Integrated Landscape Analysis as a tool to structure and analyse environmental information

Exemplified by the Negombo Lagoon catchment, Sri Lanka.

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"Environmental science plays an essential part in any discussion of the relationship between mankind and the natural world, which sustains us. Without reliable data, informed analysis and the ability to forecast we could not begin to make the increasingly complex judgement on which our future depends. But I am not convinced that it is either sensible or necessary to adopt an approach, which is based solely on dissecting the totality of any situation into ever smaller or more specialised parts. Looking into the bigger picture, and using all the insights available from different disciplines, is far more likely to produce the genuinely sustainable solutions, which are our ultimate goal".

HRH The Prince of Wales[1]
2000

1. Background and aims

Environmental sciences span a wide range of topics covering the interaction between man, society, culture and nature. Within the environmental sciences environmental impact assessment (EIA) has become an important planning tool to assess projects or implemented in strategic planning. In this context EIA can be seen as a process of importance to achieve a sustainable development.

By a formalisation of the EIA process, driven by donors and financiers, much of the focus has been set on the formal structure, the need for public participation as well as on an increased focus on stakeholder interests including the social and economic impacts. Even if formalised, the process is still to a large extent experienced based, as experience is needed of both the type of action (driving force) and of the environmental and social response to its implementation.

[1] HRH The Prince of Wales, Foreword to O´Riordan, T (Ed) Environmental science of Environmental Management, Prentice Hall 2000.

In the early development of the EIA process much efforts were put in the data collection and data assessment from a wide range of topics, before filtering out the essentials related to the impacts of a proposed activity or plan. In most applied environmental studies there is, however, a time constraint for financial reasons, which is particularly important in data scarce environments, such as in developing countries.

As a result of this, new approaches to data collection and data generation have been sought for, even if most of the EIA guidelines call for a focus on the essential issues related to the new development rather than on a more complete data collection from the affected area. Based on own practical experiences, one of the present authors outlined an extended screening strategy to at an early stage in the process filter out the essentials, the extended screening perspective, and later based on experiences from the same kind of project the application of an holistic view on the environment whereas the *landscape studies* came into focus, *i.e.* the *extended baseline perspective* (Strömquist and Tatham 1992, Strömquist 1999, Strömquist *et.al.* 1999).

In the application of environmental studies to areas with poor background data, there has been and still is, an over-confidence in shortcuts to data generation by remote sensing and to analyse the problems and suggest solutions by geographical information systems (GIS) in the EIA process. In the 1970s and 1980s those technologies were often uncritically applied and operated by technical professionals rather than by scientific specialists, a scenario that however is changing because of easy access to the techniques, at a relatively low cost, by the introduction of systems based on personal computers (*cf.* Strömquist and Larsson 1994, Strömquist *et.al.* 1994). Use of the tools in public participation and environmental communication has also been more and more important (Strömquist *et.al.* 1999).

There is still, however, a need for more scientific and local competence in the GIS processing of environmental data as pointed out by Strömquist and Larsson (1994). Openshaw (1997) says that "GIS is not a totally objective, neutral and value free technology but this does not mean that it is either random or corrupt or evil". By this project we hope to illustrate some of the potentials and alternative approaches to apply these technologies in environmental assessments, but also to illustrate some of the limitations when analysing complex environmental problems.

So far, according to our experience, the most valuable contribution of the remote sensing and GIS technologies relate to the possibilities to structure the problems according to the "project geography" including a regionalisation of the landscape information into "homogenous" regions in order to support and supplement environmental information obtained by specialist studies (Strömquist and Johansson 1976, Strömquist *et.al.* 1999).

A focus on landscapes and their dynamics can be developed into an integrated approach to environmental studies enabling different specialist competence to share and integrate the same view as a starting point for their assessments of past and present environmental change. This has been shown in several integrated EIA studies involving natural, social and cultural scientists. In this context the tools become valuable instruments, in particular if used by a multidisciplinary team in a field situation (Strömquist *et.al.* 1999). The technique, which can be defined as a "*landscape dynamics approach*" has also been explored in related studies on other parts of Sri Lanka (Haag and Haglund 2000, 2002), Tanzania (Simonsson 2001) and South Africa (Haag 2002).

The present study aims to explore if or to what extent such as an approach can be used to identify driving forces of impacts on a sensitive aquatic environment by observing and analysing changes within its catchment area.

The case study area has been selected because of its complexity in man-landscape relations throughout history and as observed change is imagined as an environmental problem of local and regional importance. The common catchment area of the Negombo Lagoon and the Muthurajawela marsh on the east coast of Sri Lanka (Figure 1) is one of the most densely populated and economically important urban areas of Sri Lanka. According to (Kumaradasa 1999)[2] the lagoon ecosystem is under severe stress caused by destructive fishing, encroachment, urbanisation, water pollution and social disparity. In addition, the IUCN has raised a concern for the biodiversity, threatened by landfill, urban development and other exploitation of the wetlands (Bambaradeniya *et.al,* 2002). Several stakeholders, including national research organisations, universities, municipalities and environmentally oriented non-governmental organisations are at present engaged in the monitoring of the recent change of the lagoon environment, all however acting as, more or less independent actors with little interaction and under separate programmes. The Urban Development Authority has created a zoning plan for parts of the Negombo catchment projected for the year 2010, The Central Environment Authority is running a participatory GIS project in the catchment area, and the National Aquatic Research and Development Agency (NARA) is monitoring lagoon changes with regards to water quality, fisheries and aquatic vegetation. The latter organisation furthermore has a research station at lagoon. All organisations are GIS focused and have access to such facilities, but there is no general coordination of the data collection and there are no long time series of environmental data available for the area.

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[2] Arlene Kumaradasa, comments submitted to ESCAP (UN) virtual conference on the Internet (http://www.unescap.org/drpad/vc/conference/ex_lk_5_mmn.htm).

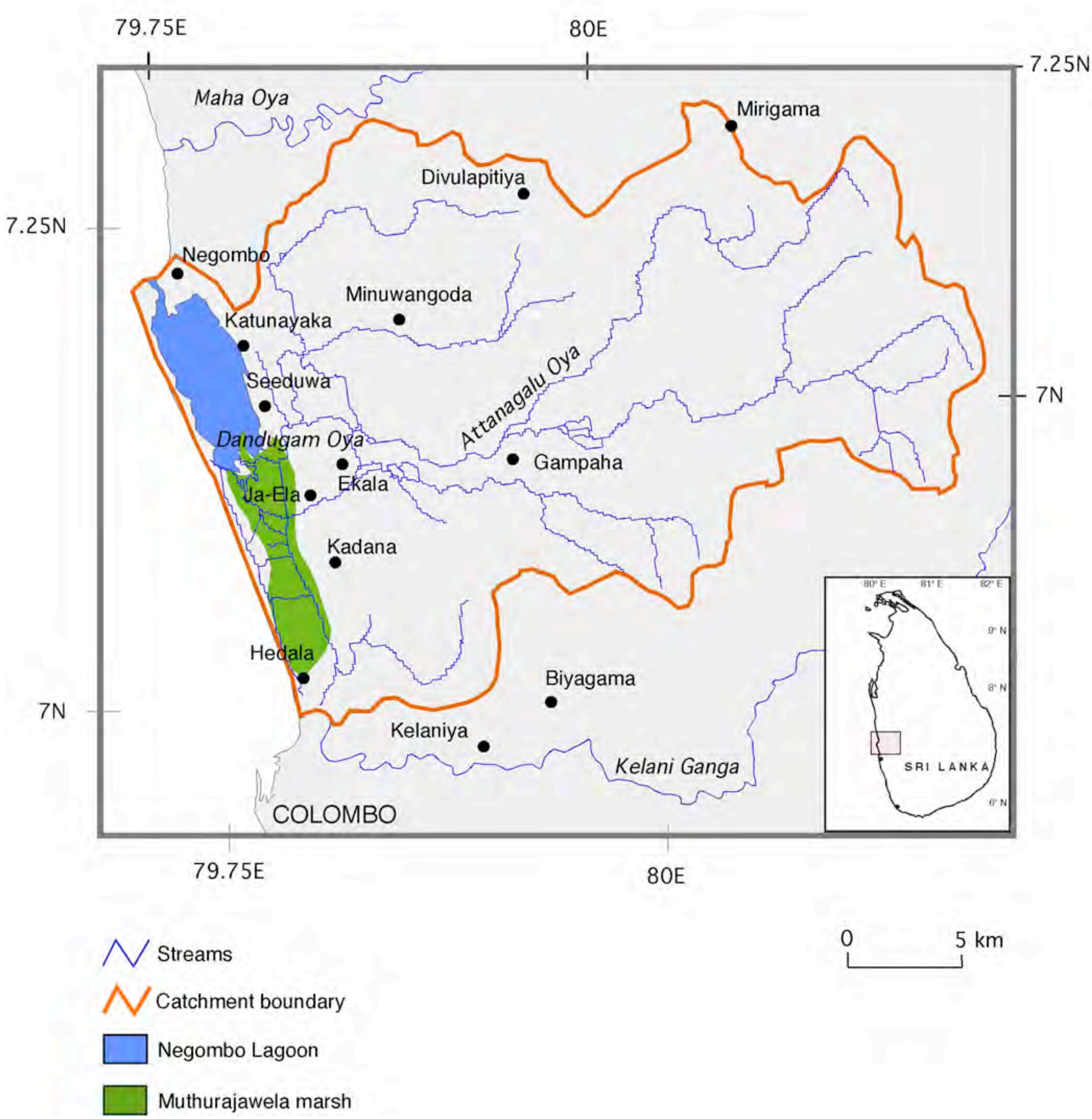

Figure 1. Outline and location of the study area. River names in italics.

