Spatio-Temporal Changes in the Wetland Ecosystem of Cochin City using Remote Sensing and GIS

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By

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Certificate

This is to certify that the research work presented in the thesis entitled "Spatio-Temporal Changes in the Wetland Ecosystem of Cochin City using Remote Sensing and GIS" is an authentic record of research work carried out by Mr.Dipson P.T. under my guidance and supervision in the School of Environmental Studies, Cochin University of Science and Technology in partial fulfilment of the requirements for the degree of ***Doctor of Philosophy*** *and that no part thereof has been included for the award of any other degree.*

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DECLARATION

I hereby declare that the thesis entitled "Spatio-Temporal Changes in the Wetland Ecosystem of Cochin City using Remote Sensing and GIS" is based on the original work carried out by me under the guidance of Dr M.V. Harindranathan Nair, Assistant Professor, School of Environmental Studies, Cochin University of Science and Technology, and no part thereof has been included in any other thesis submitted previously for the award of any degree.

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Abbreviations

CESS	Centre for Earth Science Studies
CIFT	Central Institute of Fisheries Technology
CMFRI	Central Marine Fisheries Research Institute
CPT	Cochin Port Trust
CRZ	Coastal Zone Regulation
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EM	Electro Magnetic
EMP	Environment Management Plan
FACT	The Fertilisers and Chemicals Travancore Ltd
GCDA	Greater Cochin Development Authority
GIS	Geographical Information System
GLCF	Global Land Cover Facility
ICTT	International Container Trans-shipment Terminal
KINFRA	Kerala Industrial Infrastructure Development Corporation
km	Kilometre
KSREC	Kerala State Remote Sensing and Environment Centre
LNGT	Liquefied Natural Gas Terminal
m	Metre
MLC	Maximum Likelihood Classifier
MoEF	Ministry of Environment and Forests
MSL	Mean Sea Level
NGO	Non-Governmental Organisation
NH-47	National Highway-47

NHG	Neighbourhood Groups
NIO	National Institute of Oceanography
NRSC	National Remote Sensing Centre
NWIA	National Wetland Inventory and Assessment
PCA	Principal Component Analysis
RS	Remote Sensing
SAC	Space Application Centre
USGS	U.S. Geological Survey

Chapter- 1

INTRODUCTION

Contents

1.1 General Introduction

1.1.1 Background

More than half of the global population has already become urban dwellers, and that proportion is increasing. The ecological footprints of cities are spreading fast, particularly in the developing countries, which is leading to an unsustainable growth, if not a threat to the very existence of mankind. Overexploitation of environmental resources including land, water, fossil fuel etc. are a few stamps of the modern so-called development. Land use/ Land cover patterns have dramatically been altered to cater the essentials of a geometric increase in population the world has witnessed in the twentieth century. About 60% of the world's population is located in coastal belts and hence wetlands are more liable to reclamation. Hence, rapid urbanization exerts a lot of pressure particularly on wetlands. Added to that, coastal wetlands are being destroyed by erosion, dredge and fill impoundments, toxic pollutants, eutrophication, sedimentation etc.

The present study mainly focuses on Cochin basin lying between $9^{\circ} 49'$ N to $10^{\circ} 14'$ N and $76^{\circ} 10'$ E to $76^{\circ} 31'$ E in the southwestern cost of India. It includes the Cochin city, (the erstwhile municipalities of Ernakulam, Mattancherry and Fort Kochi), Kalamasserry, Paravur and Thripunithura municipalities as well as the adjoining Panchayats. Cochin, is not only a coastal city, but also is interspersed with an extensive backwater system and tidal canals forming a part of the Vembanad Estuary which receives freshwater from several rivers and salt water from Laccadive Sea. It not only sustains a rich aquatic fauna and flora but also provides navigational facility including shipping.

Cochin City is the nerve centre of a large urban agglomeration consisting the municipalities of Eloor, Alwaye, Paravur, Kalamasserry, Thripunithura, Perumbavoor and Thrikkakara as well as several panchayaths centred around the Cochin Corporation. Cochin port has trade connections with countries all over the world. At present, the city has a Naval airport on Willington Island and an International airport on the periphery of Cochin which facilitates business and tourist connections with all parts of the world.

1.1.2 Historical Background

Prior to 14th century AD, the Port of Musiris (present Kodungallor) on the north of Cochin was the main centre of commercial activities of Kerala which had extensive global trade connections, particularly with ancient Rome and Greece. In the year 1341 AD; a heavy flood silted up the Musiris harbour and formed a natural harbour at Cochin by opening a passage to the sea at Cochin (William, 1901). This caused the shifting of harbour activities and associated trades to Cochin from Musiris resulting in the sudden *urbanisation* of Mattancherry on the west bank of the backwater system. This led to the extensive reclamation of the backwater, which started during the period 1879-1889; when the Ernakulam foreshore area was greatly improved in terms of recreation and road facilities.

Dry land was very scarce in the vicinity of the Administrative Secretariat of the Kingdom of Cochin; which resulted in the need of either reclaiming land from the lake or filling up the marshlands and canals for building purpose. This conversion continued and large scale transformation of wetlands into dry area went on unabated along with the dredging and deepening of the channel and the sand bar at the channel mouth for opening of Cochin as a major port in 1940. Using the dredged materials, an island was reclaimed. This reclaimed island is the present day Wellington Island.

1.1.3 Statement of the Problem

Urban developments have exerted immense pressure on wetlands**.** Urban areas are normally centers of commercial activity and continue to attract migrants in large numbers in search of employment from different areas. As a result, habitations keep coming up in the natural areas / flood plains. This is happening in various Indian cities and towns and large habitations are coming up in low-lying areas, often encroaching even over drainage channels. In some cases, houses are constructed even on top of nallahs and drains.

In the case of Kochi the situation is even worse as the base of the urban development itself stands on a completely reclaimed island. Also the topography and geology demanded more reclamation of land when the city developed as an agglomerative cluster. Cochin is a coastal settlement interspersed with a large backwater system and fringed on the eastern side by laterite-capped low hills from which a number of streams drain into the backwater system. The ridge line of the eastern low hills provides a well-defined watershed delimiting Cochin basin which help to confine the environmental parameters within a physical limit. This leads to an obvious conclusion that if physiography alone is considered, the western flatland is ideal for urban development. However it will result in serious environmental deterioration, as it comprises mainly of wetland and for availability of land there has to be large scale filling up of these wetlands which includes shallow mangrove-fringed water sheets, paddy fields, Pokkali fields, estuary etc.

The urban boundaries of Cochin are expanding fast with a consequent over-stretching of the existing fabric of basic amenities and services. Urbanisation leads to the transformation of agricultural land into built-up areas with the concomitant problems regarding water supply, drainage, garbage and sewage disposal etc. Many of the environmental problems of Cochin are hydrologic in origin; like water-logging / floods, sedimentation and pollution in the water bodies as well as shoreline erosion.

1.1.4 Objective

The principal objectives of the study are as follows

- Study the Land use / Land cover Map of Cochin city with special importance to Wetlands.
- Spatio-Temporal change of wetlands of Cochin City over a few decades.
- To find and map the paddy and Pokkali Cultivating areas.
- Spatio-Temporal changes in built-up area.
- To find the reasons of reclamation and disappearance of Pokkali and paddy cultivation.
- To find the areas of wetlands vulnerable to reclamation.
- Formulate management plans and policies so as to reduce the impacts of wetland degradation.

1.1.5 Limitations of the Study

This study attempts to detect LULC changes of Cochin using satellite remote sensing. As with the case of all the studies, none of them are complete. Every studies end at a point, leaving enormous scope for future studies. Similarly, during the course of every study it meet with various limitations. A few limitations faced during this study are as listed below.

- The data for the year 1944 was a toposheet prepared by the U.S military department. As it was composed using technology which is obsolete now; it was only possible to extract three classes namely Estuary, Paddy and Pokkali from it.
- After 1944, the next available authentic data was the toposheet of 1967; then for 1973, the first available satellite imagery was acquired. These discrepancies in the availability of image are a limitation, since no temporal linearity could be followed. Also, there is a long data gap of thirty years between 1944 and 1973.
- Of all the six images used for the study, image of the year 1973 was of low resolution (60 m). However, imageries with better resolution could be procured for 1990 (30 m) and with 23 m resolution for the years 1998, 2007, 2009 and 2011.

1.2 Introduction to Wetlands

Wetlands are one of the most productive ecosystems, serving as a habitat for a wide variety of flora and fauna. They serve not only as major water sources but also have other significant environmental values, which include flood control, agricultural production, pollution abatement, inland navigation, fish production etc. A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. Primarily, the factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation that is adapted to its unique soil conditions and water quality. Wetlands play a number of roles in the environment, principally water purification, flood control and shoreline stability. Wetlands are also considered as one of the most biologically diverse of all ecosystems, serving as home to a wide range of plant and animal life.

