic agrochemicals (pesticides) in both water and sediment (it should be noted that most of the commercially important exotic fish colonized in the reservoirs are sediment feeders and they are the main source of protein for the people living in the vicinity).

- Although potential accumulation of heavy metals in the tanks may be very low due to the lack of industrial effluent brought into them, the water should be examined for commonly found heavy metals as a baseline.

- More attention should be paid on the determination of pesticides used during the major crop seasons (i.e. Yala and Maha).

- Strategies should be implemented to provide clean drinking water facilities for the people who consume the tank's water at present.

7.7 References

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CHAPTER 8: KANDY LAKE

8.1 Introduction

It is a generally accepted phenomenon that man-made tanks in the dry zone of Sri Lanka were built mainly for irrigation or related activities. A small perennial tank popularly known as "Kandy Lake", located in the heart of Kandy, the hill capital of Sri Lanka is an ornamental water body. This small water body attracts thousands of local pilgrims and foreign tourists because of its very location adjacent to the Temple of the Sacred Tooth Relic of Lord Buddha and its paramount scenic value. Though boating is permitted, bathing, washing and fishing in the Kandy Lake are prohibited. The water from the Kandy Lake had been used to augment the drinking water supply for the city of Kandy, but at present, the Lake water is not being used for drinking. Direct disposal of waste into the Lake either by visitors or residents living around is hardly seen.

The sluice gate of the Lake is usually kept closed. However, excess water spills during rainy seasons. Limnologists would easily rank the Kandy Lake as a more or less stagnant, eutrophic water body judging only by its appearance. Blooming of nuisance algae or hypo-eutrophication has never been reported. Environmentalists and nature lovers in the area show a keen interest in this gorgeous water body and claim that the Kandy Lake is severely polluted and the aquatic life in it is smothered. The Kandy Lake has not been subjected to a regular monitoring programme with respect to water quality and aquatic life. However, a few studies have been carried out on the above said aspects (Dissanayake *et al.*, 1982; De Silva & De Silva, 1984; Dissanayake *et al.*, 1986), perhaps with a view to understanding the status of pollution and nature of the aquatic life present therein.

The importance and necessity of conserving the Kandy Lake, the only aesthetic water body in the island are well accepted. On the other hand, the susceptibility of the Kandy Lake to adverse organic pollution is also apparent. To avoid this situation, it is extremely important to implement management strategies which are appropriate for a small man-made tank located in a high density residential area. Indeed, consistent knowledge on water quality is a principal requirement for management and restoration of surface water bodies. As a preliminary effort, water quality data which is available is compiled in this chapter, as a prerequisite to launching a systematic water quality assessment programme for the Kandy Lake.

8.2 Study Site

The Kandy Lake, the only ornamental freshwater body in Sri Lanka was built by the last king of the country between 1810 and 1812 to add a panoramic view to the aesthetic value of the sacred city.

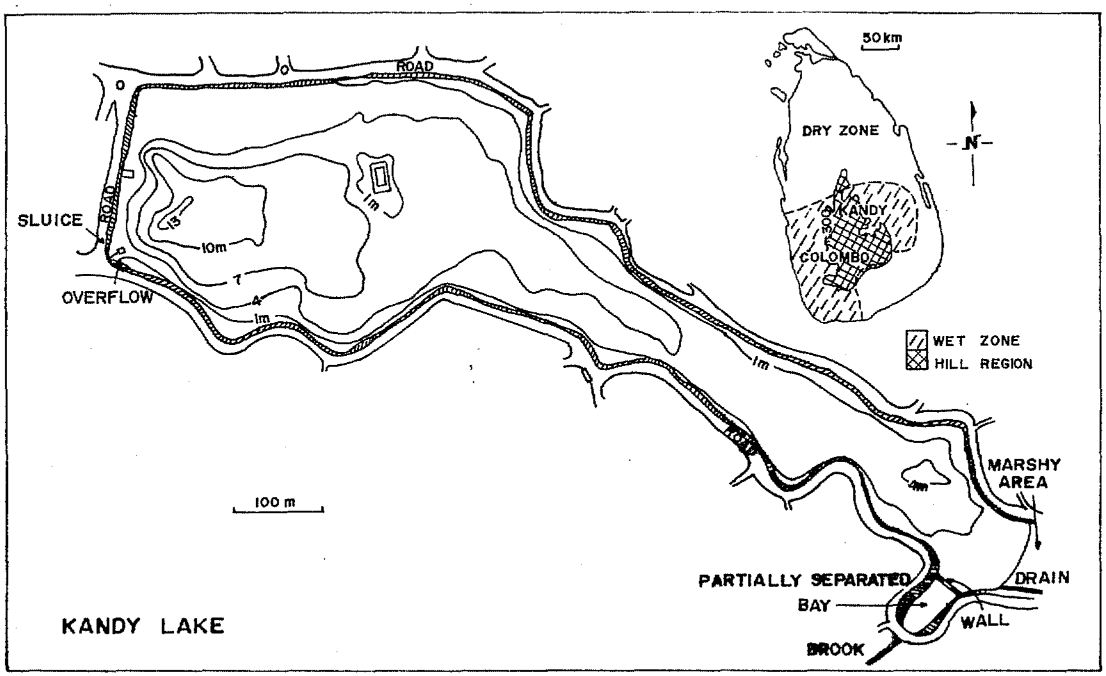

Figure 8.1 The Kandy Lake

Being located in Kandy, it lies between 7^0 18' N and 80^0 39' E at an elevation of 510 m above mean sea level. The Lake covers an area of about 18 ha within a 3.25 km circumference. A small islet located more or less at the center of the Lake enhances its scenic value. The capacity of the Lake is 8.84 MCM at its full supply level and the maximum depth is 1.8 m. A masonry weir is located at the south-west corner while the adjacent sluice is usually kept closed. The fetch of the Lake is 1.1 km and it lies along the north-west and south-west directions of the Lake while the basin has widened towards the westward segment (Fig. 8.1).

It is unique that a main road runs around the entire circumference of the embankment by means of which the Lake was formed. The Kandy Lake receives freshwater from a small brook entering it. Freshwater empties into a partially separated U- shaped bay which is located at the south-eastern corner (Fig. 8.1). This bay is separated by a concrete wall about 1.5 m high forming a sort of sediment trap while water spills over the wall into the main basin when the bay is filled. The Lake has no prominent littoral zone or shoreline. The nature of the edge of the Lake varies from place to place.

8.3 Watershed

Geologically, Kandy is located in the Highland Series which consists of charnokite-metasedimentary rocks of Precambrian origin. The predominant rock types in the watershed of the Lake are marble, quartzite, hornblende-biotite gneiss and granitoid gneiss (Almond, 1994).

The soils in this steeply dissected hilly and rolling terrain is moderately drained by reddish brown, fine textured, and medium acidic podzolic. Kandy experiences dominant rainfall during intermonsoons (IM > SW > NE). October and November (second intermonsoon) are the rainy months that receive about 40% of the annual rainfall which is about 1300 mm. The average monthly temperature of Kandy ranges approximately between 23 ^{0}C and 27.5 ^{0}C and the first three months of the year (January - March) are considered as warmer months.

The Kandy Lake is situated almost adjacent to the Temple of the Sacred Tooth Relic of Lord Buddha from its northern boundary. Being the hill capital of Sri Lanka, Kandy has become an important administrative center which shows a great urbanization with respect to land use. Homestead gardens are the predominant land use in sub-urban areas. The territory, of the world famous temple, which is commonly known as "Dalada Maligawa" is bordered by the Udawattekelle Sanctuary. The north-south boundary of the Lake faces the Kandy town. Although the Kandy Lake is only 18 ha in surface area, it drains an area of 4200 ha (Fig. 8.2).

The semi-urbanized Lake catchment shows a variety of land use. The latest topography of Kandy indicates that there are small patches of rubber and paddy. However, it is unlikely to see rubber plantations today and paddy-fields are also now abandoned and converted into

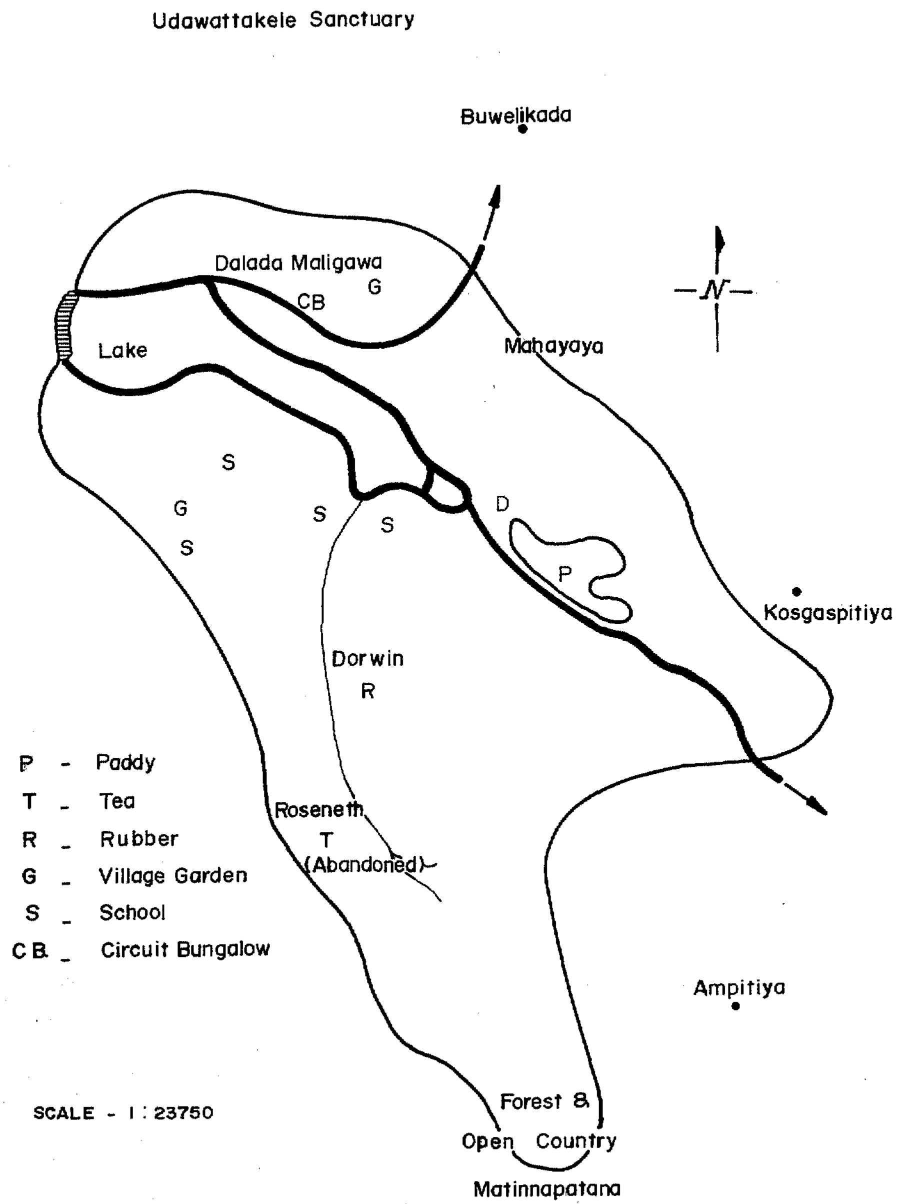

Figure 8.2 Watershed of the Kandy Lake

marshy land. One of the most striking features of this small catchment is the presence of five secondary schools in the vicinity of the Kandy Lake. In addition, several nursing homes and tourist hotels of different capacities are located in the vicinity. The southern most end of the catchment exhibits an open country land use with a small jungle where the brook arises. About 90% of the drainage basin shows high density residential land use and a few typical Kandyan home gardens are also available towards the south-west border of the drainage basin (Fig. 8.2). A marshy land resulting from abandoned paddy-fields is located at the south-eastern boundary of the Lake where there is a luxuriant growth of *Colocascea* and *Cyperus* species. A small canal, more in the nature of a drain runs parallel to the marsh, and enters the Lake from its south-eastern end. A partially separated U- shaped basin is more or less covered with rooted macrophytes with floating leaves. De Silva and De Silva (1984) counts 375 trees belonging to 51 species planted along the embankment of the Lake. Commonly found trees are *Tabibuya rosea*, *Mangifera indica*, *Plumaria noby* and *Roystomia regia*.