2. Work philosophy, data sources and strategy

As the aim of this paper is to analyse how landscape analysis can be used to identify key issues for environmental assessment, which are relevant in a development perspective, it can be concluded that in the application of science to solve acute environmental problems, the time is often too short to directly study and quantify each individual process that influences environmental change. Practical and rapid appraisal methods are therefore needed in order to focus investigations and identify key areas for detailed studies (*cf.* Strömquist et.al. 1999).

The most obvious view, a synoptic view, does therefore not always give us a full explanation of the past development. The truth is not always found in the obvious and we therefore need to be able to study landscapes from different temporal, spatial and professional perspectives. The application of a too limited set of specialist opinions or by omitting the local knowledge might not only lead to wrong, but to harmful conclusions. Especially if the results are to be applied in any kind of planning or will be used as a base for project related mitigation or monitoring purposes (*cf.* Strömquist et.al. 1999).

In order to evaluate the applicability of such a study approach a Sri Lankan environment, the following points of departure for data generation and data assessment have been used.

- Identification of the spatial distribution of socio-economic driving forces to landscape change, based on available official data displayed cartographically by a GIS.
- Identification and analysis of the temporal and spatial land cover and land use changes as observed by digital classification and change detection studies of satellite data from the catchment.
- Compilation of existing landscape information from scientific reports and studies to explain the historical landscape development in combination with recent data and synoptic views generated from other information sources.
- Information of current environmental change of the lagoon and wetland ecosystems provided by NARA.

3. The landscapes of the study area

3.1. Organisation and structuring of information

The spatial framework for the present day environment relates to the evolution of the physical landscape whereas all the major changes can be related to specific land forming events, such as dramatic changes in the erosion base which trigger a series of processes setting the scene for a new landscape ecology. Continuous processes like weathering, soil formation and erosion, transport and deposition of sediments respond to the changes during the following cycle of landscape development, which also is influenced by short or long-term changes in climate, land-cover and human land-use.

Another spatial framework is the past and present administrative landscapes, related to culture, policies and economies all setting their footprints on the observable landscape change of today.

The physical landscape can be structured and regionalised in many ways, *i.e.* in relation to terrain features, drainage systems, ecosystems or land use potential, whilst the official social data are confined to the political boundaries. The socio-economic data used in this study is so far limited to the administrative landscapes and need to be supplemented by participatory studies on the local level to fully understand the patterns of change and their driving forces.

In this study we have structured the physical landscape information in accordance with a land systems approach, which is a common approach to landscape description and assessment. It is based on the distribution and patterns of the physical features defining the terrain and to delineate units or regions of a specific, uniform character. Such studies, based on analyses of genesis and processes, as well as directly observable surface attributes, can form part of the basis for decisions about the utilization and management of land. The origins of the method lay in the application of air photo interpretation to rapid reconnaissance mapping (*cf.* Brink *et.al.* 1966).

3.2 Physical landscape history

There is a rich scientific literature on the physical landscape development of the study area, focused equally on the development of the coastal and terrestrial landscapes, which has been used as a background to our satellite data inventories and regionalisation of the landscape information.

<u>Coastal change</u>

Studies of the coastal landscape history reveal a sequence of transgressions during Pliocene, a general regression during Pleistocene, and a transgression during mid- and late Holocene (Weerakkody 1992, Preu 1989, Katupotha, 1988). Lower sea levels predominated in the Late Pleistocene and Early Holocene respectively (Katupotha, 1988), but after a long time of sea levels below the present day level, the sea level reached present day levels sometime around 6 500 BP. It then continued to rise for another 500 years and then stayed at about 2 m above present sea level until 2000 BP. The sea level then gradually was lowered to the present day level (Katupotha and Fujiwara (1988).

The barrier chains of the southwest were formed during the regression around 3000 BP according to Weerakkody (1992), The recent beaches, sand spits etc were formed during modern time.

The lagoon pattern has been stabilised by past water regression in combination with long-shore sediment deposition and by formation of beach rock, which have formed rather stable “barrier chains” further enclosing and stabilising the coastline. The lagoons are at present gradually transformed to wetlands.

<u>Negombo lagoon</u>

Negombo Lagoon is one of about 45 such lagoons along the Sri Lankan coastline of (Coast Conservation Department, 1990). Most of them are attributable to the Holocene transgression., but the Negombo lagoon was created by a process of spit growth (Swan, 1983).

The Negombo lagoon barrier is situated on beach rock (Madduma Bandara *et al,* 1987), which thus forms a protection for the lagoon and the beaches east of the barrier itself. On the other hand, the beach rock act as an obstruction to the northerly long shore drift originating south of the lagoon, at Kelani Ganga river. The beaches sheltered by the barrier are thus deprived of one of its main sediment sources (Madduma Bandara *et al,* 1987). This reasoning is supported by the data provided by Preu (1989) who states that the rate of beach retreat north of Negombo lagoon is about 2.3 m per year but only 1.1 m per year south of Negombo. Immediately to the east of the lagoon, well-developed barrier ridges are found, separated by swales. The ridges are covered by dark brown to yellow sand, covering a light grey to greyish white, coarse sand and pebbles with clay (Katupotha 1988). According to Katupotha (1988) the Murajawela marsh was part of the Negombo lagoon during the high sea level period during mid-Holocene. As the sea level was lowered, the southern part of the lagoon was gradually filled with terrestrial and marine sediments.

The estuary has a surface area of 3 502 ha (Coast Conservation Department, 1994) and is connected with the Muthurajawella marsh at south of the estuary. The total extent of the lagoon and wetland system is 6 232 ha. The maximum storage of water of the marsh is 11 million m^3 with a water level of 0.52 meters and maximum discharge is 12.5 m^3 per second. The water retention time is more than 10 days. The lagoon has four fresh water sources. The main inflowing river, the Dandugam Oya (river) drains a catchment of 727 km^2 and discharges at the junction of the lagoon and the marsh, near the Southern end of the lagoon.

Throughout the human land use history there has been pressure on the lagoon and wetlands gradually changing its environment. Negombo being the major seaport of the country in past was already in the mid 15th century connected by a series of canals through the coastal lowlands. The canals were later improved and reconstructed by the Dutch and British colonisers of the country. Part of the Dutch civil works aimed furthermore at flood control of tidal waters prohibiting paddy cultivation due to salinization of the Murajawela marshlands, which had ceased already during the early canalisation projects due to salt water intrusion.

Today the Negombo Lagoon is experiencing severe pressures from the adjoining settlements, the fishing industry, aquaculture and activities in the catchment (Figure 2).

Figure 2. The lagoon is heavily used by the fishing industry (left). Two main canals lead to the lagoon, the Dutch canal and the Hamilton canal (right). Photo by F. Haag, October, 2003.

<u>The catchment area</u>

The basis for the regionalisation of environmental data as well as the satellite data interpretation has been a land systems analysis made by Panabokke (1996). Three land systems can be identified in the basin. The three land systems illustrate the general characteristics of the Sri Lankan landscapes, which rise like a staircase from the coast to the interior, created by three different erosion surfaces. The lowest, of these is the *low peneplain (coastal plain),* with an elevation of appreciatively 0-125 metres above sea level. In this peneplain, the processes of erosion has levelled the surface almost completely and filled previous valleys with deposits (Cooray, 1984). The second is the intermediate or *middle peneplain,* with an elevation of 125-750 m. This peneplain is irregularly displayed in the country largely depending on the influence of the development of larger rivers. The highest surface is the *high peneplain*, at 750-2500 m. This level displays less of the peneplain characteristics than the other two, and is a complex of plateaux, mountains and basins (Cooray, 1984). These three tiers are easily detectable in the study area, and are visible in the three land systems.

1. *Land system I* is a part of the *coastal plains* of Sri Lanka, which are mainly made up of sedimentary deposits formed during the last two million years. These occur in a coastal belt that is narrow in the southern half of the country but widens north of Negombo (Panabokke, 1996). The topography of the area is very flat to slightly undulating, and the elevation seldom exceeds 10 m a.s.l. The land is mainly used for residential and industrial purposes, creating a complex pattern of settlements mixed with vegetation such as coconut, banana and other household plants.
2. *Land system II,* the *low country - flood plains*, is situated some 8-10 km from the coast where there is a slight change in landscape. The topography gradually becomes more hilly and rolling, with an altitudinal range of 10-50 metres above sea level. Two primary units or land facets can be distinguished, which – using Panabokke's terminology – can be defined as flood plains and residual lands respectively. The flood plains are mainly characterised by alluvial soils.