Under the Ramsar International Wetland Conservation Treaty, wetlands are areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tide does not exceed six meters. Wetlands may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands.

Wetlands are an integral part of natural landscapes. They provide diverse habitats and productive environments. Wetlands enhance environmental quality by increasing landscape diversity, providing habitat for a variety of fish and wildlife species, protecting and improving the quality of surface water and groundwater, controlling soil erosion and providing flood control. In addition, wetlands provide important economic resources and heritage values, including values and culture associated with traditional land use, the information of which are passed on from generations to generations. The value of the world's wetlands are increasingly receiving due attention as they contribute to a healthy environment in many ways. They retain water during dry periods, thus keeping the water table high and relatively stable. During periods of flooding, they mitigate flood and trap suspended solids and attached nutrients. Thus, streams flowing into lakes by way of wetland areas will transport fewer suspended solids and nutrients to the lakes than if they flow directly into the lakes. The removal of such wetland systems because of urbanization or other factors typically causes lake water quality to worsen. In addition, wetlands are important feeding and breeding areas for wildlife and provide a stopping place and refuge for waterfowls and other migratory birds. As with any natural habitat, wetlands are important in supporting species diversity and have a complex of wetland values.

The absence of land suitable for development in coastal areas has resulted in more proposals to dredge and fill existing wetlands in order to accommodate increasing urban sprawl. The potential profit to be derived from developing these wetland areas more than compensates for the initial costs of alteration. In this manner, wetlands of the study area are decreasing at an alarming rate. Wetland areas are reclaimed as fields, plantations, built-up area etc. Decline in wetland areas may result in increased environmental stress in the area. Lot of organisms depending on the wetlands will suffer habitat loss. Human society and its infrastructure in the coastal zone have already been affected by wetland loss and will face additional threats as additional wetlands are lost.

In a nutshell, the absolute significance of wetland is that, it provides habitat for aquatic birds, other animals and plants, including numerous threatened and endangered species; production of fish and shellfish; water storage, including mitigating the effects of floods and droughts; water purification; recreation; timber production; food production; open space and aesthetic values. Usually wetlands provide some composite of these values; no single wetland in most instances are inclusive of all these values. The composite value typically declines when wetlands are altered. In addition, the effects of alteration often extend well beyond the immediate area because wetlands are usually part of a larger water system.

1.3 Introduction to Remote Sensing

Remote sensing is defined as the technique of obtaining information about objects through the analysis of data collected by special instruments that are not in physical contact with the objects of investigation. Remote sensing, in other words, is the observation of an object from a distance. Information about features on the Earth's surface can be gathered from orbiting remote sensing satellites or from an aircraft (e.g., aerial photography). Satellite imagery and aerial photographs can be combined with a wide array of other geographic data for a multitude of applications, including, but not limited to assessment and monitoring of vegetation, soil surveys, mineral exploration, water resources planning and monitoring, urban planning, agricultural property management and planning, crop yield assessment, and natural disaster assessment. Remote sensing is the method which enables, measurement of object properties on Earth's surface using data acquired from aircraft and satellites. It measures something at a distance, rather than in situ, and, for this research's purposes, displays those measurements over a two-dimensional spatial grid, i.e. images.

Remote-sensing systems, particularly those deployed on satellites, provide a repetitive and consistent view of Earth facilitating the ability to monitor the earth system and the effects of human activities on Earth surface. There are many electromagnetic (EM) band-length ranges Earth's atmosphere absorbs. The EM band ranges transmittable through Earth's atmosphere are sometimes referred to as atmospheric windows. The human eye only detects, viz. the reflective solar radiance humans actually see, that part of the EM scale in the band length range 0.4 – 0.7 µm. But remote sensing technology allows for the detection of other reflective and radiant (e.g. thermal) energy band-length ranges that reach or are emitted by Earth's surface, and even some Earth's atmosphere reflects, e.g. the EM reflective qualities of clouds. Hence, for viewing purposes red, green and blue (RGB) false color composites are used to express the reflective qualities of objects in these EM band-length groups, and the combination and mixing of these false color assignments express the true physical reflective qualities of all objects present in an image. Based on the number of electromagnetic bands used; there are two types of remote sensing, namely *Multi Spectral Remote Sensing* and *Hyper Spectral Remote Sensing.*

In the visual interpretation of remotely sensed images, a variety of image characteristics are brought into consideration: color (or tone in the case of panchromatic images), texture, size, shape, pattern, context, and the like. However, with computer- assisted interpretation, it is most often simply color (i.e., the spectral response pattern) that is being used. It is for this reason that a strong emphasis is placed on the use of multispectral sensors (sensors that, like the eye, look at more than one place in the spectrum and thus are able to gauge spectral response patterns), and the number and specific placement of these spectral bands.

1.4 Introduction to GIS

Geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology. The primary benefit of GIS is the ability to interrelate multiple types of information assembled from a range of sources. These data do not necessarily have to be visual. GIS(Shape Files or Geodatabase) files are helpful for interpolating and visualizing many other types of data, e.g. demographic data. Many study and research models rely on the ability to analyze and extract information from images by using a variety of computer available research tools and then express these findings as part of a project with images in a variety of layers and scenes.

GIS in recent times has transformed into Geo-Information technology with the integration of Mapping techniques, Surveying, Remote sensing & Satellite Imagery, photogrammetric, Global Positioning Systems (GPS), Cartography. Geo-Information Technologies have the potential to make a tremendous impact on all planning & management activity. It presents a wonderful opportunity in the private & public sector for generation of useful & cost effective applications.

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Chapter- 2
LITERATURE REVIEW

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2.1 Land Use / Land Cover (LULC) Mapping and LULC Changes

Meng (1995) have studied the LULC changes occurred during 1995 to 2000 in the Zhangye oasis of Hexi Corridor, China, by taking 2 false color composite Landsat 5 TM (Thematic Mapper) images of band 4, 3 and 2 and interpreting according to the land resources classification system of Resources and Environmental Database of the Chinese Academy of Sciences. The study shows that great changes have taken place in the LULC pattern in the oasis during the study period.

Kwarteng and Chavez (1998) have studied the LULC changes in Kuwait City and environs using multi-temporal Landsat Thematic Mapper (TM) data acquired on 17th February 1986 and 28th February 1993. This study demonstrates the usefulness of such data for both surface / spectral mapping and temporal change detection. High pass spatial filters with a relatively large kernel (201 pixels by 201 pixels) were used to enhance high frequency information in both the bright desert and dark urban areas. The filtered results were edge enhanced to sharpen the local textural information. Color composites were made for analyses using the TM bands 2, 3, 4 and 2, 4, 7. The two multi-temporal images were geometrically and radiometrically calibrated to each other and used as input to an automatic change detection procedure. The `change image' composite, made from the individual change image results generated using TM bands 2, 4 and 7 illustrates the changes associated with coastal wetlands, vegetation and sand surface differences caused by the large oil spill that occurred during the 1991 Gulf War at the Greater Burgan oil field.

Miller *et al (1998)* analysed the LULC changes in the Northern Forest region of Vermont, New Hampshire, and western Maine, USA using Landsat multi-temporal and Multi-Spectral Scanner (MSS) data. They characterized the land cover types, landscape patterns and land cover changes during a 18-year time period by analyzing 8 Landsat MSS scenes from 1973, 1978, 1984/85, and 1990/91. Four watershed segments within the Northern Forest area were analyzed. Data processing was performed by using the software Micro Image (Terra-Mar Resource Information Services), IDRISI (Clark University), ATLAS DRAW (Strategic Locations Planning, Inc.), and Atlas GIS (Strategic Mapping, Inc.).

Daiyuan *et al* (1999) have done temporal (1958–1993) and spatial patterns of land use changes in Haut-Saint-Laurent (Quebec, Canada) and their relation to landscape physical attributes. Using SPANS GIS software (INTERA TYDAC 1991), they developed a spatial database which included primarily 5 temporal land use layers (1958, 1965, 1973, 1983 and 1993), a geomorphological deposit layer (Bariteau 1987, 1988) and a topography layer. From the 5 temporal land use layers, 4 land use transformation layers were extracted by overlaying the successive land use layers, namely 1958–1965, 1965–1973, 1973–1983, and 1983–1993 respectively. These 4 layers recorded the type of land use changes that occurred in these time periods. Then, the transition matrix for every successive layer was built to measure the rate of land use change in different time intervals. The 4 land use transformation layers were used for subsequent analyses with GIS and for the canonical correspondence analyses.