Direct human interference on the Kandy Lake is minimal. The semi-urbanized catchment is not industrialized. Weathering and subsequent transportation of materials eroded from the surroundings may result in siltation of the lake. However, the capacity of the lake is maintained by intermittent de-silting. A fair amount of untreated sewage and other household wastes may drain into the Lake from some houses situated in the vicinity. Dissanayake *et al.*, (1982) counts 28 such drains of varying capacity around the Lake. Mechanized boats which carry people on pleasure trips can be seen mostly during weekends. Feeding fish with rice, bread and roasted pulses and disposal of garbage into the Lake by visitors during the peak festival season are not unusual practices. Pilgrim visits are very intense during August, the time when the Esala Festival Season occurs. Human interference with the Lake may also intensify during this time. When the town becomes flooded with pilgrims, sightseers, tourists and others, the Lake may become a dumping ground for garbage.

8.4 Water Quality

Some hydrographic features, physico-chemical characteristics and aquatic flora and fauna of the Kandy Lake were first determined from January 1979 to December 1980 for a period of two consecutive years (De Silva & De Silva, 1984). In 1980, water pollution levels of the Lake were monitored to probe the impacts and influences of the urban environment on the Kandy Lake (Dissanayake, *et al.*, 1982). During this study, NO_3^-, PO_4^{-3}, Cu^{+2}, F^- and the coliform levels of the Lake water were examined and several sources of pollution were identified. Dissanayake *et al.*, (1986) further analysed 66 surface water samples of the Kandy Lake in May 1984, to examine the extent of heavy metal pollution.

Several physico-chemical characteristics and water quality parameters which could reflect organic pollution were determined in April 1986 by the National Water Supply and Drainage Board (NWSDB) on a request made by the Kandy Municipal Council. This study was repeated only for physico-chemical characteristics of surface water in May 1991. The Central

Environmental Authority (CEA) determined conductivity, dissolved oxygen, pH, turbidity, PO_4^{-3} and NO_3^- from January to October once a month in 1991. The results of the study carried out by De Silva and De Silva (1984) are summarized in Table 8.1. A comparison of water quality data of the Kandy Lake extracted from the studies carried out by NWSDB (1986, 1991) and CEA (1991) is shown in Table 8.2.

Physico-chemical characteristics of the Kandy Lake water did not show significant site-specific or time-bound variations from 1979 to 1991 (Tables 8.1 and 8.2).

Table 8.1 Water quality of the Kandy Lake (extracted from De Silva & De Silva, 1984)

Parameter	1979
pH	7.14±0.11
Conductivity (μ^0S)	153.2±2.16
Na^+ (mgl^{-1})	15.06±0.13
K^+ (mgl^{-1})	6.24.±0.21
Ca^{2+} (mgl^{-1})	21.68±0.17
Mg^{2+} (mgl^{-1})	11.12±0.26
Phenolphthalein Alkalinity ($meql^{-1}$)	0.0±0.0
Total Alkalinity ($meql^{-1}$)	0.18±0.005
Total CO_2 (mgl^{-1})	9.38±0.53
Oxygen (mgl^{-1})	7.8±0.14
Cl^- (mgl^{-1})	14.86±6.75
SO_4^{-2} (mgl^{-1})	3.86±0.27
PO_4^{-3} (μgl^{-1})	9.19±4.51
$HSiO_3$ (mgl^{-1})	3.52±0.16

The phosphate concentration in surface water fluctuated between 6.3 μgl^{-1} and 16.2 μgl^{-1} from January 1979 to December 1980. In contrast, the total phosphorous values ranged from 250 μgl^{-1} to 3250 μgl^{-1} during the study conducted by Dissanayake *et al.*, (1982). These authors found the highest PO_4^{-3} level near an outflow of a small sewage drain. Further, phosphate concentrations of surface water of the open lake ranged from 200 μgl^{-1} to 500 μgl^{-1} in April 1986 and between 140 μgl^{-1} and 580 μgl^{-1} in May 1991 as reported by the Water Supply and Drainage Board. The mean values and standard deviations computed for those results are given in Table 8.2. The CEA again reported extremely high PO_4^{-3} levels for the Kandy Lake from January to October 1991 which ranged from 730 μgl^{-1} to 2100 μgl^{-1} (Table 8.2).

Table 8.2 Comparison of water quality of the Kandy Lake

Parameter	1986 (NWSDB)	1991 (NWSDB)	1991 (CEA)
Turbidity (NTU)	13 ± 2.6	6.5 ± 1.73	8-37
pH	8.3 ± 0.74	6.97 ± 0.02	6.5-7.9
Conductivity ($\mu^{o}S$)	220 ± 34.64	225 ± 0	--
Total Alkalinity (mgl^{-1})	99.3 ± 7.50	--	--
Hardness (mgl^{-1})	90 ± 10.58	91 ± 4.76	--
Ammonium (mgl^{-1})	0.7 ± 0.14	0.09 ± 0.06	--
Nitrite (mgl^{-1})	0.19 ± 0.15	--	--
Nitrate (mgl^{-1})	7.76 ± 8.54	2.86 ± 0.25	0.28-0.62
Chloride (mgl^{-1})	19.6 ± 1.52	--	--
Sulphate (mgl^{-1})	1 ± 0.86	6.75 ± 0.5	--
Phosphate (mgl^{-1})	0.33 ± 0.18	0.32 ± 0.18	0.73-2.1
Total Iron (mgl^{-1})	0.11 ± 0.07	0.20 ± 0.09	--
Manganese (mgl^{-1})	0.05 ± 0	0 ± 0	--
Total Coliform (per 100 ml)	1000 ± 408.2	--	--
E.coli (per 100 ml)	833.3 ± 288.6	--	--
BOD_5 (mgl^{-1})	--	--	1.5-5.0

Dissanayake *et al.*, (1982) show the distribution pattern of nitrate in the Kandy Lake explicitly. The maximum nitrate level determined was 70,000 μgl^{-1} at an outfall of a urine contaminated drain. The nitrate levels in surface water of the open Lake ranged from 5,000 μgl^{-1} to 10,000 μgl^{-1} during this study indicating that high nitrogen loading has enhanced the nitrate concentration in the open Lake. However, levels of nitrate reported for the open water was within the permissible level as recommended by the World Health Organization (WHO, 1978). The nitrate values reported by NWSDB in 1986 and 1991 and by CEA in 1991 were compared with reported concentrations in previous work by Dissanayake *et al.*, (1982). The values obtained by NWSDB in 1986 were markedly high compared to those determined by CEA in 1991 (Table 8.2). Limnologically speaking, the Kandy Lake exhibits extremely hyper-eutrophic condition according to the already available information on micro-nutrients (e.g. P & N compounds).

The coliform counts of the effluents draining into the Lake varied from 34 to 1800 per 100 ml. Accordingly the contamination of open water with faecal coliform was extremely high (50-500 per 100 ml) and the water was by no means suitable for drinking in an unpurified state. Drinking water should have less than 1 coliform count per 100 ml (EPA, 1972). In addition, attempts have been made to correlate the coliform counts to the pH (Dissanayake *et al.*, 1982). The NWSDB (unpublished data) reports that the total coliform counts ranges from 500 to 1000 per 100 ml. Similarly, extremely high values were reported for *E.coli* in the same report (Table 8.2) indicating that even open water in the Kandy Lake has been subjected to severe organic pollution resulting from human waste. It is interesting to note, that the levels of BOD_5 of the Kandy Lake ranged from 1.5 mgl^{-1} to 5.0 mgl^{-1} during the study carried out by CEA (1991) indicating no sever organic pollution with respect to intended uses (i.e. aesthetic value and recreation). The ambient level of BOD_5 for surface water ranges from 0.5 mgl^{-1} to 50 mgl^{-1} (van der Leeden *et al.*, 1990)

Table 8.3 Mean values (±SD) of certain heavy metals (ppm) in the Kandy Lake (extracted from Dissanayake *et al*, 1986)

Element	Mean	Range
Total Fe	0.14±0.09	0.01-0.42
Fe^{++}	0.035±0.04	0.00-0.25
Cd	0.08±0.07	0.01-0.19
Pb	0.15±0.13	0.01-0.39
V	15.6±6.78	6 - 32

The mean concentrations (±SD) of certain heavy metals reported for the Kandy Lake by Dissanayake *et al.*, (1986) are summarized in Table 8.3. The mean concentration of total iron in the Lake water was 140 ± 90SD ppb, a value which does not exceed the WHO recommendation for drinking water. High concentrations of Fe^{++} (> 50 ppb) has been reported from the offshore areas of the Lake. The concentration of vanadium ions ranged from 6 ppb to 32 ppb (average vanadium concentration in natural freshwater is about 2 ppb). Dissanayake *et al.*, (1986) attributes high concentration of vanadium to the discharge of vanadium contaminated effluent. The mean concentrations of Pb and Cd in the Lake water were 150 ppb and 80 ppb respectively. When compared to the WHO recommended values of 100 ppb for Pb and 10 ppb for Cd, these concentrations are extremely high if the Lake water is used as a supplementary source for drinking. High concentrations of Pb and Cd in the Kandy Lake have been attributed to vehicular emissions and industrial effluent respectively (Dissanayake *et al.*, 1986)

8.5 Trends in pollution

Apparently, the Kandy Lake has not been subjected to severe land based organic pollution. However, the occurrence of nuisance algal blooms or sudden mortality of fish has never been reported. The physico-chemical characteristics and the phosphate concentration reported by De Silva and De Silva (1984) for a period of two consecutive years fell well within the range for a tropical shallow man-made tank with a rapid turn over rate. A severe organic pollution due to a variety of human activities has been reported (Dissanayake *et al.*, 1982). They have reported an irritating nature of the lake water when it contacts the skin. This situation has been attributed to heavy algal growth that they observed in certain regions. Certainly, the water quality of this water body should exhibit properties which are characteristic for a shallow tropical tank which experiences wet weather. The Lake water mixes with rapid inflows draining the hilly terrain resulting in a marked increase in turbidity during the rainy season. It indicates that the watershed of the Kandy Lake is subjected to severe soil erosion which is very common in the hill country of Sri Lanka.

Evidently, physico-chemical characteristics of the Kandy Lake did not show significant site-specific or time-bound variations over the last 10 years. Slight seasonal changes may be attributed to an intermonsoon dominant rainfall pattern. For example, changes in pH may reflect either freshwater inflow or photosynthetic activity. Increase in turbidity is always bound with sediment loading into the water body during the rainy season.