3. *Land system III, the hill country*. At an approximate distance of 30-35 km from the coast, the landscape changes character yet again. The topography now becomes even hillier, with steep hills, and a landscape dissected by valleys of varying size. The elevation is about 50-250 m. The facets are again valleys on the one hand, and hills on the other. As in the other land systems, the valleys and floodplains are characterised by alluvial soils of variable texture and drainage. The land use in this land system differs from the other two. In the valleys (i.e. floodplains), paddy is cultivated. In the smaller valleys, terracing is sometimes used. On the lower parts of the hill slopes, there is a complex mix of residential areas (less dense than towards the coast), coconut, gardens, tea and forests (open). Further up on the slopes, rubber plantations dominate. Residential areas can also be found here, but are not as frequent or dense as in the valleys. Even further up, dense forests are common as well as bare rocks or steep rock lands.

A map of the three land systems is presented in Figure 3, together with some photos. Appendix 1 summarises the characteristics of the three land systems and Appendix 2 presents a schematic transect of each landscape type.

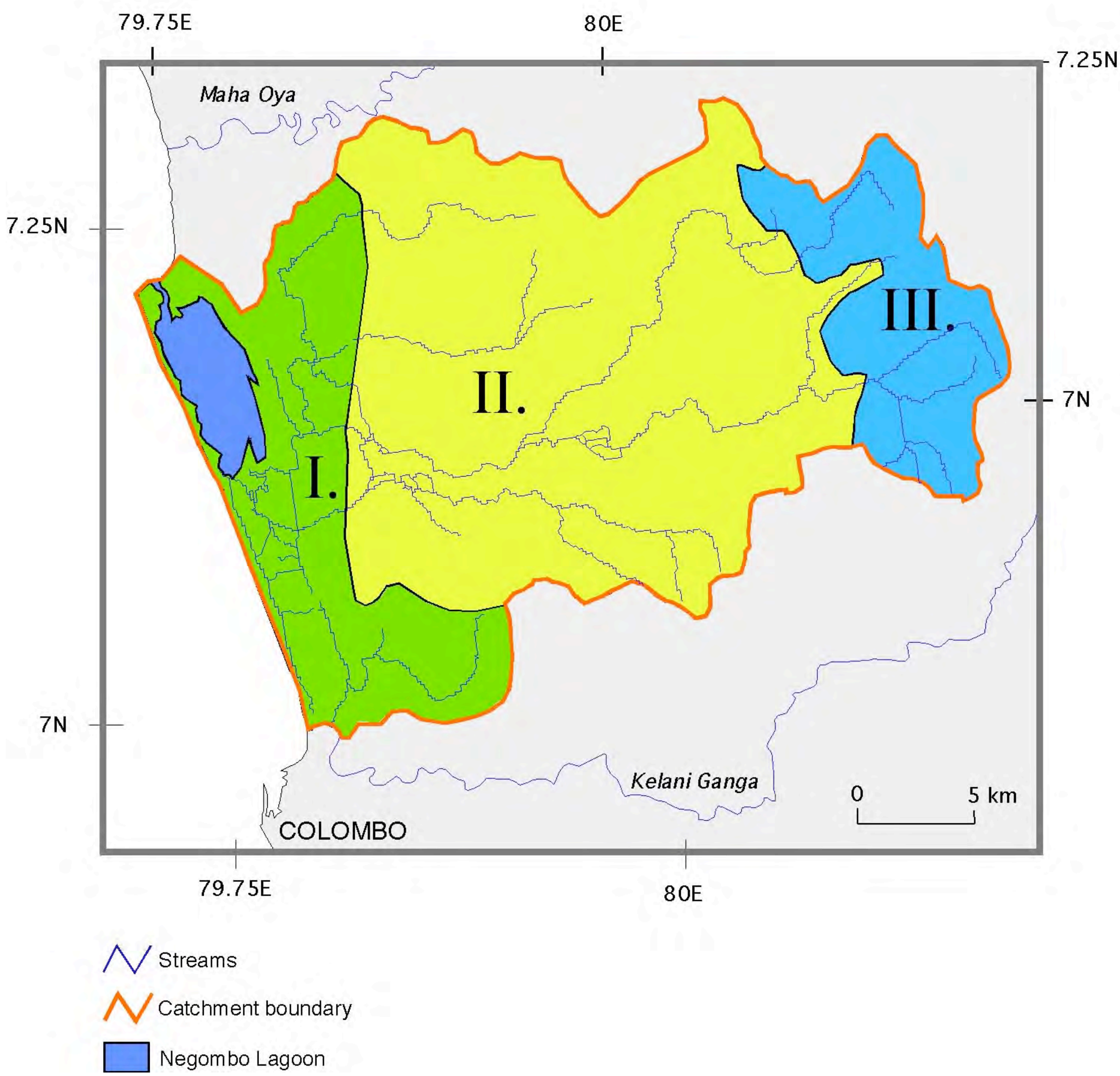

Figure 3. The land systems of the study area.

3.3. The administrative landscapes

Administratively the catchment area belongs to 11 Divisional Secretariat Divisions (DSD). Out of them 9 belong to the Gampaha district while the other two are situated in the Kegalle district (Figure 4.) Exploring the current socio economic conditions and their spatial distribution, population density, urbanisation, etc will contribute to the explanation of environmental change. The most recent populations census were made in 1981, 1994 and 2001. Gampaha district, situated in the Western province, covers an area of 1 381 km^2.

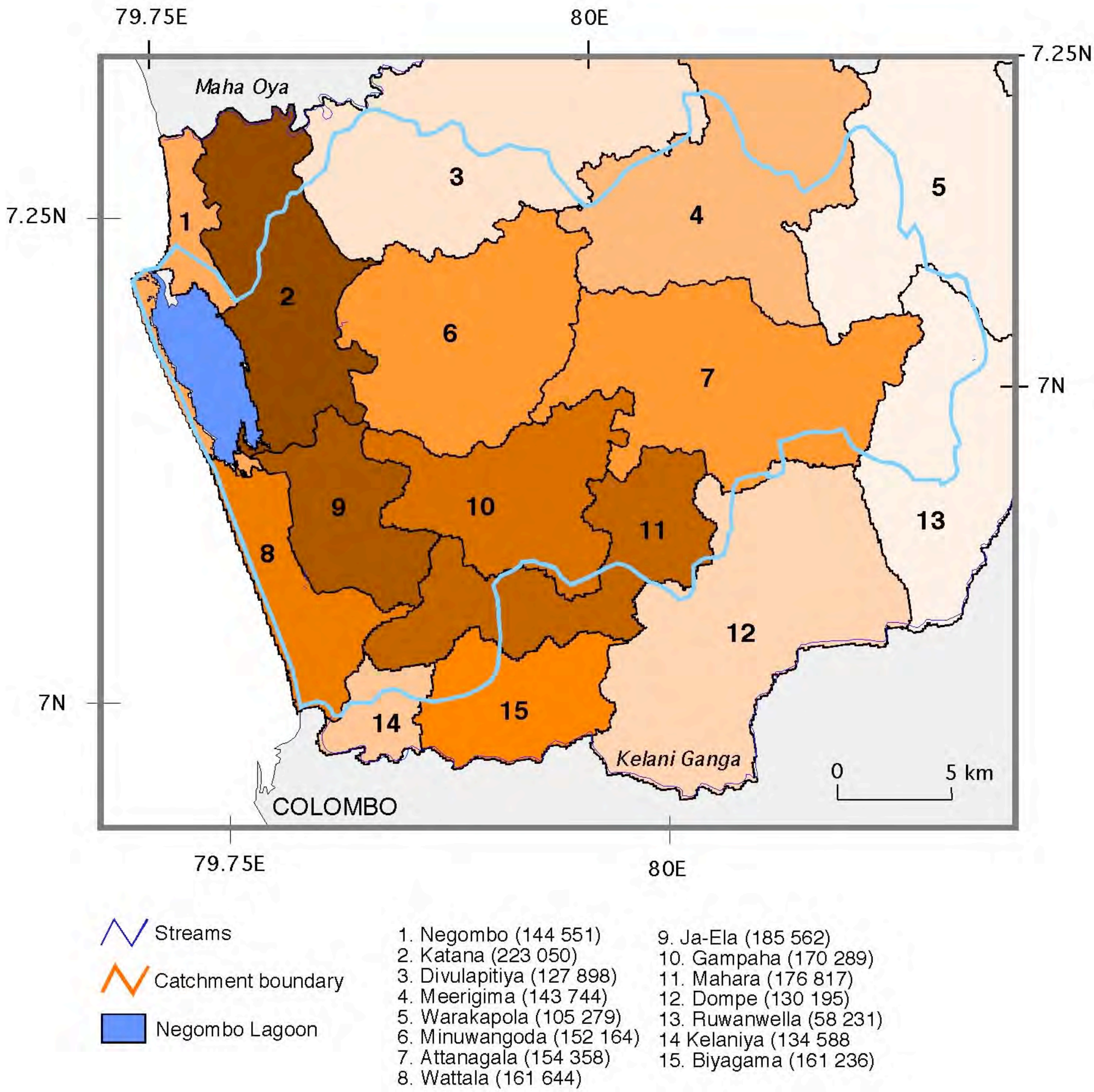

Figure 4. DSDs of the study area and their population.