Seto *et al* (2002) have monitored land-use changes in the Pearl River Delta using Landsat TM. For this study, they acquired 2 TM scenes from Landsat World Reference System path 122, row 44 taken on 10th December 1988 and 3rd March 1996. For the radiometric calibration, a number of techniques were tested. The 23 stable and changed land-covers were identified in step 2 and were used to classify land-use change. First they performed a Supervised MLC and then a supervised classification after collecting training sets by field survey. Most of the land-use change was by converting agricultural land as urban areas, which have increased by more than 300% between 1988 and 1996. Field assessments confirm a high overall accuracy of the land-use change map (93.5%) and support the use of change vectors and multidate Landsat TM imagery to monitor land-use change. Results confirm the importance of field based accuracy assessment to identify problems in a land-use map and to improve area estimates for each class.

Zhao *et al* (2003) have assessed the land-use changes of Chongming Island using cloud-free LANDSAT Thematic Mapper (TM) imageries of 3 periods: December 1990, February 1997 and June 2000 (ETM). First, the orthocorrected ETM panchromatic image of 2000 was geo-rectified and registered to a Universal Transverse Mercator (UTM) coordinate system, by using road intersections and other prominent visible features on the existing topographic map of Shanghai at the scale of 1:100000. Then, the imageries of 2000 were used as the master dataset to rectify the TM RAW images of 1990 and 1997. This study explored the relationships between island growth and LULC changes and predicted what the habitat would be like in the future and tried to find more effective use of this new growing resource. At last, this study provided some preliminary management plans for Chongming Island that will coordinate the development of local economies and the conservation of wild life and their habitats.

Wenshi *et al* (2008) have quantified LULC changes in Pearl River Delta (PRD) of South China and its impact on regional climate over the last 2 decades. The land use change analyses were accomplished by applying a change detection method to a set of Landsat imagery and ancillary data acquired from 1970s to 2000. The results indicate that the urban expansion is the prevailing land use change in the PRD. Impact of land use change on regional climate was simulated by using a meso scale climate model. Two different land cover datasets (1990 and 2000) were the inputs of the model to investigate the impact of urbanization on regional weather and climate condition in summer 2005. The simulation results show that rapid urban expansion can substantially alter regional climate conditions including monthly mean temperature, precipitation, moisture and surface heat fluxes.

Tobias *et al* (2008) studied the land use changes in Arges County of Southern Romania after the collapse of socialism. They used Landsat TM / ETM+ images to classify land cover maps and assess landscape pattern changes from 1990 to 2005. Ground truth for training and validation purposes was mapped in the field and from ancillary datasets. Extensive field visits were carried out in two communes in the summers of 2004 and 2005. Participatory mapping was conducted where local farmers mapped their fields and communal land use by using transparent overlays.

Ramakar *et al* (2008) studied the changes in spatial extent of urbanization in Haridwar, India and patterns of periodic changes in urban development (systematic / random) during 1989 to 2002 in order to develop future plans. IRS data was used to map the spatial extent of urbanization for the 1989, 1998, 2000 and 2002. Geographical Information System (GIS) and Entropy approach, which makes the use of mathematical notions related to thermodynamics and the disorder or randomness of organization of a system, were used to study the pattern of urban development. The distributed entropy and relative mean entropy values were evaluated considering two location factors: (i) Urban development at peripheries of 1000 m each from the centre of the city (ii) Urban development at peripheries of 1000 m each from the highway along the upper Ganga canal. The results indicate a significant periodic urban development in Haridwar during 1989-2002, specifically after 1998. The application of entropy is found to be a better alternative to conventional technique.

Vemu and Pinnsmaneni (2010) prepared LULC maps of Devak catchment in district Jammu (J&K) for the years 1958, 1979, 1990 and 1998 by Image processing and visual interpretation of the IRS-1A LISS II (FCC) data for the year 1990, IRS-1C LISS-III (digital data) for the year 1998 and SOI topographic maps for the year 1958 & 1979. Level-I classification was adopted and identified the various categories of land use as Mixed forest (mainly pine), agricultural land with sparse habitation, open scrub & scattered trees and water bodies (river). The study reveals a large change in the area of different land use categories during the period from 1958 to 1998. The open scrub & scattered tress covered an area of about 46.17% in 1958, which reduced to 9.90% by 1998, while during the same period the area covered with mixed forest increased from 36.68% to 65.84%. The agriculture & sparse habitation areas also increased from 7.09% to 13.92%. The main river drainage covering an area of about 10% of the total catchment in 1998.

Prakasam (2012) studied the changes in land use and land cover in Kodaikanal Taluk over 40 years period (1969-2008). The study has been done through remote sensing approach using SOI Taluk map of Kodaikanal (1969), and Landsat imageries of May 2003 and April 2008. The land use land cover classification was performed based on the Survey of India Kodaikanal Taluk map and Satellite imageries. GIS software is used to prepare the thematic maps. Ground truth observations were also performed to check the accuracy of the classification. The present study has brought to light that forest area that occupied about 70 per cent of the Taluk's area in 1969 has decreased to 33 per cent in 2008. Agricultural land, Built up area, Harvested land and Waste land also have experienced change. Built up lands (Settlement) have increased from 3 per cent to 21 per cent of the total area. Kodaikanal area is identified as one of the biodiversity area in India. Proper land use planning is essential for a sustainable development of Kodaikanal Taluk.

Carmelo *et al* (2012) conducted a study to characterise the dynamics of changes in the area of Avellino (Southern Italy) during a 50 year period (1954-2004), processing a multi-temporal set of images: aerial photos (1954), and Landsat scenes (MSS 1975, TM 1985 and 1993, ETM+ 2004). LULC pattern and its changes are linked to both natural and social processes whose driving role has been clearly demonstrated in this study: after the disastrous Irpinia earthquake (1980), specific zoning laws and urban plans have significantly altered the landscape changes.

Yohannas *et al* (2012) used satellite imagery to assess spatio-temporal LULC changes in the Bale Mountains, Ethiopia for a period of 4 decades. This study aimed to identify the main drivers of change in vegetation patterns and to discuss the implications of LULC changes on spatial arrangements and trajectories of floral communities. Remote sensing data acquired from Landsat MSS, Landsat ETM + and SPOT for four time steps (1973, 1987, 2000,and 2008) were analyzed using 11 LULC units based on the dominant plant taxa and cover types of the habitat. Change detection matrices revealed that over the last 40 years, the area has changed from a quite natural to a more cultural landscape.

Ali (2012) have analyzed the Spatio-temporal pattern of LULC changes in the Yalnizeam and Uğurlu forest planning units which are located in the northeast corner of Turkey. The investigation also evaluates the temporal changes of the spatial structure of forest conditions through the analyses of forest-cover type maps from 1972 and 2005 using geographical information systems and FRAGSTATS(TM). During 1972 to 2005, there was a net increase of 1,823 ha in forested areas, and the cumulative forest improvement accounted for 2.06 %. In terms of spatial configuration, the landscape structure in the study area changed substantially over the 33-year study period, resulting in fragmentation of the landscape as indicated by large patch numbers and smaller mean patch sizes, owing to heavy grazing, illegal tree felling and uncontrolled stand treatments.

Atiqur *et al* (2012) assessed the LULC changes in the North-West District of Delhi during 1972 to 2003 using RS and GIS Techniques. The RS data used in study is Aster image of 2003 with a spatial resolution of 15 m and SOI toposheets of 1972 at the scale of 1:50,000. Supervised digital classification using MLC classifier was applied for preparing LULC map. A change detection model was applied in ERDAS Imagine to find out the LULC changes. Eight land use classes were identified, with the main dominating classes were built up area and agricultural land. A drastic change was observed during 30 years of time i.e., (1972 - 2003). In 1972, 92.06% of the land was under agricultural practice, which reduced to 64.71% in 2003 - a 27.35% decrease in agricultural land in 3 decades. On the other hand built up area increased from 6.31% to 34% in the same period, the main cause being the population growth due to the migration from surrounding small cities and rural areas of Delhi.

Fapeng *et al* (2012) have explored the land-cover change between 1985 and 2005 in the Yarlung Tsangpo River (YTR) basin and found that only 1% of the land cover in the YTR basin changed during this time period. The significant land-cover changes included the increase in forest and built-up areas contributed by decreases in grassland, water and wetland areas. The most rapid land-cover change occurred in built-up areas with an annual increase of 2.07%. There was an obvious vertical distribution pattern for land-cover types in the YTR basin; from low to high, the average altitudes were forest, farmland, built-up, grassland, water and wetland, and bare land. The average altitude and slope for most land-cover types did not vary over the past 20 years. However, the average altitude and slope of built-up land significantly decreased, especially in the zone between 3,500 and 4,000 m. The water and wetland area in altitudes above 4,500 m increased; however, they decreased in the zone between 3,500 and 4,000 m. Natural factors cause most land-cover changes, whereas the increasing intensity of human activities cause some changes to built-up and farmland. .

2.2 Mapping and Spatio-Temporal Change Analysis of Wetlands

Several studies have been carried out using various methodologies and algorithms to map and assess the spatio-temporal changes of wetlands using various sets of remotely sensed data. Some works of international and national relevance are given below.