With respect to micro-nutrients (e.g. P & N compounds) it is very unlikely to perform a meaningful trend analysis since the available data is inconsistent. However, maximum values reported for the phosphorous and nitrogen compounds by Dissanayake *et al.*, (1982) are unbelievably high for a tropical water body which shows least deterioration with respect to its scenic value. In the case of organic pollution, most of the studies reported extremely high coliform counts for the Lake indicating faecal contamination which is common for any surface water body receiving water draining unplanned human settlements. One study reported the acceptable BOD_5 values for surface water which contradicts faecal contamination. The concentrations of certain heavy metals (i.e. Pb, Cd, V) reported by Dissanayake *et al.*, (1986) by performing one cross-sectional analysis are extremely high for a tropical water body which receives no significant industrial effluent on a regular basis. However, they attributed high concentrations of heavy metals to industrial pollution and emissions from motor vehicles. Since these justifications are not strong enough, it is extremely important to carry out further analysis on trace metals before using the already available information as baseline data.

In conclusion, the already available information on water quality of the Kandy Lake shows that it has been subjected to severe organic pollution and contaminated with heavy metals such as Pb, Cd and V. However, it needs further justification by carrying out similar analysis on a regular basis.

8.6 Recommendations

- A survey should be conducted to identify the major effluent outfalls to the Kandy Lake together with the Mid Canal.

- A systematic monitoring programme for water quality assessment of the Kandy

Lake should be carried out with special reference to micro-nutrients, heavy metals and bacteriological parameters.

- Water quality analysis should be conducted by NWSDB in collaboration with the Institute of Fundamental Studies.

- The awareness building up programmes for the public should be launched to educate the people in the vicinity on waste disposal, water related health problems etc.,

- Wastes from schools, hospitals and hotels should be treated before discharge into the Lake.

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CHAPTER 9: MEDA ELA

9.1 Introduction

A majority of natural streams that flows via densely populated and intensively urbanized areas have now been converted into artificial canals in many countries. Meda Ela (Mid Canal), which flows through the Kandy city, the hill capital of Sri Lanka is an example of a modified stream of this nature. In general, natural streams are modified mainly for infrastructure development and flood control when they flow through urbanized areas. Since these water ways are subjected to severe human activities and subsequent pollution, these stream cum canal systems are considered as effluent canals in many instances. Being located in urbanized and densely populated townships, these canals play an important role with respect to human health in the vicinity because of deteriorated water quality and unusual biotic communities.

Effluent canals are excellent breeding habitats for vectors like mosquitoes. Therefore prevalence of vector-borne diseases such as dengue, filariasis, malaria etc., is common in areas adjacent to effluent canals. Usually modified streams of this nature receive a variety of organic and inorganic effluent releasing from garages, service stations, hospitals, hotels, small factories etc., while they are flowing through business centers. There is also a good possibility to drain agrochemicals (pesticides and fertilizer) from their own watersheds since most of these watersheds are subjected to intense land use. Exhausts from motor vehicles also contain a fair amount of trace metals such as Pb in congested cities which eventually reach water ways. Accordingly modified streams are recipients of a variety of effluent and subsequently they carry a fair amount of toxic substances which may cause either acute or chronic health problems.

For example if an effluent canal carrying a substantial amount of nitrates and trace metals has unprotected wells along its course there is a great potential to contaminate the well water with these substances resulting in a grave public health risk. In the case of the Mid Canal in Kandy, the scenic value of the hill capital has been lost to a great extent due to this highly polluted effluent canal. Therefore, it is undeniable that streams flowing through major cities would affect the economy of the city in several ways.

9.2 Study Site

The Meda Ela (Mid Canal), is considered to be the most polluted running water system in the Kandy district. It originates as the overflow of the Kandy Lake and flows about 8 km, bordering the southern boundary of the Kandy city and merges with the Mahaweli River at Getambe (Fig. 9.1). The canal is essentially a natural stream whose headwater is confined to south-eastern foot hills of the Kandy Lake watershed . This stream has been modified by constructing concrete banks and paving the bed with cement at certain places. However, a

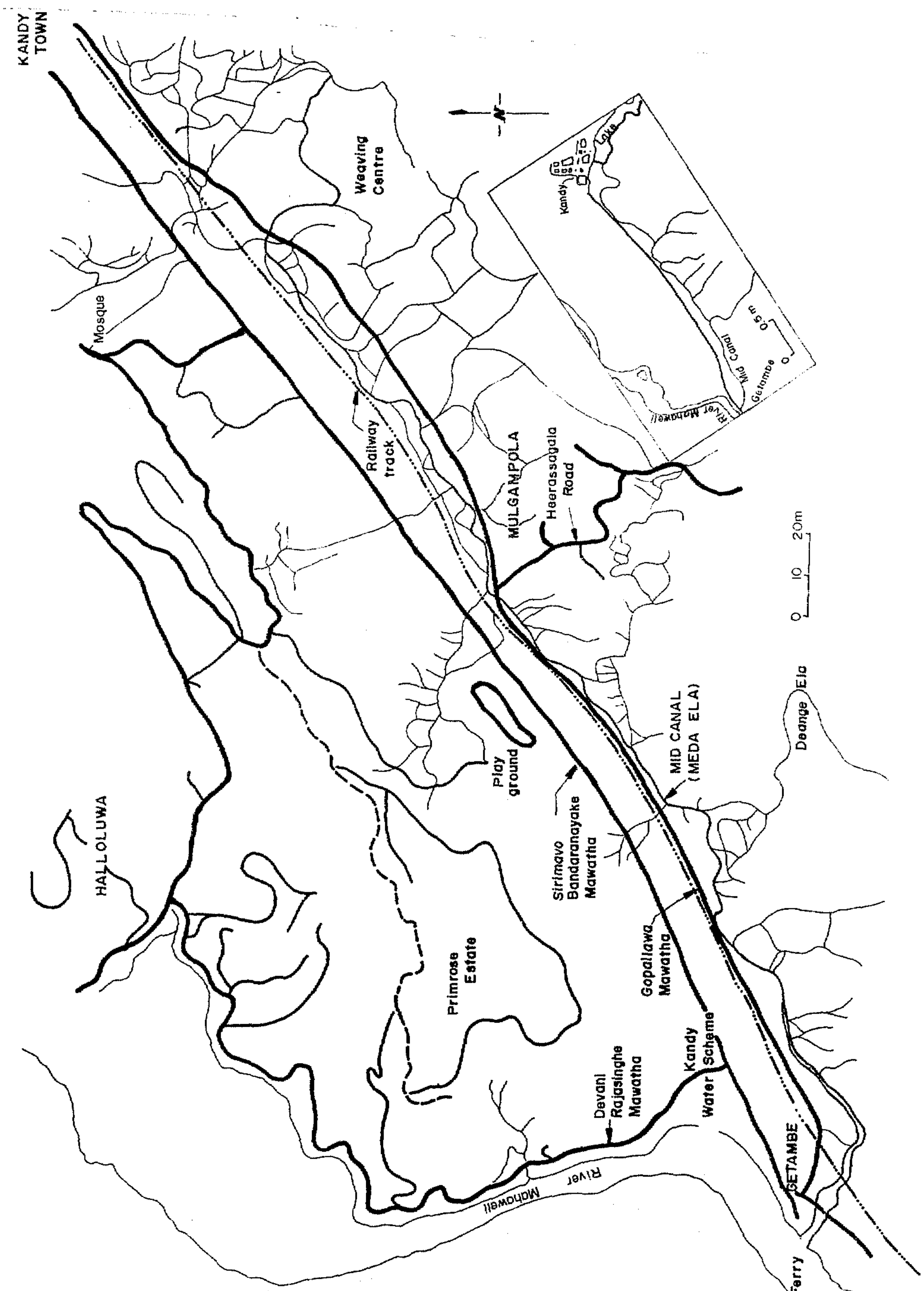

Figure 9.1 The Meda Ela and its surroundings

major part of the canal still flows as a natural course though it is commonly known as the Mid Canal.

The banks of the Mid Canal have been reinforced by cement walls from the point of its origin (i.e. lake sluice) to about 100 m downstream. The rocky bottom of this stretch is not paved. The canal flows underground from this point upto the Kandy railway station. The Mid Canal then merges out and connects with a network of waste water canals draining various parts of the Kandy city. The banks of certain parts of the Mid Canal have also been modified by cement walls from the railway station up to the Mulgampola area. Beyond Mulgampola, up to Getambe the canal flows along a more or less natural course.

The length of the canal is about eight km and the width varies from 10 m to 15 m along its course from the lake sluice to the confluence with the Mahaweli River at Getambe. Geologically, the water course of the canal lies on highly weathered quartzite, crystalline marble and a variety of gneiss. For most of its course, the canal flows through a crystalline limestone bed. The alluvial bed of the stream in the unpaved areas is heavily silted and the total amount of bed sediment is substantially higher towards the confluence of the canal with the main river at Getambe.

9.3 Watershed

Topographically, the terrain of the watershed of the Mid Canal consists of rolling hills and valleys. A large number of perennial and seasonal tributaries originating in the hilly terrain empties into the main stream on either side of the canal.

Apparently, the canal system is subjected to severe human interferences and aquatic life therein is unknown. The canal receives waste directly from tourist hotels, schools, hospitals, markets, slaughter houses, garages, laundries and service stations. In addition, human excreta and garbage are also dumped into the canal by the people living along the water course. There are many houses with bucket-type latrines, on either side of the canal. The excreta of these houses are directly disposed into the canal. Some people living in these houses utilize unprotected well water. The canal water is used only for washing by laundry men. Besides, *Tubifex* is collected in the canal to feed aquarium fish. Since the stream is considered as an effluent canal by people living in the vicinity, it is used as a dumping ground for both solid and liquid wastes.

9.4 Water Quality

The colour of water in the Mid Canal is generally brown during the dry weather and looks severely polluted even to the naked eye. The discharge of the canal during the rainy season is substantial and perhaps water carries a heavy loading of particulate and suspended sediment. As a result the water becomes brownish yellow (murky) during most of the rainy

Table 9.1 Nutrient levels, pH and conductivity of the Mid Canal and several adjacent dugout wells (extracted from Weerasooriya *et al.*, 1982)

Location	NO_3^- mgl^{-1}	NH_4-N mgl^{-1}	PO_4^{-3} t.P (ppm)	PO_4^{-3} d.P (ppm)	pH	Conductivity μ^oS
1	0.40			0.25	7.50	
2	0.30			0.25	7.00	
3	0.40			0.10	7.00	
4	0.25			0.10	7.10	
5	1.48			0.10	7.30	
6	0.23			0.10	7.30	
7	1.23			<0.05	7.20	
8	0.95			<0.05	7.10	
9	0.13			<0.05	7.20	
10	0.25			0.15	7.00	
11*	0.50			<0.05	6.01	
12*				<0.05	7.30	
13				0.15	7.50	
14	0.90			0.10	7.20	
15	0.90			<0.05	6.70	
16	1.73			0.10	6.70	
17	0.03			<0.05	6.30	
18	0.53			<0.05	6.60	
19	1.05			<0.05	7.00	
20	1.33			<0.05	6.00	
21	0.75			<0.05	7.00	
22	1.05			<0.05	6.50	
23	0.55			<0.05	7.00	
24*	7.28	0.03	0.35		6.30	280
25	3.36	0.32	4.10		6.70	270
26	1.30		0.50		6.30	130

* well water

Table 9.1 contd.,

Location	NO_3^- mgl^{-1}	NH_4^-N mgl^{-1}	PO_4^{-3} t.P (ppm)	PO_4^{-3} d.P (ppm)	pH	Conductivity μ^oS
27	1.66	0.31	4.50		6.70	390
28'	0.68	0.01	6.30		6.00	100
29'	3.76		6.25		6.00	240
30	1.26	0.48	3.80		6.50	480
31	3.76	0.10	1.55		6.50	350
32	1.50		4.70		6.90	520
33'	2.46	0.01	0.50		6.35	380
34	2.40	0.17	6.00		6.75	380
35	1.60	0.23	6.55		6.55	480
36'	4.30	0.01	0.25		5.60	200
37		4.00	15.00		6.30	780
38	1.80	0.40	2.00		6.90	250
39		0.20	3.00			
40	3.56		4.05		6.60	460
41						
42	1.00	0.07	2.30		6.50	430
43	0.46	0.40	1.80		6.40	250
44	1.16	0.50	0.15		6.55	520
45	2.10				6.75	300

' Well water

season. It has also been reported as bad smelling in several instances and the canal has no visual attractiveness.