4. Landscape change and landscape dynamics

4.1. Observations

Landscape change and possible causes

The digital classification of satellite images detected the most obvious landscape change during the study period, *i.e.* the land transformation from agricultural land use to urban or industrial use. An almost tenfold increase in areas occupied by settlements and structures (Figure 5) has been observed in all land systems. In land systems I and II the open areas (farmlands, fallow land and wetlands) have increased from about one fifth of the surface area to just less than half. As a consequence, the Home gardens/mixed crops land cover-class has decreased to a half (Figure 6). As expected the digital classification, however, did not reveal changes related to change of agricultural practices.

The observed change should be compared with the considerable increase in population density (see Appendix 3). In 1981, the density of population in Sri Lanka was 258/km^2 while it has increased to 342/km^2 by 2001. In the Gampaha District the density was 994/km^2 in 1981, and had increased to 1541/km^2 by 2001, which is the second highest population density in Sri Lanka. When the administrative divisions (DSDs) in the catchment area are analysed, a spatial change pattern can be observed that confirms with the observed landscape change (Figure 6). Out of them, the DSDs Ja-Ela and Katana (both located in the coastal plain) the density is 3042 and 2027/km^2 respectively. The lowest density recorded in the DSDs in the Gampaha District is 636 in Divulapitiya and 732 in Dompe (Land system III), further inland from the urban centres.

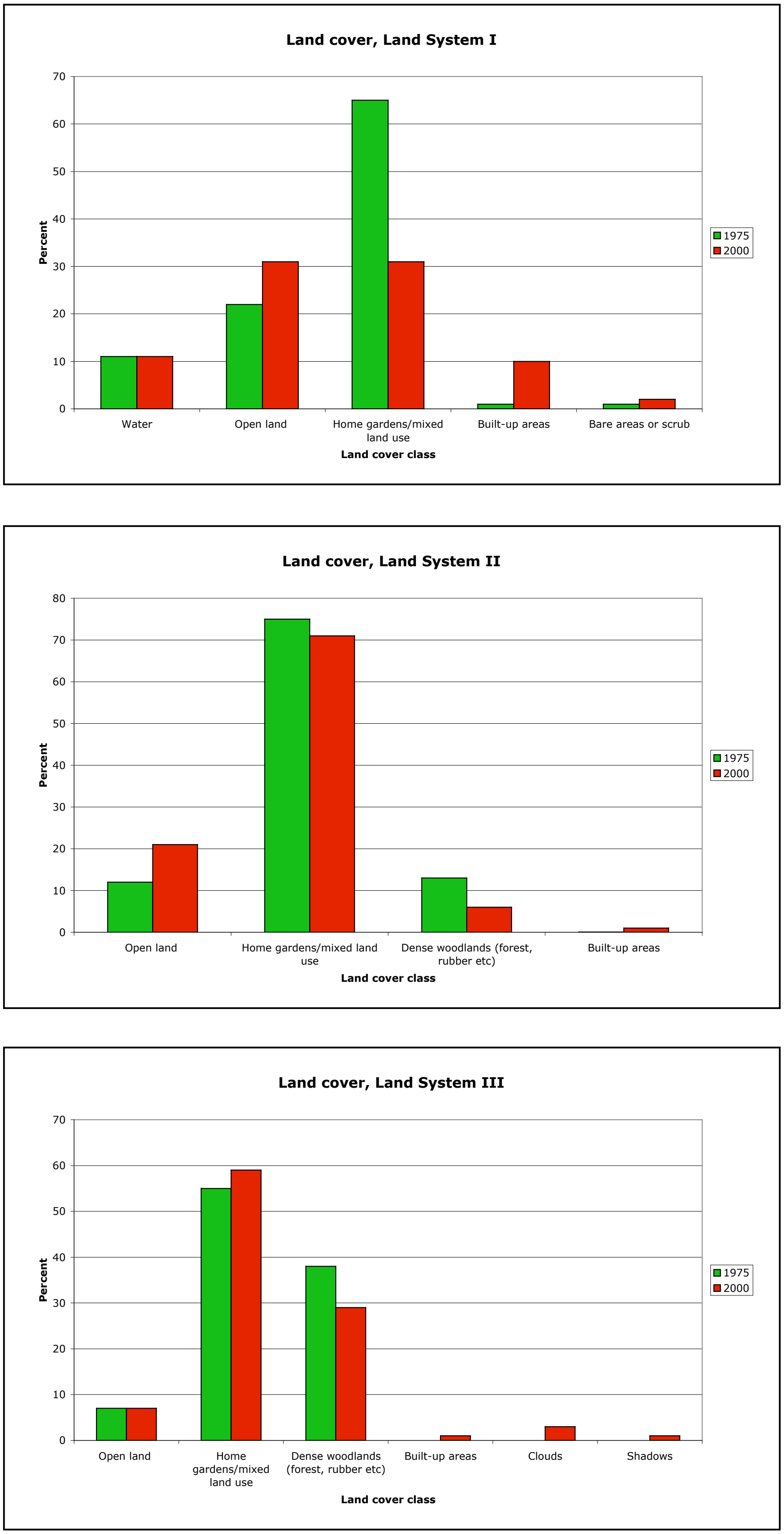

Figure 5. Land cover changes in the three land systems. The diagrams are based on data from classifications of satellite imagery.

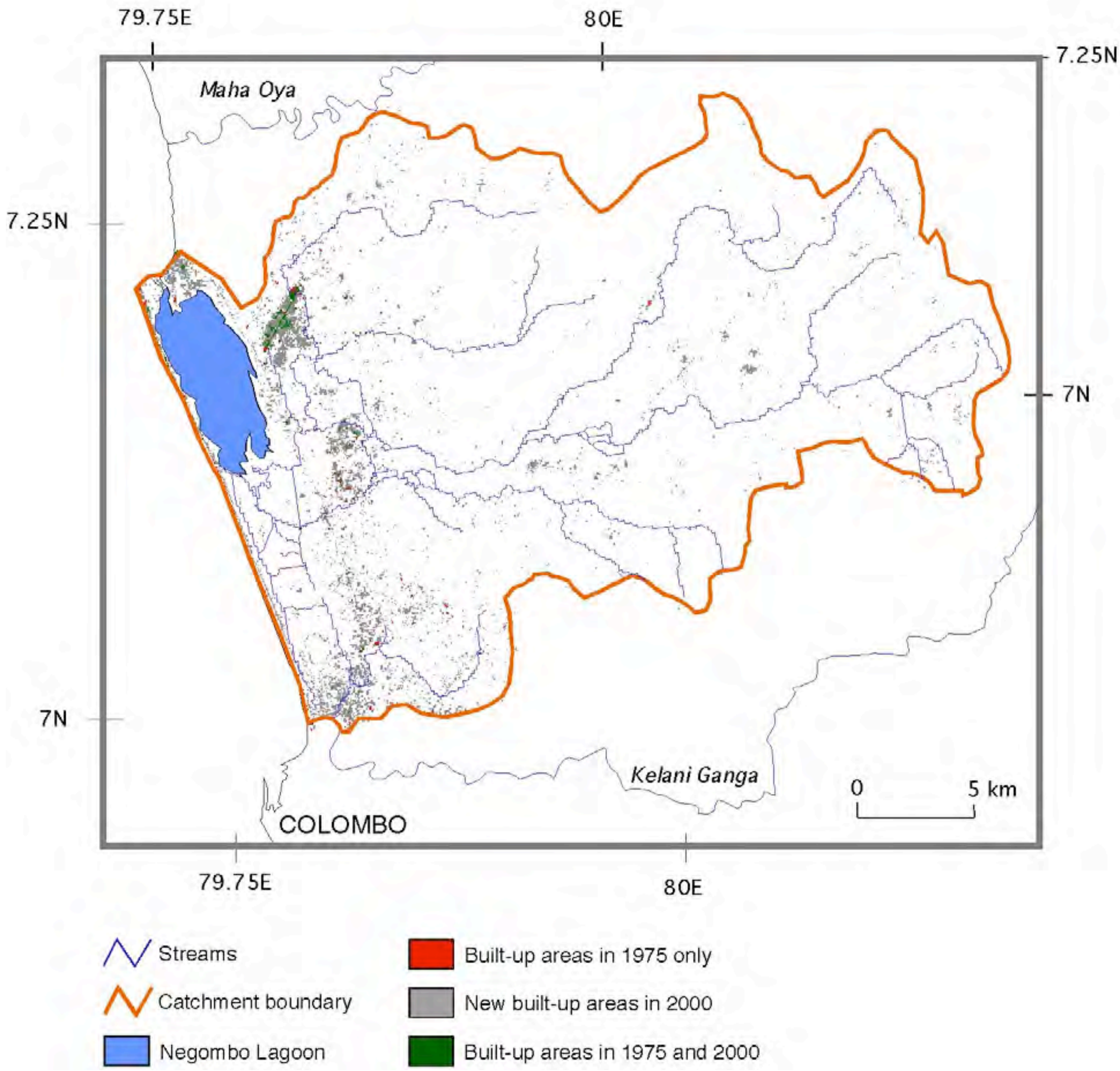

Figure 6. Changes in built-up areas, based on classifications of satellite imagery.

The analysis of satellite imagery indicates a landscape change s that correlates well with the socio-economic data. The observable change is mainly found in the divisions (DSDs) that have recorded the highest increase in population. Hence the increase of the land/man ratio of an area directly influences the landscape change, *i.e.* patterns of land use and settlements.