Baghdadi *et al* (1999) mapped wetland and studied changes observed during the vegetation season in the Mer Bleue region (near Ottawa, Canada). This paper reports the results of an experiment carried out to examine the potentials of Polarimetric C-band Synthetic Aperture Radar (SAR) for mapping various wetland classes. The Mer Bleue region was surveyed by the C-band (5.3 GHz) Polarimetric (HH, HV, VH, VV) SAR of the Canada Centre for Remote Sensing (CCRS) at 3 times within the vegetation season: 16 June (spring flush),6 July (mature growth) and 3 October 1995 (senescence). Signatures of 6 different cover types (forested and non-forested peat bog, marsh, open water, clearings and forests) have been derived as a function of incidence angle. Separability between various classes was used to determine the relationships between season(s) and polarization(s) needed to differentiate various wetland classes. A supervised classification was used for wetland mapping by means of multipolarization data. This study demonstrated some of the capabilities of SAR at C-band for mapping wetlands.

Yousif and Zuhair (1999) have compared the abilities of 3 different radar satellite imaging systems (JERS-1, ERS-1 and Radarsat) and 3 different optical satellite systems (Landsat MSS, SPOT-XS and Landsat TM). By that study, mangrove deforestation was detected in the delta of the Mahakam River, East Kalimantan (Indonesia), using Landsat MSS 1982, Landsat TM 1994, and fused images (Landsat TM 1994 and ERS-1 1996 radar data).

Gesche *et al* (2004) have mapped the mangrove coverage in North Brazil to assess the changes observed during 1991 to 1999 using Landsat TM Data. The purpose of such a mapping was the storage and evaluation of the heterogeneous data sets of the inter-disciplinary scientific research program MADAM (Mangrove Dynamics and Management), which aims to develop recommendations for a tailored integrated coastal management scheme for the mangrove ecosystem at Braganca (North Brazil). The paper describes the integration of remote sensing data, aerial photographs, as well as point data provided by fieldwork from different scientific fields. Using various innovative processing techniques and different scale-resolution levels, an assessment of temporal and spatial changes of the mangroves, the type of mangrove structure, a land-use cover analyses as well as the adjacent rural socio-economic impacts were done. The definition of the spatial level of details was found to be a major issue in the development of the GIS, as well as during the processing and analysis procedures.

Alphan and Yilmaz (2005) studied the temporal changes in the coastal landscape between 1984 and 2000 using digital interpretation of remotely sensed satellite data. Pair wise comparison methods were used to quantify changes from 1984 to 1993 and 1993 to 2000 using multi-temporal Landsat TM and ETM+ images, acquired in 1984, 1993, and 2000, respectively. The coastal area change was 2448 ha from 1984 to 1993, which increased more than two-fold, to 6072 ha during 1993 to 2000. The change trends were determined using the information provided from individual change detection outputs of different periods. The most prominent changes were estimated to have occurred in agriculture, urban and natural vegetation cover.

Xiaojun and Zhi (2005) have done a Land use / Land cover (LULC) mapping of an estuarine watershed of Pensacola estuarine drainage area (PEDA), USA during the period 1989-1996-2002 using Landsat TM imageries.

Tefri *et al* (2010) quantified the wetland dynamics and estimated the wetland loss in a 17 443 km^2 area of the Choke Mountain range in the Upper Blue Nile basin, a key headwater region of the river Nile, using satellite remote sensing imageries obtained during 1986 to 2005. A hybrid supervised / unsupervised classification approach was used to classify the images. Overall accuracies of 94.1% and 93.5% and Kappa Coefficients of 0.908 and 0.913 for the 1986 and 2005 imageries, respectively were obtained. The results showed that 607 km^2 of seasonal wetland with low moisture and 22.4 km^2 of open water were lost in the study area during the period 1986 to 2005.

Chang-Qing *et al* (2011) have studied the coastal wetland changes in the Yancheng National Nature Reserve (YNNR) using remote sensing technology and landscape matrics analysis. The results reveal that grass flat and reed areas have significantly decreased, whereas agriculture fields, aquaculture ponds and built-up areas have continuously increased from 1988 to 2006. The spatial pattern of the coastal landscape has become fragmented and heterogeneous under great pressure from rapid economic development and population growth. The wetland changes have important impacts on natural habitat of the red-crowned cranes. The results of this study provide basic information that is required for developing measures toward a sustainable management and conservation of the YNNR.

Eleni (2012) attempted a study to detect and map the changes occurred during 1987 to 2007 in the ecosystem of Evros River in Greece. The change detection techniques included the analysis of vegetation and water indices, the Principal Component Analysis (PCA), the Tasseled Cap transformation and change vector analysis as well as a Post classification analysis performed on 2 Landsat multi temporal image datasets. The first one was referred to the imageries during 1987 and 2001 and the other to 2001 and 2007.

Moayeri *et al* (2012) conducted change detection during 1990 to 2005 at Hurol Azim wetland located in the southwestern Khuzestan province, bordering Iran and Iraq using principal components analysis of TM and ETM + sensor of Landsat imagery. Wetland water supply sources include: Karkheh River and its tributaries, Mime, Doiraj subsets of Iran and the Tigris in Iraq. Landsat satellite images reveal that Hurol Azim wetland area has shrunk in recent decades. The study shows that this wetland area has shrunk from 515.4 km^2 in 1990 to 230.59 km^2 in 2000. The main reasons for wetland reduced water levels are dam of Karkheh and frequent droughts.

Rao *et al.* (1999) studied the Spatio-temporal changes occurred in the coastal wetlands of Sunderbans delta of West Bengal, India between 1973 to1993 using the Landsat MSS data for 1973 and European Remote Sensing (ERS-1) and Synthetic Aperture Radar (SAR) data for 1993. Shrinkage of the wetlands is seen on the periphery of Calcutta due to urbanization as well as the development of new islands in the active coastal zone have been observed over the period of 20 years.

Rajiv *et al* (2001) have done mapping *and monitoring* for deriving conservation strategies of Harike wetland ecosystem in Punjab *through remote sensing data*. The LULC map of the Harike wetlands was prepared by visual interpretation of IRS-1A LISS-I multidate data (post monsoon October 1992 and pre monsoon-March 1993) in the form of false colour composites (FCC) generated from bands 2, 3 and 4 on 1:50,000 scale. Standard image interpretation characteristics such as tone, texture, shape, size, pattern and association were used to delineate different land use categories. Procom 2 was used to enlarge the film diapositives for proper identification and delineation of various land use categories and to transfer the details to a topographical base map prepared by survey of India (SOI) on 1:50,000 scale. Pre monsoon and post monsoon variations in water spread and turbidity of the water in the lake were also recorded.

Dutta and Kotoky (2001) have studied the sequential changes in the wetlands of the Dhansiri River channel between the years 1914, 1975, 1990, 1995 and 2000 using SOI toposheets (1914 and 1975) and Indian Remote Sensing (IRS) satellite imagery (1990, 1995 and 2000). The satellite imageries and SOI toposheets from 1910-1914 were registered to the base map using a set of Ground Control Points (GCPs) in ERDAS IMAGINE 8.5 software. Thematic maps of different periods were prepared on 1:50.000 scale and were integrated using Arc view GIS.

Sridhar (2003) had mapped and quantified the changes in the mangrove forests of Kakinada, Andhra Pradesh Bay during March, 1994 to March, 1995 using IRS-IB LISS-II data on 1:50,000 scale and corresponding to SOI toposheets 65 L/1, L/2, L/5 and L/6. The LULC maps were interpreted visually by following the legend prescribed by Department of Space under National Mission Programme. Sequential nature of IRS data provides opportunity to monitor changes in the land use activities in the mangroves. Both visual and digital analysis of IRS data provided useful information. But, only limited ground truthing were carried out on coastal features such as mangrove forest, fish ponds, saltbeds and other land uses.

Space Application Centre (SAC), ISRO, Ahmedabad has carried out classification and mapping of the Indian wetlands during 1990-91 (Ravindran and Babu Ambat, 2007).

2.2.1 Studies carried out on Wetlands of Kerala

Nair and Sankar (1995) have done classification and evaluation of coastal wetlands of Kerala using Indian remote sensing satellite. They have used geocoded IRS-1A LISS II FCC (bands 2, 3, 4) images for the fair weather period of 1990-91 on 1:50,000 scale for the preparation of coastal wetland maps. In order to generate information on wetlands on a regional / national level, a classification suggested by Space Application Centre has been suitably modified by CESS so as to suit to Kerala's geomorphology.

Classification of Backwaters (Kayal in Malayalam) in the coastal zone of Kerala was done by Nair and Thrivikramji using IRS LISS II data of the 1990-91 period (Nair and Thrivikramji, 1996).

Environmental degradation including losses due to reclamation of Vellayani Kayal was done by Nalin Kumar and Nair using IRS data (Nalin Kumar and Nair, 1998).