The Mid Canal which is considered as an effluent canal has been hardly subjected to a systematic water quality assessment though it is a potential threat to the people living in the vicinity. The general appearance of the stream is environmentally unacceptable. Two studies have reported on some physico-chemical parameters (e.g. pH, EC, NO_3-N, NH_4-N and d-P and t-P) and the presence of several heavy metals (i.e. Pb, Cd, V and Fe) in the canal and water collected from several dugout wells adjacent to the canal (Weerasooriya, *et al.*, 1982; Dissanayake *et al.*, 1987). The data reported by these workers is summarized in Tables 9.1 and 9.2.

The specific conductivity of the canal water was high in some cases being as much as 780 μ^0S, indicating the presence of high concentrations of dissolved ionic species. It is of interest to note that five samples obtained from drinking water wells, near the canal had a conductivity range of 100-300 μ^0S. These values did not differ significantly from that of the canal samples, indicating a possible migration of ionic species into the wells through the permeable alluvium. The pH of the canal water varied from slightly alkaline to acidic. The lowest pH reported in these studies was 5.6 while the highest was 7.5. The pH levels of the canal did not reflect a polluted condition with respect to acidic effluent and are acceptable for stream waters in hilly areas.

The nitrate concentration of the Mid Canal varied between 0.2 ppm and 3.56 ppm. The nitrate loading to the canal was attributed to biogenic waste such as human and animal excreta which accounts for a large percentage of the total nitrogen loading. However, extremely high nitrate concentrations were not reflected in the analytical data as some of the nitrogen species could have been incorporated in organic forms, particularly in the bottom sediment according to the authors (Weerasooriya, *et al.*, 1982). Further, the heterotrophic potential of microbes such as denitrifying bacteria could release more nitrogen into the aqueous phase. The canal itself is stone paved only in part, and receives human and animal excreta along almost its entire length, from pit latrines and a large number of slum dwellers who use the canal for open defecation.

A maximum nitrate value of 7.28 ppm was reported for the adjacent well water (Table 9.1). This figure may appear to be within a safe limit for drinking water. Although a large amount of human excreta is discharged into the canal, a complete nitrification does not occur within the system. Therefore, it appears that most of the nitrogen loaded into the canal is retained as organic complexes which can eventually be converted to nitrate. NH_4-N levels reported in this study (i.e. 0.01-0.50 mgl^{-1}) fall within the acceptable range for running water systems. However, an extremely high value of 4.0 mgl^{-1} reported by Dissanayake, *et al.*, (1987) could be considered erroneous (Table 9.1).

The total phosphorous level of the canal ranged from 0.15 ppm to 15 ppm. The upper level was extremely high and unacceptable for stream water. In general, the total phosphorous levels were higher than that of nitrates in the canal. Extremely high phosphorous concentration in this stretch could be attributed to the massive input of phosphorous from human and animal excreta and organic garbage. Anoxic stagnant waters with no epilithic algae may have extremely high concentration of phosphates.

In the case of heavy metals, the total Pb levels in the canal water varied between 20 ppb and 850 ppb while the average was 268 ppb (Table 9.2). The Pb levels ranged from 20 ppb to 640 ppb in some wells having a Pb concentration higher than the upper limit (100 ppb), recommended by the World Health Organization (WHO, 1978).

Table 9.2 Concentration of some heavy metals of the Mid Canal and several adjacent dugout wells (extracted from Dissanayake *et al.*, 1987)

Location	Total Pb mgl^{-1}	Total Cd mgl^{-1}	Total V μgl^{-1}	Total Fe mgl^{-1}	Fe^{+2} mgl^{-1}
1	0.12	0.02	9.9	3.3	3.0
2	0.10	0.03	8.3	3.3	3.0
3	0.11	0.23	8.5	3.3	3.0
4'	0.04	0.01	7.3	0.5	0.2
5	0.22	0.06	10.3	3.1	3.0
6	0.18	0.03	13.7	3.4	2.6
7	0.48	0.07	16.0	2.8	2.5
8	0.31	0.04	13.5	3.0	2.7
9	0.38	0.12	14.0	3.2	2.8
10	0.02	0.02	12.0	1.3	1.0
11'	0.02	0.01	7.0	0.4	0.3
12	0.60	0.16	12.0	3.1	2.8
13	0.64	0.12	17.0	3.4	3.4
14	0.52	0.16	8.5	3.75	3.2
15'	0.12	0.01	6.0	3.0	2.8
16	0.52	0.18	9.0	4.1	3.0
17	0.12	0.10	12.0	4.0	3.2
18	0.14	0.01	11.0	4.5	4.44
19	0.10	0.02	10.0	2.3	2.1
20	0.76	0.24	15.2	5.0	4.9
21	0.79	0.26	35.4	4.8	4.5
22	0.85	0.26	17.5	4.3	4.2
23	0.17	0.24	15.0	5.0	2.9
24	0.76	0.25	14.5	5.6	5.2
25	0.79	0.22	45.1	4.5	4.2
26	0.73	0.31	27.8	6.0	5.4
27	0.50	0.25	21.0	4.3	3.6
28	0.38	0.11	15.5	7.5	5.3
29'	0.09	0.01	5.5	1.4	0.2

Table 9.2 contd.,

Location	Total Pb mgl^{-1}	Total Cd mgl^{-1}	Total V μgl^{-1}	Total Fe mgl^{-1}	Fe^{+2} mgl^{-1}
30*	0.13	0.01	4.5	0.3	0.3
31	0.64	0.18	10.0	0.1	0.1
32	0.05	0.01	7.5	0.1	0.1
33*	0.11	0.10	2.5	0.6	0.4
34*	0.15	0.01	2.0	0.2	0.2
35	0.10	0.10	30.5	5.2	4.9
36*	0.06	0.01	4.0	0.4	01
37*	0.04	0.03	5.5	2.3	0.9
38	0.06	0.15	6.5	0.5	0.5
39	0.09	0.25	29.0	5.1	5.1
40*	0.64	0.01	10.5	0.3	0.2
41*	0.02	0.10	9.0	0.3	0.2
42	0.04	0.09	40.0	6.5	5.9
43	0.60	0.12	25.5	0.9	0.6
44	0.23	0.18	22.5	5.5	4.8
45*	0.06	0.01	7.0	0.8	0.8
46*	0.03	0.01	9.5	2.8	0.7
47	0.02	0.26	17.5	3.2	3.0
48	0.70	0.10	41.0	8.5	7.3
49	0.06	0.10	32.0	6.9	6.4
50	0.05	0.01	14.0	2.1	2.0

* Dug wells

Being situated close to the Colombo-Kandy main road Pb emanations from the automobile exhausts could be a contributory factor for high Pb levels in the canal and adjacent wells according to the authors (Dissanayake *et al.*, 1987). Municipal wastes are often a major contributor to Pb pollution and the Mid Canal receives much of the municipal wastes of the Kandy city. In addition, accumulation of Pb in the Mid Canal could be due to the waste petroleum products from garages and service stations (Dissanayake *et al.*, 1987). The total Cd concentration of the canal water ranged from 10 ppb to 310 ppb with 138 ppb as an average value. The well water contained 10 ppb of Cd and this value is the maximum permissible limit as recommended by the WHO. The total V concentration in the canal water ranged from 6.5 ppb to 45 ppb with an average of 18 ppb. In the case of well water, the total V concentration ranged from 2 ppb to 10.5 ppb. Possible sources of V are the waste fluids from batik manufacturing factories, hospitals, sewage sludge, petroleum products and decaying plants (Dissanayake, *et al.*, 1987). However, the relative abundance of V in potable water ranges from 0.1 ppb to 100 ppb (van der Leeden, 1990). Total Fe level of the canal water ranged from 0.1 ppm to 8.5 ppm with an average of 4 ppm. The well water had a total Fe level ranging from 0.12 ppm to 2.8 ppm. Four of the 13 well water samples had a total Fe level exceeding the maximum permissible value of 1000 ppb as recommended by the WHO.

Evidently, the already available data indicates a significant input of the above mentioned metal ions into the Mid Canal. The presence of metal ions in high concentrations in the nearby dugout wells bordered by residual soil indicates a possible migration of metal ions from the canal through permeable soil cover (Dissanayake *et al.*, 1987).

9.5 Trends in Pollution

Apparently the Mid Canal is considered to be one of the most polluted water ways in the country. However, the values with respect to acidity and specific conductivity of the canal water reported in previous studies indicates non pollution conditions. In other words the Mid Canal does not show acidification or secondary salination. It is assumed that the canal itself carries an enormous amount of nitrogenous substances resulting from human and animal excreta. In spite of this, the nitrate and ammonium concentrations were found to be low indicating perhaps the existence of nitrogen in other forms. This is supported by the high concentration of nitrate found in adjacent dugout wells. However, investigation on the speciation of nitrogen (i.e. NO_2^-, NO_3^-, NH_4^+) in an effluent canal should be given more emphasis. Since there is a possibility of migration of nitrate through the alluvial layer of the floodplain of the Mid Canal, the levels of nitrate in dugout wells may increase over time. Therefore, it is clear that there is a potential danger of groundwater pollution by nitrate. Extremely high concentration of the total phosphorous cannot be readily explained by analyzing a single set of data. Perhaps the site-specific variation in the phosphate concentration may be attributed to different effluents discharged into the canal. Heavy loading of phosphorous may promote algal blooms downstream (e.g. Polgolla impoundment and Victoria Reservoir).

The high concentration of Pb found in the canal water (20-850 ppb) is a positive sign of lead pollution perhaps due to Pb emanation by automobile exhausts and waste petroleum products generated from service stations and garages. This situation may be further aggravated over time due to increasing automobile transportation and use of leaded gasoline. The cadmium concentration in the canal (10-310 ppb) was well above the permissible level of Cd in drinking water (i.e. 10 ppb) as specified by the WHO.

The concentration of V in the canal water (6.5-45 ppb) and dugout wells (2-10.5) were well above the concentration reported for natural waters. In addition, the total Fe levels in the canal (0.1-8.5 ppm) and in the adjacent dugout wells (0.12-2.8 ppm) were also higher than the maximum permissible values recommended by the WHO.

Apparently, the data available on several heavy metals in the Mid Canal indicates a heavy loading of metal ions into the canal. These metal ions may eventually pollute the groundwater sources used for drinking by the people living in the area. However, it is very unlikely to reach an affirmative conclusion on the pollution status of a surface water body by carrying out one cross-sectional analysis specially with respect to trace elements. On the other hand a recent study carried out on the pollution status of the Meda Ela during storm and dry weather conditions showed high organic pollution but the concentrations of certain trace metals were not that high as reported by earlier workers (Silva & Poddalgoda, unpublished).