The upstream landscape change is less pronounced with regard to urbanisation/industrialisation but land use changes due to changes in agricultural practices could be observed, particularly in the Hill country, where decline in paddy cultivation may lead to a similar development as observed in the coastal plain.

Changes in the environmental situation of the lagoon and wetlands

Negombo Lagoon – Muthurajawela marsh is a tidally influenced coastal wetland acting as a recipient for the upstream catchment under change. The lagoon is an important provider of ecosystem services as it acts as an area for marine shrimp and fish breeding located in the transitional zone between marine and riparian environments. It acts as supplier of nutrients to the aquatic fauna within the lagoon as well as to the two adjacent fishing grounds in the sea. There is an expanding fishery for shrimps in the lagoon and the associated coastal eco-system. About 20 000 people are directly or indirectly dependent on the lagoon resources for their livelihood.

The wetland however, faces many environmental problems due to the changes in the catchment as previously described and by an increased external demand on the lagoon and wetland for other purposes related to the expansion of the urban area. Problems identified in the marshland relate to encroachments (land take), habitat degradation and pollution and in the lagoon to sedimentation and maintenance of tidal exchange related to human impact (mangrove plantation) in outlet area, habitat degradation by destructive fishing, industrial and human pollution (recipient of untreated waste) and oil pollution from vessels.

In order to reduce these impacts several management plans have been drafted and discussed. One such plan from Central Colombo Economic Commission is the Master plan of Muthurajawela and Negombo Lagoon, (May 1991). It suggested an optimal land use in the wetland area which was divided into four zones; a Conservation Zone (57 % of the study area or 92% of the functional wetland), a Mixed industrial/ residential development zone (3% of wetland), a Buffer Zone (5% of wetland) and a Residential Development Zone 28% of the study area (Outside the wetland).

In addition to this plan, a mangrove-zoning plan was proposed (within the conservation zone) it also demarcated the four zones a Conservation zone, a Preservation zone, a utility zone and a no mangrove zone. Mangrove on the islets has previously been protected by government gazette.

No management plans have, however been made of the catchment. However, looking catchment as a driving force to change also in the wetland and lagoon as illustrated by this survey it is clear that such plans should be of greatest importance and relevance to provide a sustainable resource use of the marine eco systems. .

At present an initial monitoring of the lagoon is under implementation at NARA. In addition to conventional sampling and measurements monitoring of change is also developed with regard to remote sensing, GIS and GPS based mapping of seaweed in the lagoon. The monitoring system should however be expanded to the whole basin, in particular to the areas of rapid change as identified in this study.

5. Discussion

Based on our findings, we can identify a number of interrelated driving forces to environmental change both in the catchment influencing the wetlands and lagoon habitats, namely (i) population increase; (ii) urbanisation; and (iii) changing patterns of agriculture.

5.1. Population increase

According to the census conducted in 1981, 1994 and 2001, some notable features in the population can be identified. In 2001, the population growth rate in Sri Lanka was 1.2%. In Gampaha District the growth rate was 1.9%, the second highest rate among the 18 districts investigated in the census. In the Kegalle District, the growth rate is 0.6%. Similarily, when the inter census period from 1981 – 2001 is considered, the inter census growth rate in the Gampaha District is 45.5% which is high compared to other parts of the country. As a comparison, Colombo District has a growth rate of 31.5% and Kalutara District 27.9%. The urbanisation and industrialisation of the Gampaha District can be contributed to a number of factors, such as the population growth, the nearness to Colombo and its suburbs, and the rapid increase in rural settlements.

These statistical data have been analysed according to the census in 1981 and 2001 and the Demographic survey data. As the data reveal, the total population in the Gampaha district has increased by 215 406 from 1981 – 1994 while the increase from 1994 – 2001 is 459 754. Thus, the population more than doubled the 13 years period.

The changes discussed above are presented as increases in population density in Figure 7.

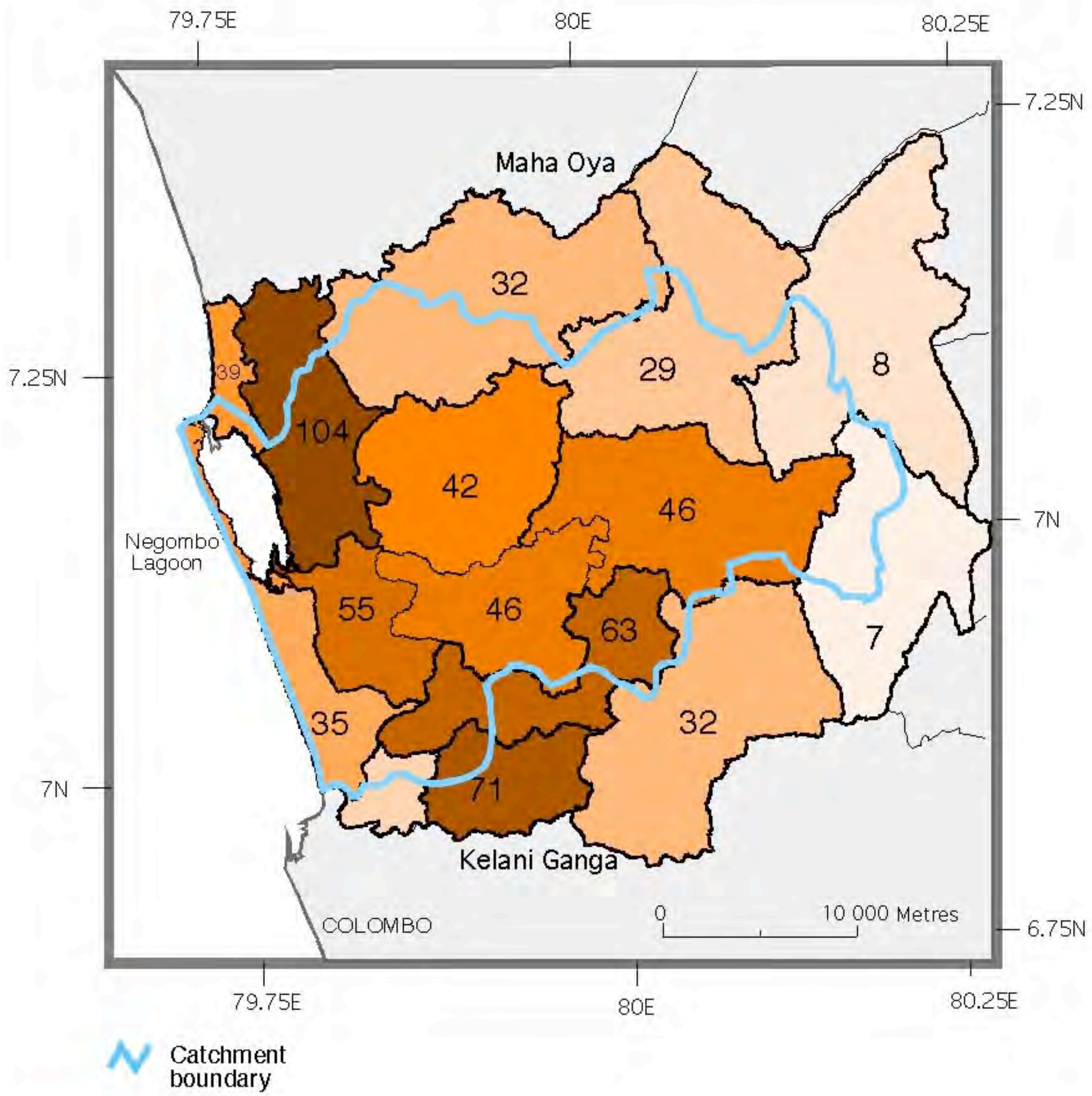

Figure 7. Increase in population density (percent) per DSD.

5.2. Urbanisation

The land transformation, as indicated by the increase in built-up areas and open land is the result of high growth rate of the population of the catchment. The other main factor is a rapid change in the settlement pattern. Out of the three types of settlements in the area - namely the rural, ruban and urban - the rural settlements are undergoing a rapid change. In this process, the rural settlements are being changed to ruban and ruban to urban settlements. As a result of these changes the urban centres are connected to each other through urban strips by the built-up areas scattered along to the roads, thus forming urban agglomerations which is a remarkable features in the District (Wanasinghe, 1998).

These scattered settlements are difficult to identify in the satellite imagery, as they are sparsely located and often together with a variety of crops, trees and bushes. It is therefore mainly through the changes in built-up areas and open areas that we can observe these changes through satellite imagery.

There are 22 settlements that perform urban activities in the Gampaha District including 7 officially accepted urban centres (Negombo, Ja-Ela, Minuwangoda, Peliyagoda, Seeduwa, Wattala and Mabole) 11 settlements which are under local government although they had been under small towns prior to 1987 and 4 other settlements which do not belong to either of the two, but display urban characteristics. Further, there are many junction settlements, which also perform urban activities thus creating a net of urban settlements across them.

These urban centres cater to the commercial, health, educational, financial, administration, cultural and recreational needs of the people living in and around them. Institutes like banks, large shops, hospitals, collages, police stations and courts render good services to the area. However, many cities in the Gampaha district are centred around the suburbs of the Colombo city. People who worked in the Colombo city resided in these new settlements due to lack of space, high land price and high building rent in the city. Urban centres like Wattala, Mabole and Hedala developed as settlements in the vicinity of the metropolis which Peliyagoda, Kelaniya and Ja-Ela which supplied commercial and other services, later developed as Employing Suburbs (cities supplying jobs).