Sajeeva and Subramanian (2003) have quantified LULC changes in the Ashtamudi wetland region from 1967 to 1997 using IRS-1A LISS II, and IRS-1C LISS III images and SOI topographic maps. The study reports that the increasing population density, change in family system, extensive coconut husk retting and deposition of husk waste along the margin of the estuary, solid waste deposition from factories, reclamation of the estuary by local population and low profit obtained from paddy cultivation are the main responsible factors for the large-scale LULC conversions in the wetland region.

The impact of sand and clay mining on Muriyad Kayal which forms part of Vembanad-Kol was pointed out by Sreekumar and John (2004).

Survey and inventory of wetlands of Kerala was done by Centre for Environment and Development (CED). They mapped a few selected areas of wetlands in Kerala on 1:125000 scale using SOI 1:50000 scale toposheets and IRS LISS III data during December 2000 to March 2001. In that study only a part of Vembanad-Kol Wetland was included (Ravindran and Babu Ambat, 2007) .

Vijayakumaran Nair (2010) has prepared a Directory of Wetlands of Kerala, A Research Project of Kerala Forest Research Institute. They have mapped all the wetlands, both inland and coastal regions of Kerala. But the resolutions of the map are very low.

Space Applications Centre (SAC), Ahmedabad and Kerala State Remote Sensing & Environment Centre, Thiruvananthapuram (SAC & KSREC, 2010) have mapped all the wetlands of Kerala and prepared a Wetland Atlas, as a part of the National Wetland Inventory and Assessment (NWIA), a Project sponsored by Ministry of Environment and Forests (MoEF), Government of India.

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Chapter- **3**

STUDY AREA

Contents

Study area is located at the western side of Kerala, the south-western state of India. It comes under the Ernakulam district located between 76°9'25" E - 76°24'28" E longitudes and 9°47'26" N - 10°10'38" N latitudes. The total extent of this study area is approximately 711 km^2 covering the following areas of Cochin Corporation, 7 Municipalities and 31 Panchayaths. The Study Area is shown in Map-3.1. and the List of local governing bodies in the study area is given in Annexure 1.

About one third of the study area comes under the Ramsar Classification (1971) of Wetlands, of which nearly half (42.75%) of the portion is the Vembanad estuary. It is part of Vembanad Kol wetland, which is one of the largest coastal wetland systems of India and is among the 3 Ramsar sites of Kerala. The study area is a complex system of wetlands - Pokkali fields, paddy fields, estuary, mangroves, rivers and beaches. Even though, the paddy fields are located in the eastern fringes of the study area, for this study, they are considered as a part of the wetlands according to Ramsar Classification System for Wetland Type, since they are seasonally flooded.

Also, unlike the Pokkali fields in the study area, these paddy fields are not subjected to mangrove intrusions.

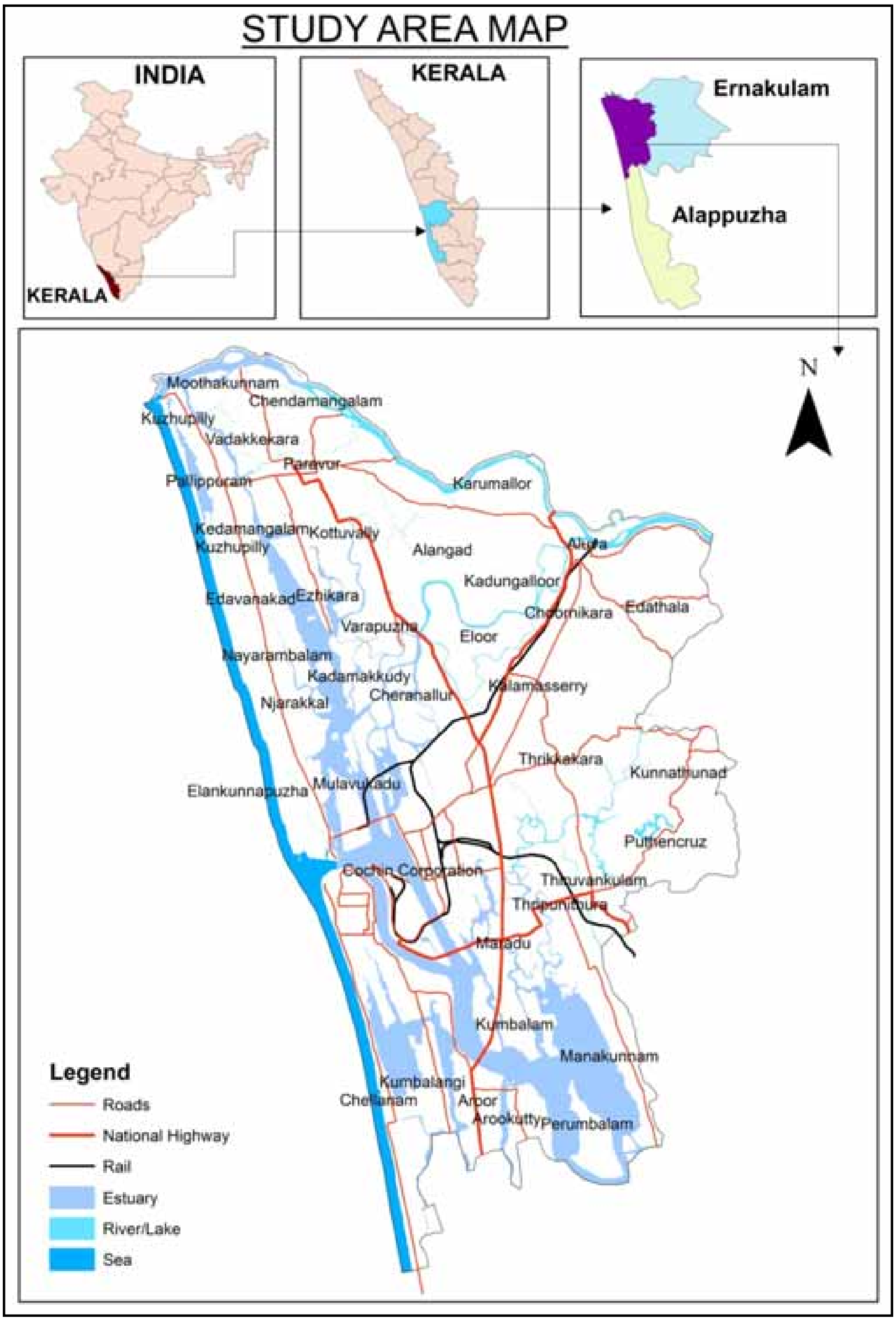
Cochin city is the fast developing economic capital of Kerala. Wetlands also, bear the brunt of this development and as a result, its extent is diminishing rapidly. The new projects like International Container Trans-shipment Terminal (ICTT) at Vallarpadam and Smart city act as catalysis for the wetland degeneration.

3.1 Climate

There are two rainy seasons; 1. The prominent south-west monsoon season during June, July, August and September and 2. A weaker north-east monsoon (also considered as the retreating phase of the south-west monsoon (during the months of October and November) with a brief dry spell between the two during early October. The yearly average rainfall is about 300 cms. Since the rainy season extends to about 6 months, drainage is very important particularly in the urban core of the study area. Also, since there are continuous rains during the rainy season, any modification of the land surface without due consideration to the rainfall climatology, is likely to cause denudation in the eastern sloped terrain due to erosion as well as water logging in the flat western areas.

The driest month is January followed by February, December, March, April and November respectively. These months are the most ideal for construction activities as the number of man-days lost due to heavy rains will be less.

The hottest months (March to May) coincide with the time when the sun is positioned near 9^{o} N latitude. During a year, south-facing slopes are more exposed to the sun making it very uncomfortable, particularly since the humidity is very high. Hence, southward slopes in a hilly terrain as in the eastern low hills of the study area are less suitable for human occupation.



Map-3.1 Study area Map

The relative humidity, which is a major determinant of human comfort, is minimum during January followed by December, February, March, April and November. Maximum humidity is observed during July, August and June. The hottest months of the year is April with a daily maximum above 32 ^{o}C and coolest month of the year is July with a diurnal variation between 28.1 ^{o}C and 23.7 ^{o}C. It can be said that the study area is free from winter season and has only rainy season and summer season (Benjamin, 1998).