9.6 Recommendations

- A survey should be conducted to identify the major effluent outfalls to the Mid Canal and ways and means of human waste disposal into the canal.

- Regular assessment of water quality of the Mid Canal and selected adjacent dugout wells should be carried out highlighting physico-chemical parameters, micro-nutrients, heavy metals and bacteriological properties.

- Attempts should be made to identify the locality of pollutants in relation to the type of effluents draining into the canal.

- Awareness building up programmes should be launched to educate people in the vicinity on appropriate methods of waste disposal and use of clean water.

9.7 References

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CHAPTER 10: HAMILTON CANAL

10.1 Introduction

Hamilton Canal, is an artificial water course which connects two major brackish water systems viz., the Kelani Estuary and the Negombo Lagoon in the western province of Sri Lanka. The British ex-colonizers constructed the Hamilton Canal along the western boundary of the Muthurajawela Marsh connecting the Kelani Estuary and the Negombo Lagoon. The water course of the Hamilton Canal is influenced by the tidal flows of both the Negombo Lagoon and the Kelani Estuary. The canal was constructed with a view to flushing out the salt water from the Muthurajawela Marsh and consequently, to restore it for rice cultivation. On the contrary, this artificial water course resulted in more salt intrusion into the marsh. The Hamilton Canal, which is now considered as part of the Negombo Lagoon-Muthurajawela Wetland System, serves a variety of purposes (e.g. washing, bathing, recreation, transport, fishing, etc.,) for people living in the vicinity. Human association with the Hamilton Canal was known since its construction to date.

It was proposed to examine the water quality of the Hamilton Canal in detail under the proposed IFS/NAREPP-IRG project on quality assessment of surface water in Sri Lanka because the Hamilton Canal is used for general purposes such as washing, bathing etc. Since the Hamilton Canal is the connecting water course of the Kelani Estuary and the Negombo Lagoon, water quality of the canal would certainly reflect the pollution status of the Negombo Lagoon-Muthurajawela Wetland System which has now being subjected to a series of development and conservation activities. Therefore, in this chapter, an attempt is made to compile and analyse the already available data on water quality of the Hamilton Canal.

10.2 Study Site

The Hamilton Canal is 14.7 km long, 1.6-1.8 m wide and its depth ranges between 1.50 m and 1.75 m. It runs parallel to the west coast from the north to the south along the Muthurajawela Marsh and connects the Negombo Lagoon at its southern tip, 1 km north-west where the Ja Ela empties into the Negombo Lagoon (Fig. 10.1). The confluence of the Hamilton Canal and the Kelani Estuary is located about 250 m south of the bridge where the Wattala-Hekitta road crosses the canal. The canal is influenced by tidal flows of the Negombo Lagoon and the Kelani Estuary and receives water from parallel canals which have been constructed across the Muthurajawela Marsh connecting the Hamilton Canal and the Old Dutch Canal. There are 28 cross canals in the marsh which run parallel to each other (GCEC, 1991a). Because of this hydrological network, the cross canals drain the entire Muthurajawela Marsh and flow into either the Kelani Estuary or the Negombo Lagoon via the Hamilton Canal depending on the tidal or flood flows. The flow direction is always seaward at both the lagoon end and the river confluence during low tides and vice versa during the high tide. The fluctuation in current velocity during high and low tides indicates that the Kelani Estuary has a greater influence on the water movement in the canal (Dassanayake, 1993). This is because the tidal height in the Negombo Lagoon is minimum at its southern tip. However, the freshwater flow of the Kelani River and the tidal height in the estuary may be relatively high at the confluence of the Kelani River at the canal mouth.

10.3 Watershed

General climatic features of the area are influenced by the South Asian monsoon, the adjacent oceanic environment and partly by the topography of the mainland. The rainfall in the area is directly influenced by the south-west monsoon but the watershed of the Hamilton Canal receives a considerable amount of rain throughout the year (2000-2500 mm) except during a few months. Long term rainfall data indicates that this area receives the highest rainfall during the second intermonsoon (i.e. October-November) which is characteristic for the northern part of the wet zone. The highest mean daily air temperature occurs during March-April and the lowest during January and February. The highest day temperature generally occurs during early afternoon and the lowest during early morning. The daily air temperature ranges between 19 ^{0}C and 35 ^{0}C and the highest daily temperature fluctuation occurs from December to February.

Geologic history of this area is more or less similar to that of the Muthurajawela Marsh (Fairbridge, 1961; Cooray, 1984; Katupotha, 1988 and Dissanayake, 1990). Soil types occurring in the adjacent marsh varies from poorly drained organic soil (bog soil) to poorly drained mineral alluvial types. In addition, soils that are rich in sulphur and soluble salts are referred to as acid sulphate or potentially acid sulphate soils. The predominant soil type of the marsh is bog soil which contains pyrites to the extent that it is classified as potential acid sulphate soil. However, the soils of the western boundary of the marsh along the canal are more saline because of the tidal influence. Physico-chemical characteristics of the bog soil are reported in the Environmental Profile of Muthurajawela and Negombo Lagoon (GCEC, 1991a).

The northern part of the Hamilton Canal, where the Dandugam Oya and the Ja Ela empty into the lagoon, is in fact a swampy brackish water tidal flat. This area receives freshwater from rainfall and occasionally due to high floods of the Kalu Oya and the Kelani Ganga in addition to the freshwater flow from the Ja Ela and the Dandugam Oya.

When the marsh receives freshwater, excess water flows through the cross canals into the Hamilton Canal due to elevational differences. Sea water enters the lagoon and penetrates towards the tidal delta. A substantial dilution may occur at the mixing phase due to the continuous flow of freshwater from the Dandugam Oya and the Ja Ela. This situation is more or less similar at both ends of the canal. This is due to tidal floods from the estuary and the downstream freshwater flow of the Kelani Ganga. The seaward flow predominates during low tide at both ends and vice versa during high tide (Dassanayake, 1993). The magnitude of tidal fluctuation and current velocity are much higher at the southern end of the canal compared to the northern end.

Since the Hamilton Canal links the Kelani Estuary and the Negombo Lagoon, the water budget and the flow dynamics of the canal are directly affected by these two water bodies. At its northern end, the canal is influenced mainly by the Ja Ela and the Dandugam Oya or in other words by the flow of the Attanagalu Oya in addition to the tidal flow of the Negombo Lagoon. Tidal water from the Kelani Estuary and the downstream flow of the Kelani River are the major determinants of water movement and hydrodynamics of the canal at the southern end. The Old Dutch Canal which runs parallel to the Hamilton Canal along the eastern boundary of the Muthurajawela Marsh may have minimal influence on hydrology of the Hamilton Canal. Occasional inflows may occur during exceptional floods from the Kalu Oya which has its own catchment of 61 km^2 and connects with the Old Dutch Canal near the village called Mabole. Presumably, the excess freshwater of the Attanagalu Oya and Kalu Oya watersheds empties into the sea mainly via the inlet of the lagoon and for a lesser extent through the Hamilton Canal into the Kelani Estuary respectively. However, it has been estimated that the inflow of sea water through the Kelani Estuary into the Hamilton Canal is negligible. The Hamilton Canal also receives some water from an area of 0.5 km^2 located to the west of it. The flow dynamics and water movement in the canal are also determined by other factors such as cross canals.

The tidal amplitude at the north end of the Hamilton Canal is more or less similar to that at the sea. However, the tidal amplitude at the south end of the canal is only one third of the tide at the sea and almost in counter phase with it. The tide alone causes oscillating flows in the canal with a discharge of 1.5 - 4.5 m^3sec^{-1} and it increases up to 13-15 m^3sec^{-1} during the rainy season when water drains into the canal from the marsh. A characteristic discharge capacity appears to be 12.5 m^3sec^{-1} at both ends with a total of 25 m^3sec^{-1}. The tidal volume at the southern end of the canal is around 45000 m^3sec^{-1} and the tidal water penetrates over a distance of 1.5 to 4.5 km into the canal. The tide is thus suppressed in a greater part of the canal under the prevailing conditions.

The Muthurajawela Marsh, now consists of previously cultivated paddy-fields, a network of canals, and scattered ponds. The substrate characteristics of the marsh along the Hamilton Canal hardly permit the growth of a diverse plant community. Instead, it can be seen that grasses and sedges belonging to the Family *Praceae* and Family, *Cyparacae* and cattails belonging to the Family *Typhaceae*.

In addition, a variety of aquatic plants are found in different aquatic habitats indicating an enrichment of these habitats by organic and inorganic nutrients. For example, stretches with low salinity in the Hamilton Canal have been invaded by a dense growth of an introduced noxious fern, *Salvinia molsta*. The cover of emergent plants in the canal is generally low, perhaps due to the fact that most of the canal banks having been stabilized by masonry. The canal's water is reported to be very rich in planktonic algae (GCEC, 1991a).

Of the vascular plants found in the Muthurajawela Marsh, none could be qualified as endemic or confined only to this particular wetland (GCEC, 1991a). An endemic palm (*Phoenix zeylanica*) and two endemic sedges (*Eleocharis lankana* and *Fimbristylis zeylanica*) which are rare in the marsh but occur elsewhere have also been reported.

For centuries, the Muthurajawela Marsh has been subjected to a variety of human activities. At the beginning, this marsh had been utilized for rice cultivation. The construction of the Old Dutch Canal and the Hamilton Canal causes sea water infiltration resulting in failure of agricultural crop cultivation. Ongoing human activities may have direct or indirect impacts on the present status of water quality of the Hamilton Canal. The infrastructure development and land reclamation for new settlements along the fringes of the marsh, cutting of fuel wood, incidental fires, peat exploitation and dumping of waste into the canal are among the ongoing man-made activities.

The surroundings of the Hamilton Canal is densely populated and the total population of the Negombo Lagoon and the Muthurajawela Marsh area was about 0.2 million in 1990 (GCEC, 1991a,b). There is no sewage treatment facility in this area and a majority of people use either pit latrines situated away from the houses or raised squatting platforms. Therefore, the risk of contaminating water in the Hamilton Canal with human faeces is very high since the canal is a part of the Negombo Lagoon-Muthurajawela Wetland System.

Privately owned home gardens in the vicinity of the canal consist of agricultural products such as coconut, banana, jak, breadfruit, vegetables and other fruit types. Application of pesticides such as quinolphos is common, to protect the cultivation of different types of leafy plants and popularly known vegetables such as "Keerai" grown in the marsh proper. Some residents rear swine in pens with wooden floors and poultry in cages.

10.4 Water Quality

The water quality of the Hamilton Canal was unknown until the recent past (GCEC, 1991a; Dassanayake, 1993). The basic physico-chemical characteristics and several pollution indicative water quality parameters of the Hamilton Canal at a site close to the village called Uswetakeiyawa have been reported in the Environmental Profile of the Muthurajawela and Negombo Lagoon (GCEC, 1991a). Similar parameters with a few exceptions were examined at seven sites along the canal (Fig. 10. 1) at eight occasions from June 1991 to February 1992 in relation to some climatic features (Dassanayake, 1993).