Apart from these, the major junctions which supplied various services functioned as a cluster, thus developed as a commercial nucleus. This situation affects seriously then forming a mixture of rural – urban characteristics. At the same time, several towns are connected together by the built up ribbons which spread linearly as a result of the buildings pot up for roads that connect the urban centres. This situation can be seen in most of the catchment areas of the Negombo lagoon. As a result only a few settlements that reveal the traditional rural characteristics remain. Hence the tendency for rural settlements to become ruban settlements has increased because of the urbanization and industrialization that took place rapidly, especially in the Gampaha District.

Establishment of investment development zones like Katunayaka, Biyagama and Ekala and the amalgamation of production industries have affected the transformation of the settlements in the Gampaha District. Another reason is the large number of immigrants who migrated to the catchment areas looking for jobs. According to demographic survey in 1994 the number of permanent residents was 79.1% out of the total population. The rest were immigrants, the majority being job seekers. As the urbanization process accelerate, transformation in the agricultural sector and the development of the non-agricultural land consumption and other activities have substantial effects on the natural environment.

5.3. Industrialization of the area

The contribution of the industrial sector in the DSDs of the catchment area of the Negombo lagoon is likely to be substantial. The study area has seen a rapid expansion of the urban influence and the impact of the cluster of industries established in the area since the introduction of the open economy in 1978. As a result, rapid urbanization, increase in immigration, changes in land use and increase in the discrepancies of income levels are high. According to a 1996 Colombo Metropolitan Plan, 109 509 were employed in 477 industrial units in the relevant DSDs by 1993 (Appendix 4).

Diversity in the number of industries in DSDs of the catchment areas can be identified according to the requirements of such institutes. While some industries have been registered at the Central Environmental Authority, some others are registered at the Mines and Excavation sectors and Coastal Conservation Department. The industrial development board and many industries are registered at the Local Councils. Out of these, 307 industries in the Gampaha district with the EPL (Environmental Prolusion License) are registered under the Central CEA and they can be categorized under 18 sections (Appendix 5).

As these data imply, the contribution in some sectors remain very high. Sand mining and industries related to bricks and coir do not belong to the group of industries found here. But they are found in plenty in the catchment areas. Apart from this, the data in the DSDs reveal that a large number of small-scale businesses and cottage industries have been registered. Out of the DSDs in the Gampaha District 4 do not belong to the catchment area. There are also a large number of industries in the rest of the DSDs. Roughly, there are about 700 industries in each DSD and that number varies roughly from 200 – 2500. Weaving, coir mills, rice mills, cement and mud pots, bricks, sand mining, garments, metal quarries, coconut oil mills, wood processing, are some of these industries. Environmental problems crop up when such a large number of industries function together.

Figure 8 illustrates the spatial distribution of EPL industries and urban centres in relation to the sub-catchments of the study area. As the map and statistical data reveals, most of the urban centres and industries are situated within the coastal plain (Land system I). From a catchment perspective, these urban centres and industries are situated in the lower parts of the rivers Attanagalu Oya, and in the sub-catchment belonging to the Dandugam Oya, Ja-Ela and the canals. Considering Figure 5 and 6 in combination with this data indicates some areas (DSDs) that are exposed to a higher pressure from urbanisation. These are foremost Ja-Ela and Negombo (especially the northern and eastern parts), but also Wattala, Mahara, Kelaniya, Biyagama and Gampaha.

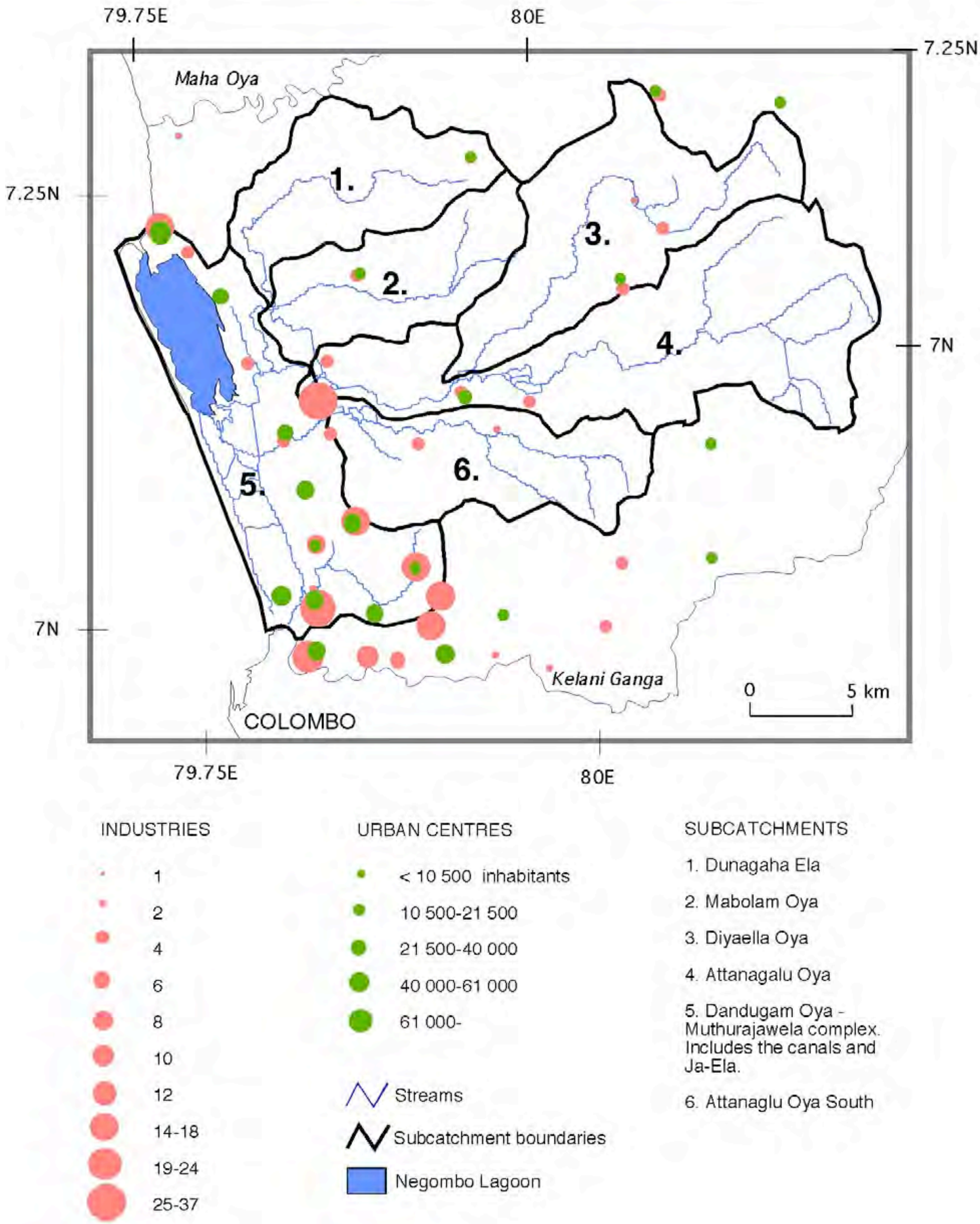

Figure 8. Urban centres and EPL industries in relation to the sub-catchments of the study area.

5.4. Changing patterns of agriculture

When the increase of population of the catchment area is taken into consideration, rapid changes in the usage of agricultural land can be noticed. In recent times, some agricultural sectors have under gone changes due to various factors. Paddy, Coconut and Rubber cultivation can be cited as examples. Although, most of the low land in the area has traditionally been utilized for paddy cultivation, most of that land has become unsuitable for paddy cultivation due to different environmental factors. Especially an area of about 5 – 10 km from the beach has become barren due to the intrusion of saline seawater. In other places, the industrial and urban waste matters get mixed up with water making the land unsuitable for cultivation,. Sand mining, excavating earth for brick making and filling up of low land for purposes other than cultivation also help to create this situation. According to the official statistics, in the DSDs in the catchment area 25 – 50% of the whole cultivated land is under paddy cultivation.

According to the Census of Agriculture (Department of Census and Statistics, 2003), areas under paddy cultivation in Sri Lanka have been stable or increased slightly from 1979 to 2000. In Gampaha District though, paddy cultivation shows a slightly declining trend (Appendix 6).

Another trend that is affecting the land use patterns is the increase in fragmentation of land as observed in the Census of Agriculture (Department of Census and Statistics, 2003). The fragmentation is attributed to higher demand for land in the market as well as the division of land among family members and is highest in wet-zone districts such as Gampaha, Colombo and Kegalle.

Also, discussions in the field indicate that the paddy fields are abandoned due to a lack of profit. The revenues generated are not enough, and thus the land is either left abandoned, used for grazing, sold or used for other crops.

5.5. Methodological concerns

This case study has shown that the official data combined with new data generated by remote sensing are useful tools in a geographical identification of key areas of change influencing an affected environment. The tools are, however, limited if not combined with other studies generating relevant quantitative and qualitative data. One common limitation is the lack of explanation of the causes of change and also to assess the value of change for the affected environment and its population.