3.2 Vegetation

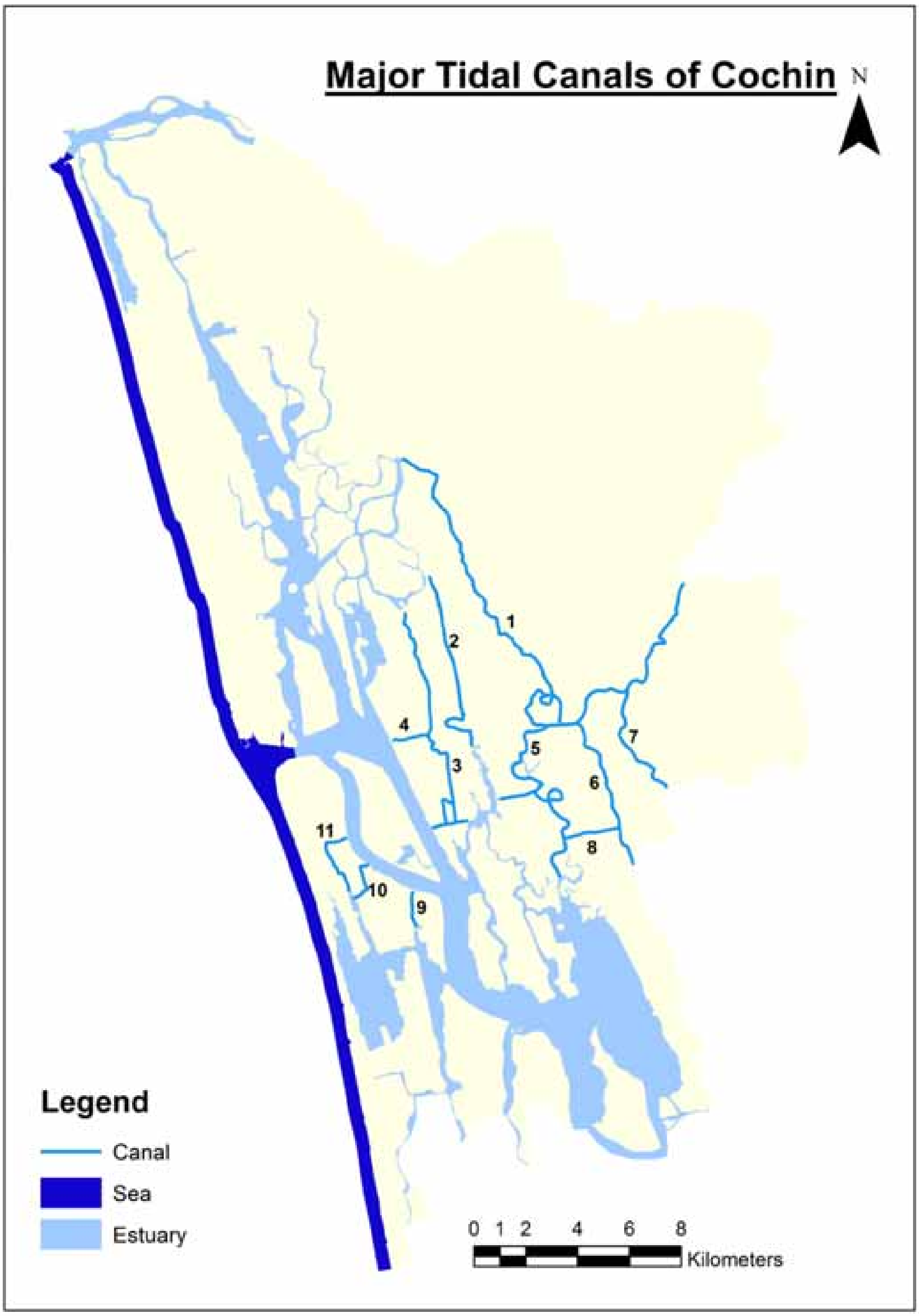
Vegetation of any area is determined by different combinations of edaphic, climatic and biotic factors. Each plant needs a particular soil pH for its best growth and most of the plants prefer neutral to slightly alkaline condition. Another decisive factor is the water table. Salinity of the soil, if very high, causes physical dryness in the soil by causing exosmosis from the roots resulting in the death of the plant. Further, near the seashore, salt spray can scorch the leaves of plants. However, there are lots of plants like mangroves, coconut trees etc., which are resistant to high soil salinity and sea-salt sprays.

In the eastern lowhills, soil is lateritic with a low water table and easy drainage. The western flatland shows a distinct edaphic condition of clayey or sandy-clay or sandy soil with a very high water table. The land is less than 1 meter above MSL. The plants are found to reveal remarkable zonation even within few tens of meters from the backwater system (Benjamin, 1998). In the waterward and landward edges of intertidal areas, vegetation is found to be exclusively mangrove species, whereas in the areas above the high tide level, remnants of mangrove species along with mesophytic vegetation are found to co-exist. Vegetation of the backwater shores (Mangrove and associated vegetation) exists in patches in the shorelines of the backwater system, particularly, in the intertidal areas. These plants, that once relentlessly protected the shores, are now being destroyed to residual remnant stands.

3.3 Surface Hydrology

Muvattupuzha and Periyar are the two rivers that flow through the city of Kochi. Estuarine area covering about 101.4 km^2 is a part of the Vembanad Lake (Kaayal in Malayalam) which spreads out in the 4 districts of Trichur, Ernakulam, Kottayam and Alappuzha covers an area of about 210 km^2. Vembanad wetland system is the largest of its kind on the Indian west coast. Nearly half of the population of Kerala depends directly or indirectly on this wetland or its drainage basins. The wetland system with its drainage basins cover an area of about 16,200 km^2, which is about 40% of the area of Kerala. The Vembanad Lake receives most of its fresh water supply through a network of rivers: the Pampa, Achankoil, Meenachil and Muvattupuzha rivers in the south and Periyar in the north. These rivers also bring sediments, plant nutrients and toxic pollutants. Vembanad estuary is comparatively deeper in navigation channels where the depth varies from 8 to 12 meters, whereas in other parts, it is 0.75 to 5 meters. The width of the backwater system varies from 100 m to several kms (Benjamin, 1998). The backwater system is fringed with wetlands, a good part of which has been already reclaimed. The extent of the backwater is continuously decreasing due to siltation and land reclamation. The backwater system has two permanent openings to the sea, one at Cochin and the other at Azhikod, through which seawater enter the estuary system.

Tidal canals play a vital role in the surface hydrology of Cochin City. They are Edappally thodu, Thevara-Perandoor canal, Changadampokku thod (Barge way canal), Karanakkodam thod, Adimuri thod, Punchapadam thod, Kari thod, Pooripuzha, Chithrappuzha, Panar, Mullasserry canal, Kanjiramattom canal, Andhakaran thod, Chittoor puzha, Pashni thod, Pallichal thod and Rameswaram canal (Alex, 2005). Major tidal canals are shown below in Map 3.2.



Map-3.2 Major Tidal Canals of Cochin

1- Edappally thodu	7- Karingachirapuzha
2-Changadampokkuthod) / Karanakkodam thod	8- Andhakaran thod
3- Thevara-Perandoor canal	9- Pashni thod
4- Mullasserry canal	10- Pallichal thod
5 Chithrappuzha / Poornipuzha	11- Rameswaram canal
6- Kaniyampuzha	

3.4 Physiography (Landform)

Cochin is a coastal settlement interspersed with backwater system and fringed on the eastern side by laterite-capped low hills from which a number of streams originate and drain into the backwater system. The western part of the study area is a flat coastal zone which forms a part of the coastal plains of Kerala and the eastern low hills are part of the midland region. Based on physiography, the study area lies in the low land region (<7.5 m above MSL) (Benjamin, 1998).

According to Benjamin (1998) the western flat land comprises of 52 drainage units covering an area of 115 km^2 and islands in the backwater system with a total area of 56.4 km^2. The backwater extending to an area of 72.6 km^2 also comes within this zone. The eastern low hills, covering an area of 291 km^2, comprises of 21 stream basins or micro-catchments, each with independent watershed area. These 21 major streams originating from the eastern low hills, run mostly west in between the low hills and drain into the tidal canals with a linkage to the backwater system. The drainage basins of these streams have laterite or lateritic soil with occasional rock outcrops. The tidal water canals of Chithrappuzha, Karingachirapuzha and Edappally thodu receive the waters from the east (Alex, 2005).

3.5 Geology & Geomorphology

Cochin basin is having 2 physiographically and geomorphologically distinct zones running in a North-South direction, viz., the hilly eastern uplands and the western flat terrain which forms part of the midland region and coastal plains of Kerala respectively. The eastern part of the Cochin basin is an eroding area with mostly lateritic low-hills and their valleys formed by differential erosion and the western part is a deposition area with the characteristic flat landform with meandering streams and shallow water sheets. The lateritic nature of the eastern low-hills ensures their survival because of low erodibilty. On a local scale, laterite formations which may have originated beneath lower slopes of valleys are now found as summit copings, forming ridges, plateau or small mesas because of its low erodibility. Wherever morphological changes have taken place and continue within the laterite terrain, it is clear that surfaces unprotected by the laterite duricrust are lowered more rapidly, unless they form bare rock hills. This kind of differential erosion has given rise to the present 'etched plain' of low laterite hills in the eastern part of the study area. This proves that laterite-covered areas are erosion-resistant and stable.