It has been reported that an equilibrium exists between the inflow of freshwater and the intrusion of sea water in the Muthurajawela Marsh and the Hamilton Canal (GCEC, 1991a). However, there is a tendency for this balance to change if the sea level rises. In general, the acidic water emerging from the Muthurajawela Marsh proper may eventually reach the Hamilton Canal through cross canals since the Hamilton Canal is located at the lowest

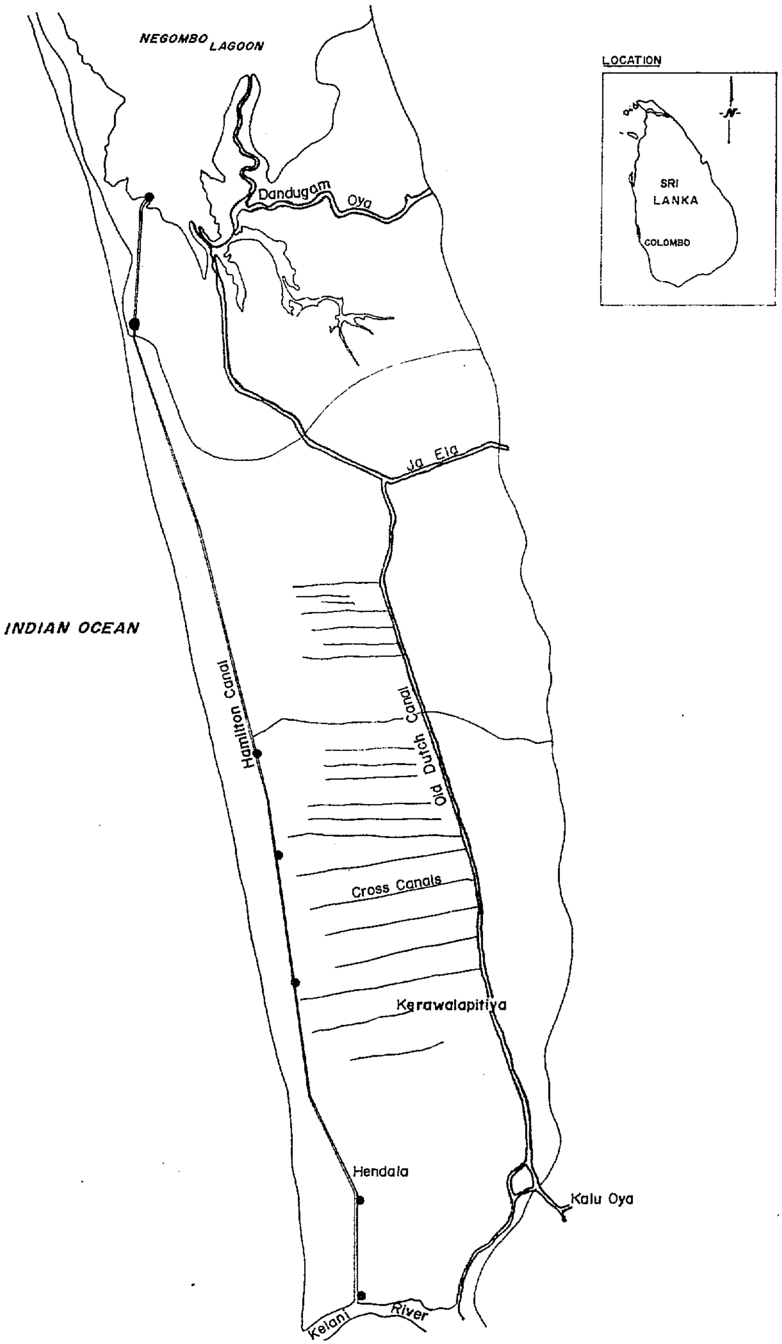

Figure 10.1 The location of the Hamilton Canal with respect to the Kelani Estuary and the Negombo Lagoon

elevation. The westward flowing water may be contaminated further with other organic and inorganic chemicals resulting from the aforesaid man-made activities. High organic pollution is evident in the vicinity of dense human settlements in the surroundings of the Hamilton Canal. High levels of chromium have also been recorded in the surface water in the vicinity where solid waste is dumped.

There is some evidence that the Hamilton Canal may be subjected to organic and inorganic pollution. The general physico-chemical characteristics and several pollution indicative water quality parameters of the canal water have been reported so far only in two studies (GCEC, 1991a; Dassanayake, 1993). The GCEC (1991) reports values for sixteen water quality parameters for one site of the Hamilton Canal near Uswetakeiyawa, 7 km north of the south end of the canal. This study was carried out in October 1990 and the sampling strategies and analytical methods were not mentioned in the report. A systematic survey on water quality of the Hamilton Canal was conducted for a period of eight months from July 1992 to February 1993 (Dassanayake, 1993). Attempts have been made during this study to examine the effects of tidal fluctuation (low tide vs high tide) and rainfall (i.e. rainy and dry season) on water quality of the canal. The methods used during this survey are more acceptable except for a few cases (e.g. suspended solid, nitrate). The results of these two studies are analyzed and discussed in the following sections with a view to identifying the status of water quality and trends in pollution in relation to the proposed ambient water quality standards for Sri Lankan surface water.

The spatial and temporal variation in temperature in surface water of the Hamilton Canal indicated that the canal water was not subjected to thermal pollution resulting from a discharge of thermal effluent. The surface water temperature ranged from 26.1 °C to 35.5 °C with a mean value of 31.2 °C (Dassanayake, 1993). The minimum value may change if the survey was conducted in order to examine the diurnal pattern in temperature variation.

The salinity of the Hamilton Canal (Dassanayake, 1993) fell within the range which is acceptable for coastal water bodies influenced by both sea water and freshwater (Tables 10.1, 10.2). The range of salinity (0.00-33.5 ppt) observed by Dassanayake (1993) has an overall mean of 11.9 ppt when the daily means are compared (Table 10.1). However, the spatial and temporal distribution in salinity was extremely wide except for a few occasions during the study conducted by Dassanayake (1993). Higher salinities could be seen at both the lagoon and the river ends compared to the middle portion of the canal (Table 10.2). This situation was more prominent during the dry season rather than the rainy season because the influence of freshwater inflows through the rivers and the marsh proper was minimum during the dry season.

The influence of the tidal floods of the lagoon and the river and the freshwater overflow of the marsh on the Hamilton Canal was clearly shown by the distribution pattern of pH along the canal (Table 10. 2). The overall pH ranged from 6.04 to 8.23 during the study

Table 10.1 Comparison of some water quality parameters reported by the GCEC (1991a) and Dassanayake (1993) for the Hamilton Canal

Parameter	GCEC 1991			Dassanayake 1993			
	Mean	Min	Max	Mean	±SD	Min	Max
pH		7.0	8.3	6.97	±0.10	6.81	7.12
Turbidity (NTU)		2.0	8.0	14.24	±7.54	9.5	30.8
Conductivity ($\mu^{o}S$)	4.0						
Salinity (ppt)	14.2			11.97	±3.40	9.7	18.8
Total coliform (per 100 ml)			2300				
Faecal coliform	450	70	3000	2824	±4062	283	11807
BOD_3 (ppm)		.8	30	2.67	±0.57	1.8	3.5
Phosphate (ppm)		0.04	1.02	0.014	±3.06	0.011	0.02
Zinc (ppm)	0.01						
Chromium (ppm)	<0.01			0.006	±0.007	0	0.018
Copper (ppm)	0.01						
Ammonia (ppm)	<1.0			0.088	±0.041	0.059	0.177
Nitrate (ppm)	0.11			0.062	±25.19	0.020	0.091
Nitrite (ppm)	0.001			0.002	±0.41	0.002	0.003
Cadmium (ppm)	0.02						
DO (ppm)				4.74	±0.85	3.5	6.0

carried out by Dassanayake (1993). Generally, the canal water was more acidic in the middle part than in the seaward extremes perhaps, indicating the influenced of acid sulfate soil in the marsh.

Since turbidity is a function of suspended solid, spatial and temporal distribution of both parameters in the canal was more or less similar. During the study carried out by Dassanayake (1993), the turbidity varied from 3.5 NTU to 60 NTU with a mean value of 13.1±11.9SD NTU and the turbidity was generally higher at the lagoon end. The distribution of suspended solid in the canal was more or less similar to that of the turbidity (Table 10.2). The higher contents of suspended solid found at the lagoon end has been attributed to the enormous amount of sediment loading into the lagoon through the Dandugam Oya and the Ja Ela. Further, the amount of suspended solid in the canal water may also increase due to local disturbances in the canal resulting from boating and navigation. The values of suspended solid recorded during the study conducted by Dassanayake (1993) were higher than those recorded for natural waters in some cases (Table 10.2) and beyond the upper limit of the proposed ambient water quality standard for Sri Lanka.

Table 10.2 Physical, chemical and bacteriological characteristics (mean ± SD and range) of the water in the Hamilton Canal (extracted from Dassanayake, 1993)

Parameter	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7
Temperature (^{0}C)	30.6±2.74 (26.5-34.5)	30.9±2.19 (28.0-34.5)	31.13±1.94 (29.5-34.5)	31.5±2.12 (29.5-35.0)	31.5±1.94 (29.5-34.5)	31.5±2.32 (29.0-35)	31.6±1.78 (29.0-34.0)
Salinity (ppt)	10.6±11.9 (0-31.5)	9.8±10.6 (0-30.0)	10.3±9.3 (0-25)	10.3±11.7 (0-24.5)	9.7±9.5 (0-25)	14.3±9.4 (0.5-32.5)	18.8±13.8 (0.5-33.5)
Turbidity (NTU)	14.7±17.3 (3.5-58.0)	11.6±12.7 (5.0-45)	13.2±7.4 (5.2-31.0)	10.2±3.5 (5.8-18)	9.5±1.4 (6.2-11)	9.7±4.8 (4.8-20.0)	30.8±19.5 (8.5-60)
Suspended Solid (ppm)	20.6±25.6 (1.9-85.1)	14.7±9.4 (5.5-32.6)	20.1±13.9 (4.6-41.9)	19.2±10.8 (6.8-39)	14.5±10.0 (5.8-36.6)	12.6±8.6 (3.3-33.3)	46.6±33.1 (3.9-114.2)
pH	7.06±0.73 6.13-8.23)	7.04±0.68 (6.10-8.18	6.94±0.62 (6.1-7.85)	6.93±0.54 (6.15-7.68)	6.81±0.46 (6.04-7.52)	6.9±0.39 (6.32-7.31)	7.12±0.57 (6.24-7.96)
NH_3-N (ppm)	0.177±0.293 (0.031-0.950)	0.1±0.075 (0.016-0.265)	0.067±0.032 (0.018-0.124)	0.071±0.037 (0.026-0.144)	0.059±0.021 (0.024-0.089)	0.078±0.057 (0.023-0.210)	0.068±0.04 (0.0132-0.143)
NO_3-N (ppb)	91.9±152.9 (6.8-492.2)	20.9±11.1 (6.0-42.4)	81.0±88.5 (1.07-265.8)	40.7±45.3 (1.1-150.3)	80.4±83.6 (1.0-250.1)	54.1±43.5 (5.52-127.6)	65.1±125.0 (7.72-393.5)
NO_2-N (ppb)	2.2±1.5 (0-4.6)	2.8±1.6 (1-5.4)	2.4±2.3 (0-5.8)	3.0±2.5 (0-7.4)	2.4±2.9 (0-8.7)	2.1±1.8 (0-5.2)	3.2±4.7 (0-14.6)
PO_4^{-3} (ppb)	20.7±13.1 (3.2-45.4)	12.7±7.9 (4.3-28.6)	11.9±6.9 (1.6-21.1)	12.2±8.0 (2.6-25.3)	14.6±10.9 (0.9-30.3)	15.3±12.8 (1.0-42.0)	13.0±9.4 (1.7-32.8)
BOD_3 (ppm)	3.2±1.4 (1.4-5.0)	2.6±0.9 (1.4-4.4)	2.8±1.3 (1.4-5.2)	2.2±1.0 (1.0-3.6)	2.6±1.5 (1.0-4.6)	1.8±0.7 (1.0-3.2)	3.5±2.6 (1.0-8.4)
DO (ppm)	6.0±0.6 (5.0-7.0)	5.4±1.7 (2.1-8.3)	4.9±2.4 (1.3-8.2)	5.0±2.6 (0.9-7.9)	3.9±1.9 (1.0-6.0)	3.5±1.6 (1.2-5.6)	4.5±1.5 (1.8-6.5)
Faecal coliform (cells/100 ml)	2740±4723 (40-15000)	11807±23060 (20-72000)	2043±3427 (130-11000)	699±475 (120-1300)	1724±3054 (120-9700)	473±388 80-1300)	283±283 (40-700)
Chromium (ppb)	0.006±0.01 (0-0.018)	0.007±0.009 (0.0-0.018)	0.006±0.01 (0-0.018)	0.005±0.005 (0-0.04)	0.003±0.006 (0-0.011)	0.012±0.01 (0-0.018)	0.005±0.005 (0-0.011)
Canal Distance (km)	0	1.4	4.5	6.3	7.8	9.55	14.7

However, the ambient value for artificial coastal canals whose water is being used mainly for washing and bathing is not given elsewhere.