An environmental impact assessment is, however a process where the regional and temporal problem identification are important components to design further in depth studies. In this case the findings might lead one of the participating partners (NARA) to design an observation programme aiming at a quantitative and qualitative analysis of pollution sources to explain observed changes in the coastal area (lagoon and wetlands) and to suggest relevant mitigation. If further developed the studies can advice the planning authorities on geographical key areas for immediate intervention in the more or less spontaneous urban expansion process to reduce future environmental change and to maintain sustainability. To achieve such goals a stakeholder involvement is needed in the process supported by participatory studies involving affected communities.

The limitations of remote sensing

In the development of remote sensing techniques and GIS from high tech tools for the few to more or less public tools to be shared by many on their personal computers it as easy to forget the intra disciplinary scientific competence and local knowledge needed to make correct interpretations. This utmost evident in landscapes of complex history, rapid change and interleaved land use patterns like in the actual case study area. The digital image interpretation techniques applied only revealed the most evident change, *i.e.* the urbanisation of the landscape, not the as important changes in agricultural production illustrated by the official statistics. The technical reasons for this are obvious as the production system is a mix of activities within the same area.

This is nothing new as the limitations of the digital techniques have been stressed in many studies of the past *(cf.* Larsson and Strömquist 1991, Strömquist and Larsson 1994). One approach suggested to overcome the problem is a combination of tailor made images from different spectral band combinations (and/or seasons) and visual interpretation combined with an intensive and efficient field control.

In this study, two different approaches were utilised to overcome the obstacles imposed by the complex landscape. First, a stratification of the study area into land systems was made, in order achieve more homogenous areas for interpretation in order to improve the classification as previously made in a coastal area of South-eastern Sri Lanka (Haag and Haglund, 2002). In the present study area this strategy failed to deliver a reliable land cover classification due to the reasons presented above, therefore statistical data was displayed on a map of the sub-catchments in order to increase the understanding of the spatial relations between industrialisation/urbanisation and impacts on the lagoon (see Figure 8). This is, however, not sufficient as it does not take other landscape changes into account. Therefore the utilised approach to remote sensing was compared to other approaches in order to improve the accuracy of further studies based on the principles discussed in this report.

Two methods of land cover classification were compared to the land cover map from UDA. The land cover map from UDA is based on information from the topographic map, which has been updated by visual interpretation IKONOS satellite data This map has been compared with a supervised classification of Landsat 7 data (2000), using bands 2,5 and 7 and with a raster based visual classification utilising a 250x250 m raster placed (digitally) over the satellite image to allow each cell to be classified according to dominating land cover class.

The comparison was made in the coastal plain sub-catchment area. The land cover classes were based on the classes in the UDA classification but consequently grouped into larger subgroups due to the constrains of the classifications. The results, which can be found in Appendix 7, reveal that each approach poses a number of advantages and constraints. In the digital and visual classifications, rivers and canals are much less prominent than in the UDA map. This relates to the fact that the UDA material is based on a topographic map, while the digital and visual classifications are based on data with a 30 and 250 m resolution respectively.

The land cover classes containing tree vegetation (Home gardens, Coconut, Forest and Rubber) are difficult to separate by visual classification. These are also difficult to separate in the digital classification and the classes were therefore grouped into one subgroup.

The classification of built-up areas illustrates the differences between the three approaches. In the UDA map, these are confined to urban centres and larger industrial clusters, which means that large parts of urban and semi-urban areas are omitted from the classification. In reality, as was described earlier in the text, large parts of the study area could be described as ruban (or semi-urban) areas. In the visual and digital classifications these are easily picked up.

Some conclusions can consequently be drawn from this test (summarised in Appendix 7 Table 1). All three mapping approaches have their strengths and weaknesses and there is not a single solution that reduce all identified problems. The best possible approach for land cover inventories in this area might therefore be a supervised digital classification based on smaller units than the land systems One way to achieve this, would be to use better background data on drainage be able to identify smaller sub-catchments. Another option would be to base the stratification on the DSDs and correlate the findings to available data on land use at this level. The visual, raster based method is another possible solution, but due to the extreme fragmentation of the land cover and land use, a different classification scheme should be used, with larger, homogenous classes. Which ever option is chosen, extensive fieldwork, engaging several scientific disciplines, is needed, especially to be able to extend the record back to the 1975 image.

	Weaknesses	Strengths
UDA	Built-up/industrial areas are only mapped if urban centres or major industrial sites. It thus misses the important ruban settlements.	Detail, such as roads, rivers and canals
Digital classification	Bad separation between classes containing tree vegetation (homegardens, scrub, coconut, rubber forest and similar)	High spatial resolution
Visual classification	Low spatial resolution. Could not separate coconut, homegardens, rubber and forest.	Flexibility, control.

Table 1. Strengths and weaknesses of the tested approaches to land cover classification.

6. Conclusions

Landscape dynamics

- A rough model of the dynamics of the landscape dynamics was generated through the study: In the past, the land use of the area was well adopted to the physiography of the landscapes. The urbanisation process seems to follow a stepwise mode where initial steps relate to a densification along existing infrastructure utilising the drier landscape elements (land facets), in cases leading to abandonment of traditional land uses in other parts of the landscape (for instance paddy fields on wetland margins and floodplains) finally leading to a rapid landscape change by landfill and deforestation.

- The observed environmental change of the coastal zone thus need a more holistic view in the assessment process incorporating the contributing areas, without which any mitigation programme of the coastal zone itself would be limited because of lack of background information. In this process, however, more ground data is needed on quality change (water quality data, pollution rates related to sources, etc.) to be able to link spatial patterns observed to measurable environmental change. The approach could, however be used to implement such programmes and to focus them to be implemented in the most appropriate areas of the catchment.

- By relating the statistical data and remote sensing generated data on land cover change to the drainage of the study area, it can be concluded that the majority of the urban centres and industrial clusters are found within the sub-catchment that constitute the coastal plain. These key areas can be found in the following DSDs: Ja-Ela, Negombo (especially the northern and eastern parts), Wattala, Mahara, Kelaniya, Biygama and Gampaha.

Methodology

- This case has illustrated that official data combined with new spatial data generated by remote sensing can be used as tools in a geographical identification of key areas of recent landscape change. The method is however not value free if the tools are applied straight "out of the box".

- The remote sensing methodology developed and applicable in other environments fail because of the complexity of land use patterns and associated diversity in spectral signals. This is however not a new conclusion and we have therefore compared the results with a conventional visual interpretation of satellite data and an official land cover map from UDA The results from the test illustrate the need for land cover mapping to be based on high resolution data and supported by a spatial stratification of the study area as well as intensive fieldwork and interdisciplinary efforts. In order to achieve an understanding of the landscape dynamics and its underlying processes, detailed studies at local level are needed.

- The GIS methodology utilising official statistics and administrative boundaries give us a rough idea of the spatial pattern but not really the critical areas of change, and certainly not the reasons. As done in many applied studies the socio-economic data has to be analysed at a community or even family level to be rightly understood.

- The tools are, however, limited if not combined with other studies generating relevant quantitative and qualitative data. One common limitation is the lack of explanation of the causes of change and also to assess the value of change for the affected environment and its population.

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Other data sources

Catchment area:
Digital topographic data (1:250 000)
Scanned, geocoded topographic maps (1:250 000)
Socio-economic data
- Population
- Agricultural land use
- Paddy production
- Industrial employment
- Distribution of EPL industries

Soil, geology and vegetation maps (derived from National Atlas)
Land use map, digital format (from UDA, Urban Development Authority)
Satellite imagery (Landsat 7, 2000-01-23, Id: L71141055_05520000123, Landsat 2, 1975-12-27, Id:LM2152055007536190)

Negombo Lagoon area
Marine resources (NARA)
Distribution and state of mangrove (NARA)
Distribution and state of sea grass/algae (NARA)
Aerial photographs