The 'valleys' of such 'etched plain' are highly erodible and these valleys are formed originally due to high erodibility. Human activities further aggravate the erodibility by mechanical loosening of such areas or by removing vegetation cover resulting in the formation of gullies in such areas not protected by laterite duricrust.

The western flatland portion is basically a deposition area. These sediments were brought from the eastern hills by the streams in the study area as well as from far off places by Periyar, Muvattupuzha, Pamba, Meenachil and Achankoil rivers which drain into the Vembanad lake to which the flatland area is closely linked.

Two distinct kind of geological strata exist in the study area. In the western parts the geological strata is that of sediments in layers of sand, clay, clayey sand or sandy clay with a band of laterite at varying thickness and varying sequences. Any one of these layers form the uppermost layer of the soil. This strata of sediments in the western part bears close resemblance to the general litho-stratigraphy of coastal belt of Kerala.

The coastal sediment of Kerala, of which Cochin is also a part, consists of Vembanad formation (3-60 m) with various kinds of sediment layers with an unconformity at its bottom marked by laterite. Below this is the Ambalapuzha formation (3-140 m) with various kinds of sediment layers. Below this is the Quilon formation (0.5-130 m) consisting of limestone, sandstone, clay, lignite etc. This is followed by unconformity (Gneiss, Charnockite, Leptinites etc.) (Benjamin, 1998).

3.6 Soil types of the Study Area

The soil of the region can be broadly classified into sandy soil (in area coming under Kochi Taluk and the area in north western part of Parur taluk). Peaty or Kari soil (occurs as a small belt on the western part of Kanayannoor Taluk) and lateritic soil on the eastern part of the region. The sandy soil varies from pure sand to sandy loam.

The basic characteristic of the soil of the study area is that, the soil throughout is invariably acidic. In the eastern laterite area, the pH varies from 4.5 to 6 in the case of wetlands (paddy fields) and 5.2 to 6.3 in the case of dry lands. In the western flat land area, the pH is as low as 4.2 in many places and vary from 4.2 to 6 in wetland and vary from 4.9 to 6.5 in dry lands (Benjamin,1998).

3.7 Economic Importance

Cochin is the economic capital of Kerala by volume of trade. The city is one of the principal seaports of the country. The ICTT has started functioning at Vallarpadam. The LNG Terminal will be commissioned soon. Major business sectors include gold and textile retailing, seafood and spices exports, information technology (IT), tourism, health services, banking, shipbuilding and the fishing industry. The city also houses Kerala's only bourse, the Cochin Stock Exchange. Cochin is a major destination for IT companies. Various technology and industrial campuses including the government promoted Info Park, Cochin Special Economic Zone and KINFRA are functioning in Cochin. Several new industrial complexes for research, trade and development in biotechnology, electronic hardware and information technology are in various stages of construction in the suburbs of the city. Eloor, situated 17 km north of the city, is the largest industrial belt in Kerala, with more than 250 industries manufacturing a range of products including chemicals and petrochemical products, pesticides, rare earth elements, rubber processing chemicals, fertilisers, zinc and chromium compounds, and leather products. Amblamukal industrial area also in the city premises.

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Chapter- 4

MATERIALS AND METHODS

Contents

For this study several satellite imageries after necessary processing (Radiometric correction or Geo- rectification) were procured from various data sources. The list of data used is given in Table. 4.1. Various toposheets were also used as reference data (Table 4.2). These data were subjected to various data processing techniques, which are explained in the methodology part (4.2) given below:-

Table 4.1 Images used for the Study

Spacecraft	Acquisition Dates	Sensor	Bands	Spatial Resolution (Meter)	Radiometric Resolution (Bits)	Source	Image Details	Level of Processing
IRS-P6	01-02-2011	LISS-III	2,3,4,5	24	7	NRSC	Path-99,Raw-66 (70%Shifted to Raw 67)	Radiometric corrected
IRS-P6	20-12-2009	LISS-III	2,3,4,5	24	7	NRSC	Toposheet Number 58B4,58B8,58C1,58C5	Geo-Rectified
IRS-P6	07-12-2007	LISS-III	2,3,4,5	24	7	NRSC	Path-99,Raw-66 (70%Shifted to Raw 67)	Radiometric corrected
IRS-IC	04-01-1998	LISS-III	2,3,4,5	24	7	GLCF	Path-99,Raw-66 (70%Shifted to Raw 67)	Radiometric corrected
Landsat 5	24-01-1990	TM	1,2,3,4,5 ,6,7	30 (For 6th band 120)	8	GLCF	Path-144,Raw-53	Geo-Rectified
Landsat 1	10-02-1973	MSS	1,2,3,4	60	6	USGS	Path-155 Raw-53	Radiometric corrected

Table 4.2 Toposheets Used

Toposheet No.	Last Surveyed year	Scale	Prepared By	Source
58C1	1967	1:50,000	Survey of India	Survey of India
58C5	1967	1:50,000	Survey of India	Survey of India
58B4	1967	1:50,000	Survey of India	Survey of India
58B8	1967	1:50,000	Survey of India	Survey of India
NC 43-7	1944	1:250,000	US Army Map Service	Texas University Library
NC-43-11	1944	1:250,000	US Army Map Service	Texas University Library

4.1 Software used for the Study

4.1.1 ArcGIS 9.3.1

ArcGIS 9.3 is a very powerful and one of the latest available GIS tool. It is a unique platform that permits easy storage, handling and display of geographic data in the form of maps, models (DEM, DTM etc) and globes. ArcGIS desktop consists of ArcView, ArcEditor, ArcInfo and other optional ArcGIS extension products, which are listed below:

- Spatial Analyst - for advanced spatial modelling and analyses.
- 3D Analyst - for three dimensional visualization and analyses.
- Network analyst - Create, manage and analyze network datasets.
- Tracking Analyst - Play back, analyze, and visualize complex time series data and spatial patterns.
- ArcScan - Tools for raster to vector conversion.
- Data Inter-operability - direct read, transformation and export for a wide range of spatial data formats.

4.1.2 Erdas 9.3

Erdas Imagine is a user friendly, raster based software designed specifically to process geospatial satellite imageries. Unique features of

ERDAS are increased productivity, very good accuracy and unparalleled flexibility. Erdas Imagine products used are listed below.

- Imagine Advantage.
- Imagine Essentials.
- Imagine Professional.
- Imagine Vectors.
- Imagine Radar Mapping Suite.
- Virtual GIS.
- Raster Interoperability.
- Image Compressor.
- Mpeg Patent Support.

4.2 Methods of Analysis

4.2.1 Procuring the Images

IRS LISS Images 2009, 2011, 2007 were procured with minimum cloud cover with the help of NRSC Image browsing facility. The images of 1990 downloaded from GLCF and 1973 image was downloaded from USGS.

4.2.2 Geometric Correction of Images and Toposheets

Remotely sensed data are distorted by the earth's curvature, relief displacement and the acquisition geometry of the satellites (i.e. variations in altitude, attitude, velocity and panoramic distortion). The intent of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map (Lillesand & Kieffer, 2000).

Images of the years 1973, 1990, 1998 and Toposheets were co-registered or geometrically corrected using image to image registration with reference to geometrically corrected 2009 LISS III Image using first order polynomial equation with nearest neighbour resampling techniques. The Image was projected to UTM WGS 84, zone 43 N projection. All the images were co-registered up to 0.5 pixel accuracy.

4.2.3 Atmospheric Correction

Atmospheric correction was done using minimum pixel subtraction method to all the Images. The dark pixel subtraction technique assumes that the pixel of lowest DN in each band should really be zero, and hence its radiometric value (DN) is the result of atmosphere-induced additive errors (Crane, 1971; Chavez et al, 1977). Atmospheric correction was done by subtracting DN values with the minimum DN of each Image. Kok *et al* (2009) and Offer & Arnon (2010) used these methods for atmospheric correction.

4.2.4 Land Use / Land Cover (LULC) Mapping

LULC was mapped with digital mapping and post classification editing after converting the Raster map to Vector Data of the 2009 image, details of which is illustrated in Fig 4.2.

4.2.4.1 Digital Image Classification

Digital image classification method was used for this study. The overall objective of the three digital image classification procedures is to automatically classify all pixels in an image into land cover classes or themes (Lillesand & Keifer, 2000). Three different methods were tried for digital classification, which are Supervised Maximum Likelihood classifier (MLC), Unsupervised Classification and Principal Component Analysis (PCA) with Maximum Likelihood classifier.

For digital classification 10-Classes classification system prepared with the help of Toposheets of 1967 and Ground Survey was used. To this one more class - *"Water Body with floating Plants"* was added to avoid the miss classification with *"Mangrove"*. Hence an 11-Classes System is adopted in this study, which is given below.