Spatial and temporal distribution of NH_3-N in the Hamilton Canal was reported by Dassanayake (1993). Although there was a slight increase in NH_3-N towards the river end of the canal compared to other sites, the reported values did not exceed the ambient values proposed for Sri Lankan surface water (Table 10.2). Slight increases in NH_3-N towards the river end in some instances have been attributed to direct dumping of human waste into the canal and intrusion of water polluted with faecal matter from the estuary.

The spatial distribution of nitrate in the Hamilton Canal did not show any specific pattern (Dassanayake, 1993). The nitrate varied from 1.01 ppb to 492 ppb with a mean value of 58.8 ± 93.2SD ppb (Table 10.2). Significantly higher nitrate concentrations were determined specially during the rainy months. The concentration of nitrite recorded for the Hamilton Canal was within the ambient range for surface water (Table 10.2) and their temporal patterns were more or less similar to that of the nitrate.

With respect to the dissolved phosphorous (d-P) in the Hamilton Canal, reported values by Dassanayake (1993) were within the acceptable levels for surface water (Table 10.2). Significantly higher concentrations of d-P were determined for the rainy months than for dry months. However, the d-P concentrations did not show a particular distribution pattern in the canal. This information is not sufficient to arrive at a definite conclusion that there is a significantly higher concentration of d-P during the rainy months in the Hamilton Canal.

The biochemical oxygen demand (BOD_3) at 30 ^{0}C in the Hamilton Canal varied between 1.0 and 8.4 mgO_2l^{-1} with a mean value of 2.49 ± 1.25 mgO_2l^{-1} (Dassanayake, 1993). The author computed a higher mean value for rainy months which was statistically significant. It can be seen that relatively higher values of BOD_3 occurred towards the river end and the lagoon end (Table 10.2). BOD_3 values exceeded the proposed ambient water quality standard for Sri Lankan inland waters (i.e. 0.4 mgO_2l^{-1}) in several instances (Table 10.2).

The dissolved oxygen (DO) concentration reported for the Hamilton Canal by Dassanayake (1993) did not reflect that the canal water was subjected to well mixing or to active photosynthesis during the study period. The dissolved oxygen values varied between 0.9 mgl^{-1} and 8.3 mgl^{-1} with a mean of 4.2 ± 1.92SD mgl^{-1} during the study period. Accordingly, the water in the canal shows a more or less stagnant nature.

The faecal coliform counts of the canal water varied from 20 to 72000 cells per 100 ml with a mean value of 2930 ± 10356SD cells per 100 ml. Extremely low counts were found during some occasions except for sampling sites towards the river end. In addition, the faecal coliform counts at the sites towards the river end always exceeded the Sri Lankan standard for ambient water quality for inland surface water but did not exceed the proposed value for coastal waters (Table 10.2). Dassanayake (1993), attributes significantly higher faecal coliform counts of the canal water during the rainy months to high a mortality of coliform bacteria caused by high salinity stress.

Relatively high concentrations of chlorophyll-a reported in the canal is evident for a luxuriant growth of planktonic algae. The reported chlorophyll-a values indicate that the planktonic algal growth is more predominant in the middle part of the canal during dry months. Of the heavy metals, only the chromium ion concentrations in the canal water have been determined during the rainy months by Dassanayake (1993).

The concentrations of the chromium ions varied from non-detectable level to 18 μgl^{-1} with a mean of $6.5 \pm 6.3SD$ μgl^{-1} but did not show a significant spatial distribution. It is important to examine speciation and spatial distribution of chromium in the Hamilton Canal since the tannery effluent is discharged into the Kelani Estuary directly and chemical behaviour of the canal water is influenced by the Negombo Lagoon and the Kelani Estuary and vice versa.

Dassanayake (1993) regresses independent and dependent variables with respect to water quality parameters and found significantly positive correlations for pH and salinity and dissolved phosphorous and ammonia and significantly negative correlations for salinity and BOD_5 and salinity and faecal coliform counts. Significantly positive correlations between salinity and pH is well understood under natural conditions. Simultaneous increases in dissolved phosphorous and ammonia may be attributed to nutrient enrichment and subsequent decomposition. Since high salinities are less favourable for the growth of bacteria already adapted to other environments, faecal coliform may decrease with increasing salinity. Similarly when salinity increases the growth of heterotrophic bacteria adapted for freshwater would decrease resulting in low biochemical oxygen demand.

10. 5 Trends in Pollution

The water quality of the Hamilton Canal is influenced by three natural watersheds (i.e. Attanagalu Oya, Kelani River and Kalu Oya) as well as the overflow of the Muthurajawela Marsh. Since this water passage is a link between two coastal water bodies, the amount of water in the canal is influenced by the tidal rhythm. Therefore, the tidal fluctuation would certainly be one of the determinants of the physical and chemical properties of the canal's water (i.e. pH, salinity, DO, etc.,). These parameters directly or indirectly affect the physiological activities of micro-organisms (e.g. bacteria, planktonic algae). In addition, the tidal floods and the freshwater overflow of the marsh may transport organic, or toxic pollutants originating in different parts of the catchment land use or in the Muthurajawela Marsh itself.

Apparently, some physico-chemical and pollution indicative water quality parameters of the canal's water could be significantly correlated with the rainfall pattern of the area, because rainwater drains a substantial amount of toxic constituents. The input of freshwater will also decrease the concentration of chemical constituents due to dilution. However, the distribution pattern of inorganic chemicals or toxic contaminants in the canal is determined by the volume of water and hydrodynamics of the canal which is influenced by associated water bodies. Human activities may also play a fairly important role especially with respect to organic pollution in the canal.

In general, water quality of the Hamilton Canal fluctuates between two extremes conditions (i.e. fresh and brackish). These changes are directly related to the annual rainfall and therefore shows a rhythmic fluctuation. The rhythmic fluctuation of fresh and brackish water in the canal should be studied for a complete climatic cycle in order to obtain more information. Organic pollution reported in the canal may be due to contamination by human waste. The Hamilton Canal is not yet subjected to heavy metal pollution according to the available information. However, a possibility of pollution by organic residues (i.e. pesticides) cannot be overlooked.

The Hamilton Canal is susceptible to non-point source pollution due to ongoing development activities in the Muthurajawela Marsh. The canal water is not utilized for human consumption except for washing and bathing because of its euryhaline nature. This water course should not be considered as a conservable ecosystem for natural biota. However, monitoring the status of water quality and related physical characteristics and chemical and biological constituents, would be of importance because the water quality of the Hamilton Canal reflects the water quality of the Muthurajawela Marsh, and the southern tip of the Negombo Lagoon and the Kelani Estuary upto a certain extent.

10.6 Recommendations

- Water Quality of the Hamilton Canal should be monitored on a regular basis at three points (i.e. north end, south end and middle of the canal).

- More emphasis should be placed on the analysis of micro-nutrients, heavy metals and bacteriological properties.

- A mathematical model should be derived for salinity intrusion along the canal using systematically collected data.

- Water quality of the Hamilton Canal should be compared regularly with the Kelani Estuary and the southern part of the Negombo Lagoon.

- Baseline information on trace elements including Pb, Hg, Mn and Cr should be collected to be used for environmental impact assessments since this area is targeted for future development.

10.7 References

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CHAPTER 11: HIKKADUWA MARINE SANCTUARY

11.1 Introduction

Coral reefs are unique in ecosystem formation because, coral polyps construct the largest natural living organisms cohesively associated with a non-living substrate. A reef ecosystem is an assemblage of many types of plants and animals whose life show a complex type of mutualism or commensalism. To construct the calcite skeleton, coral polyps utilize calcium ions available in sea water which forms the life supporting media. In addition, coral reefs are important breeding and nursery grounds and form a refuge for many marine organisms including reef fish. Thus, they form a unique spectrum of biodiversity while reef fishes are economically important in capture fishery and in the ornamental fish trade. The intricate form of a reef, its extreme variety of shape and colour and diversity of the polyps and reef fish living, make coral reefs to attract eco-tourists, nature lovers, researchers etc.

Coral reefs occupy approximately 0.1 % of the earth's surface and provide critical habitats for a large number of species which have become exclusively dependent on the reef for their existences. It has been reported that about 3000 species representing all types of marine organisms exist in these diverse ecosystems.

The coral reefs found along the coastal line of Sri Lanka also play an important role with respect to natural beauty, biodiversity and hence the national economy. However, the ecology of these precious virgin ecosystems, are hardly known. A majority of the coral reefs found in Sri Lanka are fringing reefs. The Hikkaduwa Reef is an excellent example of a fringing reef. Sand stone or beach rock reefs and boulder reefs are also found along the coastline of Sri Lanka (Rajasuriya, 1991).

The equilibrium of coral reef ecosystems is principally determined by clean flowing water, biological recycling, retention time of nutrients and light penetration capacity. These aspects are directly or indirectly regulated by the water quality (e.g. turbidity, micro-nutrients, organic matter, heavy metals etc.,) of the reef environment. Therefore, changes in water quality resulting from anthropogenic activities may deteriorate the steady state equilibrium of these delicate ecosystems. In this chapter, emphasis is paid on identifying the potential man induced effects on water quality that can positively affect the Hikkaduwa coral ecosystem and its productivity.