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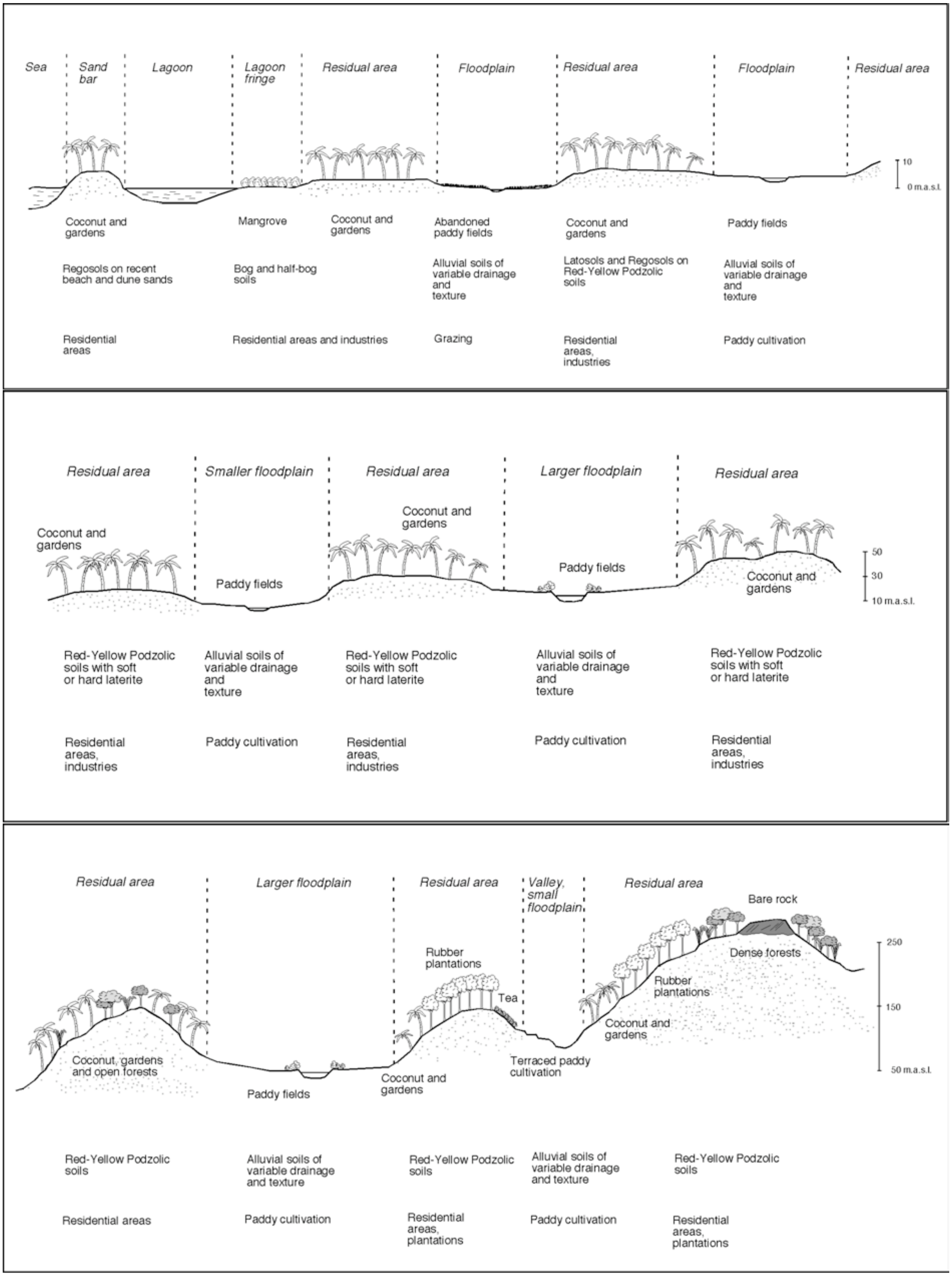
2. Schematic transects of the land systems
3. Population in the DSDs, 1981, 1994 and 2001.
4. Industrial employment in the study area
5. Distribution of EPL (Environmental Propulsion License) industries in the study area
6. Area under paddy cultivation 1979-2003 in Sri Lanka and in Gampaha District
7. A comparison between three approaches to land cover classification

Appendix 1. The characteristics of the land systems of the study area.

Name	The coastal plain	The low country (floodplains)	The hill country
Name according to Panabokke, 1996	Kotte-Muthurajawwela	Gampaha- Veyjangoda, Kadawata-Nittambuwa	Mirigama
Relief	Flat terrain	Gently rolling and undulating terrain	Hilly and rolling, steeply dissected terrain
Soils	Regosols, beach sands Bog and half-bog soils Latosols and regosols on old red-yellow sands	Red-Yellow Podzolic soils with soft or hard laterite Alluvial soils of variable drainage and texture	Red-Yellow Podzolic soils Red-Yellow Podzolic soils with strongly mottled subsoil and Low Humic Gley soils
Land use	Residential areas with gardens. Coconut. Industries.	Residential areas with gardens. Coconut. Industries. Paddy fields.	Residential areas with gardens. Coconut. Paddy fields. Rubber plantations, forests, tea
Geology	Quaternary deposits Rocks of Highland series (Hornblende gneiss, hornblende-biotite gneiss, biotite gneiss) of Precambrian age	Rocks of Highland series (Charnockite and hornblende/biotite/gneiss)	Rocks of Highland series (Charnockite, corderite-garnet granulite or gneiss)
Elevation	0-10 m asl	10-50 m asl	50-250 m asl
Agro-ecological zone	WL4 and WL3	WL3	WL2

Appendix 2. Schematic transect of the landscapes in the three land systems (system I on top, II in the middle and II far below. Modified from Pannabokke (1996).



Appendix 3. Population of Divisional Secretarial Divisions in the Catchment of Negombo Lagoon 1981 – 2001.(Department of Census and Statitics, 2001).

DSDs	***1981***	***1994***	***2001***	***Increase 94 – 01***	***Density Per Sq km***	***Land Area Sq km***
Attanagala	105781	121862	154358	32496	995	155
Biyagama	94237	105262	161236	55974	2600	62
Divulapitiya	96746	97800	127898	30098	636	201
Dompe	98649	109871	130195	20324	723	180
Gampaha	116297	134005	170289	36284	1871	91
Ja-Ela	119520	133289	185562	52273	3042	61
Katana	109476	160969	223050	62081	2027	110
Kelaniya	109927	121226	134588	13362	5608	24
Mahara	108391	121859	176817	54958	1842	96
Minuwangoda	107277	119447	152164	32717	1170	130
Mirigama	111294	126489	143744	17225	773	186
Negombo	103706	134809	144551	9742	4984	29
Wattala	119635	119453	161644	42191	2886	56
Sub Total	***1390936***	***1606342***	***2066096***	***459754***	***1541***	***1381***
Ruwanwella	-	54337	58231	3894	419	139
Warakapola	-	97319	105279	7980	537	196

Appendix 4. Industrial Employment – 1993. (Colombo Metropolitan Plan , 1996)

DSDs	Units	No. of Employers
Gampaha	72	3488
Minuwangoda	9	1054
Ja-Ela	136	22672
Dompe	8	2108
Mahara	31	3534
Divulapitiya	12	250
Katana	149	71289
Mirigama	23	379
Attanagalla	37	4735
Total	477	109509

Appendix 5. Distribution of EPL Industries in the Gampaha District – 2000. (Central Environmental Authority , 2000)

Category	**Number of Industries**	**%**
Agricultural Chemical, waste Water Treatment Plant, Coil	26	8.5
Filling Station and Service Stations	59	19.2
Car Sale and Spair Parts	2	0.6
Timber and coconut shells	5	1.6
Metal Quarry	19	6.2
Rubber, Plastic and glass	59	19.2
Food, Beverages and Liquor	21	7.0
Hotel Industry	13	4.2
Animal Husbandry and Poutary	11	3.6
Pharmaceutical products and traditional medicines	5	1.6
Garment	9	3.0
Fabric, Paper, Printing and Ink	25	8.1
Coir Industry	3	1.0
Iron, Cement and Alluminium	33	10.7
PVC Items	7	2.3
Storage	3	1.0
Coconut Oil	2	0.6
Electricals and Electronic Items	5	1.6
Total	*307*	*100*

Appendix 6. Sown area and production of paddy, 1979-2003 (Department of Census and Statistics, 2003).

	Sown area (Ha)		**Production ('000 metric tons)**	
	Sri Lanka	*Gampaha*	*Sri Lanka*	*Gampaha*
1979	838 626	23 586	1 920,7	47,2
1980	844 647	25 948	2 136,8	59,9
1981	876 746	27 689	2 233,1	62,9
1982	844 163	28 213	2 159,2	72,2
1983	824 101	21 030	2 487,7	53,9
1984	990 208	29 151	2 416,5	76,3
1985	880 691	28 666	2 689,5	73,7
1986	895 691	26 370	2 584,6	62,1
1987	781 225	25 533	2 129,3	70,7
1988	867 809	26 211	2 480,9	61,8
1989	726 958	21 242	2 067,3	54,2
1990	853 354	26 147	2 540,5	66,5
1991	816 646	24 929	2 390,0	51,2
1992	803 173	19 960	2 345,3	47,7
1993	834 295	19 970	2 575,2	51,6
1994	929 620	19 848	2 687,8	51,6
1995	915 021	14 879	2 814,8	39,3
1996	748 743	12 531	2 065,1	34,5
1997	729 809	14 577	2 243,3	40,9
1998	848 263	13 503	2 697,0	28,4
1999	892 053	14 465	2 862,1	37,4
2000	877 994	12 015	2 858,8	32,2
2001	798 260	10 338	2 696,9	28
2002	852 527	11 280	2 863,7	32,4
2003	*982 216*	*15 290*	*3 069,0*	*36,9*

Appendix 7. Results from three classifications of land cover in a sub-catchment in the study area. All results in percent of total area.

	UDA	Digital class	Visual class
Rivers and Canals	0,9	0,66	0,15
Bays and lagoons, tanks	16,3	16	16,4
Home gardens	28,8	17	34,3
Scrub	2	2,3	0,9
Coconut	19,1	12,2	
Rubber	0,1		
Forest	0,04		
Subtotal	*50,04*	*31,5*	*35,2*
Paddy	15	27,4	8,5
Roads and tracks	8		
Industrial	1		
Built-up areas	0,5	18	27,4
Subtotal	*9,5*	*18*	*27,4*
Sand or beach	0,5	1	0,9
Marsh	8	5,3	11,4