11.2 Study site

The Ambalangoda-Hikkaduwa Rocky Islets have been declared as a marine sanctuary under the Fauna and Flora Protection Ordinance (CCD,1990). The Hikkaduwa reef, one of the finest coral formations in Sri Lanka is located in the west coast near the Hikkaduwa town, about 100 km south of Colombo. This small township is primarily a fishing village and gradually became a popular tourist resort because of its clean and wide beaches, coral reefs and colourful reef fishes. The reef area lies within a stretch of between 84 and 113 km from Colombo. This stretch has been declared as an area from which no sand, stone, or any other substance should be removed under the Crown Land Ordinance (Sections 15 and 60). Geographically, this area extends from Balapitimodera, where the Madu Ganga empties into the sea to the river mouth of the Gin Ganga at Gintota. Hikkaduwa and two adjacent areas (i.e. Seenigama and Telwatte) have been subjected to coral removal in large quantities to feed the lime kilns located on either side of the Colombo-Galle main road. The Hikkaduwa Reef is intensively utilized for subsistence, income generation and recreation. This site is hardly subjected to any detailed ecological study although many people have written on its economic importance, natural beauty, resource potential, etc.. At present, the Hikkaduwa Reef has been identified as an endangered ecosystem due to a variety of human activities. The remaining coral reef (primarily fringing reefs) occurs in the sanctuary between the Coral Garden Hotel to the south and the Fishery Harbour groyne to the north. The reef extends for about 130 m, seaward before developing into soft substrate at 7-10 m depth. The reef is separated from the shore by a 3-4 m deep channel to the north. In the south, it abuts directly onto the shore. Spur and grove formations are found on the seaward face of the reef particularly in the southern section. There is generally no marked coral zonation. A series of sand stone reefs are also found beyond the rocky islets at about 20 m. The topography, geology, and climate as well as the land use of the Hikkaduwa area are well described in the Coastal Environmental Profile of Hikkaduwa, (Coastal Resources Management Project 1993).

11.3 Watershed

Evidently, the coral reefs found along the coast line of Sri Lanka are continuously being destroyed and degraded. A survey conducted by the National Aquatic Resources Agency (NARA) in 1987 has shown that there are only 25% of live coral cover in the Hikkaduwa Reef. In addition, it has been estimated that the area of coral reefs has declined by 40-50% at Hikkaduwa between 1960 and 1993 (Sadacharan, 1991). Long time residents of Hikkaduwa are also of the opinion that certain parts of the reef have been completely destroyed. The principal reason for destruction is coral mining. However, it has been observed that the occurrence of coral mining has decreased markedly in this area during the recent past. Instead, a large number of glass bottom boats used for tourism have now become the major culprit of coral reef destruction. These boats operate without following proper regulations and often hit the corals, while anchors are dropped on the corals. In addition, corals can also be damaged due to walking on them and by waste gasoline pollution by the boats.

Most fringing reefs are subjected to heavy fishing pressure. The fishing activities on them include angling, gill-netting, use of set nets (trammel nets) to catch spring lobsters and the collection of live marine organisms for the aquarium industry. Since the Hikkaduwa Reef is a sanctuary, fishing is completely prohibited. The coral reefs in the southern coast are also severely affected by tourist activities. Coral mining to produce lime for construction purposes has wiped out some of the near shore reefs in the Akurala area.

Improper management of the watershed will increase sedimentation which may affect the reef due to changes in underwater light penetration. Water turbidity may also increase due to direct or indirect discharge of waste water from hotels onto the beach. There is evidence that the Coral Garden Hotel and other large hotels directly discharge primarily treated waste water into the reef area. Indirect discharge of waste water from smaller hotels and other establishments can also be seen. In addition, a brackish water canal enters the reef area.

It has been reported that faecal pollution is a major problem at Hikkaduwa. The dumping of waste oil some distance away from the coast and dumping of waste oil by fishing boats even within the bay enclosed by the reef is apparent in this area. It is common that untreated waste water from hotels is discharged into the bay enclosed by the coral reef at Hikkaduwa.

11.4 Water Quality

It has been assumed that the water quality of the Hikkaduwa Marine Sanctuary and its surroundings is variable but it is relatively good at times. Stagnant areas resulting from poor flushing is visible mainly in the dry season. In contrast, relatively high sedimentation and poor transparency have been observed during the wet season which may be attributed to increased discharges from two freshwater outlets. Another problem manifested by the poor water quality is that on several occasions, swimmers in the sanctuary have been coated with oil released from boats. However, neither physico-chemical characteristics nor microbiological properties of the Hikkaduwa Marine Sanctuary has hitherto been determined.

A survey was commenced in September 1993 by the National Aquatic Resources Agency to examine the water quality of the Hikkaduwa Marine Sanctuary and its environment. The results of this survey are not yet available to incorporate in this volume and to make a meaningful diagnosis on the status of water quality or to make predictions on trends in water pollution.

11.5 Recommendations

- Water quality of the Hikkaduwa Marine Sanctuary should be studied at least for two annual climatic cycles in a stratified manner, highlighting

    * physico-chemical characteristics
    * organic matter and heavy metals
    * bacteriological parameters

- Major effluent and waste water outfalls emptying into the bay should be identified and analyzed on a regular basis for their chemical and biological constituents

- Emphasis should also be placed on identifying ways and means of sediment (particulate and suspended) loading into the bay in order to regulate the sediment loading.

- Investigations should be carried out to determine whether the physico-chemical characteristics of offshore water may have a significant impact on water quality of the reef ecosystem.

- Strict rules and regulations should be imposed on operation of glass bottom boats and activities of tourists whom they transport.

11.6 References

CCD, 1990. **Coastal Zone Management Plan Sri Lanka.** Coast Conservation Department, Colombo, Sri Lanka.

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Rajasuriya, A., 1991. **Location and condition of reefs along Sri Lanka's coast.** In: Proceedings of the Seminar on Causes of Coastal Erosion in Sri Lanka. 203-210 pp.

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CHAPTER 12 : CONCLUSIONS

It is understood that there has been a steady depletion in clean water resources on the earth. A progressive deterioration in water quality has led to the emergence of water-borne diseases and acute or chronic health problems. However, it is not absolutely clear whether the water resources in Sri Lanka are polluted, threatened by pollutants or chronically contaminated. In general, when water related issues are addressed, haphazard investigations are carried out in a scattered manner and the results are not properly diagnosed. Furthermore, these scattered data which are already available through various project based or research oriented studies or client based analysis are not systematic enough to be subjected to a meaningful trend analysis. This has been clearly observed during the compilation of the available water quality data of twelve water bodies in Sri Lanka which are assumed to be hot-spots of the country.

This exercise indicates that scattered data on water quality of some water bodies is available from the late sixties to date (e.g. water quality data of the Kelani River at the Ambatale Water Intake). The literature survey on selected water bodies also indicates that the Kelani River has been subjected to the highest number of studies at various levels. On the other hand, the water quality of some other selected sites have been poorly examined (e.g. Koggala Lagoon) or not reported as yet (e.g. Hikkaduwa Marine Sanctuary). The diagnosis of available data clearly reveals that the surface water resources in Sri Lanka have not been subjected to a systematic monitoring programme.

Although the Kelani River has been examined at the Ambatale Water Intake for several parameters since 1968 to date, the results are not available for meaningful use. Whatever data available is important as baseline or historical information. It should be considered that such scientific information available on any aspect is a national asset. Therefore, there should be a mechanism to acquire the available information, and for documentation and dissemination.

The main reason for the assessment of water quality of the aquatic environment has been the traditional need to verify whether the present water quality is suitable for aquatic life or for intended use. Regular monitoring has also involved the determination of trends in the quality of the aquatic environment and how it affects the release of biogenic or technogenic effluent. More recently, water quality monitoring has been undertaken to estimate nutrients or pollutant fluxes discharged into rivers, lakes and oceans or access to international boundaries. Monitoring of background quality of the aquatic environment is also now widely carried out since it provides baseline data for impact assessment exercises associated with developement activities.

It is evident that the quality of Sri Lankan surface water has been affected mainly by irrigation related watershed management, deforestation, crop cultivation and direct discharge of untreated industrial effluent and human waste. Water related problems in the country have already been identified as eutrophication, salination, faecal contamination, siltation and contamination with organic residues and trace metals. Unfortunately the magnitude of deterioration of water quality and the subsequent effects on biotic and abiotic components of aquatic ecosystems and its direct or indirect effects on human health are hitherto unknown to any degree of precision. It is further supported by the diagnosis of available data of twelve selected surface water bodies. The selected water bodies represent all types of aquatic ecosystems (e.g. streams and rivers, basin estuaries or lagoons, riverine estuaries, coastal reef, irrigation and aesthetic tanks, hydroelectric reservoirs, and artificial canals). In addition, these water bodies represent all types of geographic locations (i.e. highland, lowland, and coastal) and two major climatic regions (i.e. dry zone and wet zone). The quality of water is, in essence an important determinant of the aquatic life that has evolved for millions of years therein and vice versa. Therefore, the natural surface water bodies are also included in this spectrum where endemic species have been reported (e.g. rivers, streams, estuaries, lagoons and coral reefs). Finally, the water bodies selected for this study represent the type of human requirement and the specific types of intended use (e.g. aesthetic lakes, irrigation tanks, hydropower reservoirs).

The question however, that arises is whether the available information on water quality of these surface water bodies reflects the present status and the future trends of water quality. If not, what ingredients are lacking in this information. Apparently some studies have attempted to examine upstream salinity intrusion (e.g. Kelani River studies at Ambatale) or the secondary salination of irrigation reservoirs. Attempts have also been made to discover the status of heavy metals in the Kelani River within a stretch that the river receives industrial effluent and also where the river intercepts the most urbanized segment of the island. Faecal contamination of the Kelani Estuary has received great attention. The inflows of the Kotmale Reservoir have been examined for concentrations of micro-nutrients. The Negombo Lagoon has been subjected to a detailed investigation of silt loading and sedimentation. Apparently, most of the studies carried out on the water quality of the selected water bodies had clear objectives. To achieve these objectives studies should be conducted in a proper scientific manner which involves appropriate experimental design, systematic sampling, accurate analysis, relevant treatment of data, meaningful presentation and interpretation of results. If these schemes are not followed step-wise, the data produced through water quality assessment programmes is just numbers and the time spent for such programmes is an utter waste.

The available information at present, on water quality (physical, chemical and biological properties) of the selected sites were collected as far as possible. The published, reported and even unpublished information were carefully examined and attempts were made to identify the following:

- Objectives of the study or survey
- Experimental design
- Methodologies used
- Analysis and presentation

- Interpretation of results

It has been clearly shown that most of the studies and surveys conducted so far on the selected sites have focussed on examining the present status of water quality either in terms of physical and chemical constituents or biological properties. Some studies have attempted to examine the impact of human activities on water quality. However, with respect to impact assessment exercises or survey plans, these studies are poorly designed. For example, when the impacts of effluent discharge on certain aspects of water quality were examined, the rhythm of effluent discharge into the water body and the pattern of their distribution were not properly monitored. Therefore, it is evident that most of the studies have been carried out without a properly designed scientific approach. Field techniques employed and laboratory methods used in analysis were poorly stated in most cases. It is extremely important to mention the sampling techniques during quality assessment programmes (how, when, where and for what purpose water samples were collected).

In the case of analytical methods, it has been just mentioned that Standard Methods have been employed. In many instances, proper references are required to examine the precision and reproducibility of methods used. Readily available field analytical kits have been used in some instances to determine chemical constituents such as trace metals and micro-nutrients, consequently low levels have been reported. It is important to take into account that precise analytical methods should be employed when trace elements, micro-nutrients and organic residues are analyzed. Unbelievably high concentrations of micro-nutrients and trace elements have been reported in certain instances. It should be noted that distribution of either chemical species or organisms in natural aquatic ecosystem is mainly determined by physical characteristics of the water body (e.g. stratification, flow dynamics etc.,). Therefore, when there is an extremely high variability in the distribution of chemical species attempts should be made to justify the spatial heterogeneity.

Analysis of results and their meaningful presentation is also important to interpret the collected information. The most appropriate presentation is to use a small set of data as it is. When the data set is quite large, these data should be treated by simple statistics. Care should be taken not to employ statistics when it is not necessary. Treatment of data with simple statistics reveals errors involved in analysis. However, these simple statistical treatments are required for meaningful interpretations.