Table 4.3: LULC Classes used for Digital Classification

SI.NO	LULC CLASS
1.	Built up
2.	Mixed Land use
3.	Paddy Fields
4.	Pokkali Fields
5.	Rivers / Lake
6.	Mangrove
7.	Estuary
8.	Sea
9.	Sandy Area / Beach
10.	Rubber plantations
11.	Water Body with floating Plants

a) Supervised Maximum Likelihood Classifier (MLC)

In supervised classification system, the image analyst supervises the pixel categorization processes specifying numerical descriptors (Group of DN Values) of the various land cover type present in scene, to the computer algorithm. To do this, representative sample sites of known cover types, called training areas are used to compile a numerical interpretation key that describes the spectral attributes for feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key. and labelled with the name of the category it looks most like (Lillesand *et al*, 2004).

The MLC quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel (Lillesand *et al, 2004*). Yayoub *et al* (2006), Adel and Ryutaro (2007), Benoit *et al* (2000), Birsen *et al* (2009), Qiong *et al* (2006) and Jieying *et al* (2006) used this method for classifying their images.

For the present study, about 200 training areas were chosen in the study area for classification of which, at least 10 training areas for each class were selected.

b) Unsupervised Classification

In the unsupervised approach, the image data is first classified by aggregating them into natural spectral grouping or clusters present in the scene. Then the image analyst determines the land cover from these spectral groups by comparing the classified image to ground reference data (Lillesand *et al*, 2004). Yan *et al* (2005) and Yasser (2005) used this method for classifying their images.

For this study, the 2009 image was subjected to unsupervised classification with a cluster size of 250 clusters. Following the classification, each of the 250 clusters was assigned with one of the 11 land use classes by comparing the classified image to ground reference.

c) Principal Component Analysis (PCA) with Maximum Likelihood Classifier

PCA is often used as a method of data compression. It allows redundant data to be compacted into fewer bands - that is, the dimensionality of the data is reduced. The bands of PCA data are non-correlated, independent and are often more interpretable than the source data. (Jensen, 1996, Faust, 1989). Mahdavi (2010), Hossien *et al* (2011), Nillanchal and Brijesh (2010) and Amba *et al* (2005) used this method for Image Classification.

4.2.4.2 Ground Truthing and Classification Accuracy

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. Usually, the assumed-true data are derived by ground truthing. It is usually not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (or will be) known. The reference pixels are randomly selected (Congalton, 1991). After the classification, accuracy assessment to each classified image was done. 600 sampling points were selected and the accuracy assessment was done with the help of Ground Truthing (GPS survey, for which Garmin GPS-60 was used) and toposheets of 1967.

Of these 3 classification methods, the Supervised MLC was found to have the highest classification accuracy in the present study, which is shown in Table-4.3. Also in the individual classes, almost all the classes got better accuracy in Supervised MLC, except for Rivers and Rubber plantations. Rivers show slightly better accuracy in the Unsupervised classification and Rubber plantations got slightly better accuracy in PCA with MLC Hence, Supervised MLC was chosen for further mapping.

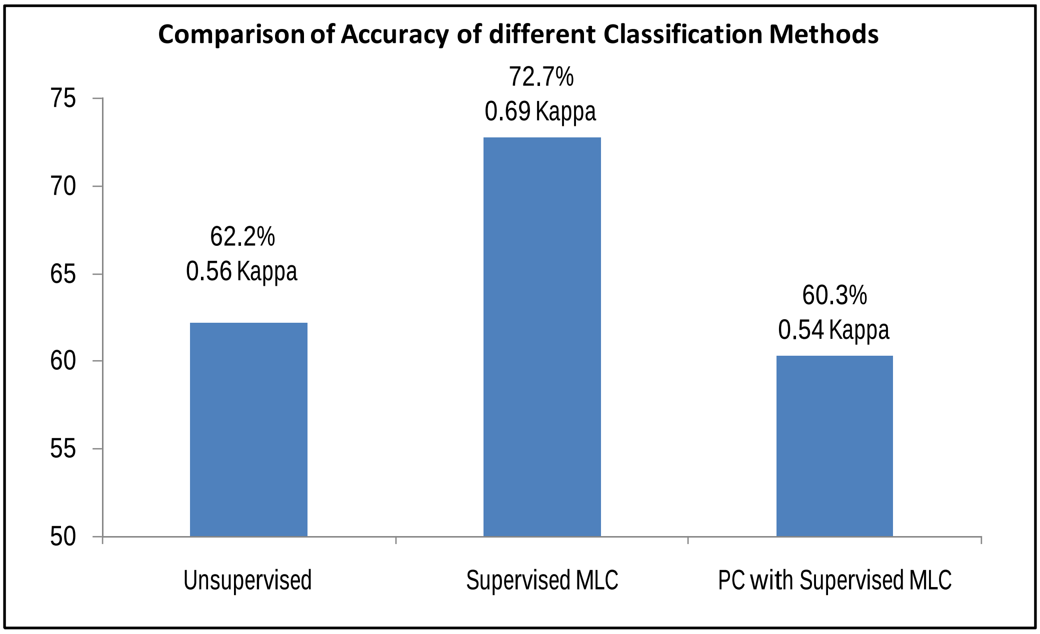

Figure 4.1 Comparison of Accuracy of Different Classification Methods

4.2.4.3 Post Classification Editing

Post Classification Editing is the editing done after the digital classification with expert visual interpretation. Yayoub et al (2006) used this method for LULC mapping. Post Classification Editing is done after converting the classified Supervised MLC Map to Geodatabase (Vector) format. The vectorised map was further edited with the help of Ground Truthing (ground Survey), toposheets and Google earth images. After the Post Classification editing, the classes were increased to 17, which is found most suitable for the present study area terrain. This classification system was modified largely following the coastal classification system made by Space Application Centre (SAC), Ahmadabad. (George, 2005).

Table 4.4 LULC Classes present in the Study Area

SI.NO	LULC CLASS
1.	Built Up
2.	Built Up-Industrial
3.	Estuary
4.	Dense Mangrove
5.	Sparse Mangrove
6.	Paddy Fields
7.	Pokkali Fields
8.	Rivers/Lake
9.	Aquaculture with Coconut Plantation
11.	Clay Mines
12.	Canals
13.	Reclaimed Land
14.	Rubber
15.	Mixed Land Use
16.	Sea
17.	Sandy Area/Beach

The above classes are self explanatory, except for Class 8, which is given as Rivers/ Lake. In this class the Lake is the freshwater body, in the premises of FACT at the Ambalamukal area. Estuary Class is the brackish water body present in the Study Area.

4.2.4.4 Map Composing

Maps were composed with ArcGIS software adding North arrow, Scale bars, Headings and Legends of the land use / land cover.

4.2.5 Mapping of 2011 LULC Map

LULC map for the year 2011 was prepared by digital classification with Supervised MLC, followed by post classification editing by comparing with the 2009 map.

4.2.6 Change Detection

The Changes brought about in the land use of the Study Area during the period of the present study were assessed. Details of which is illustrated in Fig 4.3.

4.2.6.1 Mapping of LULC.

Detailed LULC maps for each of the years 2007, 1998, 1990 and 1973 were prepared by digital classification by Supervised MLC, followed by post classification editing comparing with the previous available map. Due to the absence of sufficient resolution, only 3 classes (Estuary, Pokkali Fields and Built up area) were mainly identified.

4.2.6.2 Post-Classification Comparison

Post-Classification comparison was done for each LULC Classes particularly for Wetland Classes. The changes were compared and is graphically represented. Kamini *et al* (2006), Birsen *et al* (2009) and

Metternich (2001) used Post Classification comparison for change detection analyses.

4.2.6.3 Preparation of Change Matrices

Change Matrix shows how each Land use / Land cover patterns changes to other LULC patterns. Change matrices where prepared using the overlay analysis UNION in ArcGIS environment for the years 1944 to 1973, 1973 to1990, 1990 to 1998, 1998 to 2007, 2007 to 2009, 2009 to 2011 and 1973 to 2011 and were tabulated in Microsoft Excel. Yayoub *et al* (2006) and Birsen *et al* (2009) have used this method for change detection analyses.

4.2.6.4 Visualising the Changes

Overlay analyses were performed using SYSTEMATIC DIFFRENCE in ArcGIS for the years 1973 to1990, 1990 to 1998, 1998 to 2007, 2007 to 2009 for Paddy Fields, Pokkali Fields and Estuary. For the Estuary Class, analysis was also done for 1943-1990.

4.2.7 Mapping the Paddy and Pokkali Cultivating Area.

Extensive ground surveys were done with GPS for locating the Paddy and Pokkali farms and were mapped on 2011 LULC Map.

4.2.8 Finding out the Reasons for Wetland Reclamations

The reasons for reclamation of wetlands particularly Paddy and Pokkali fields and stoppage of paddy cultivation were found out by collecting secondary data from different government offices, extensive surveys and interviews with the native population.

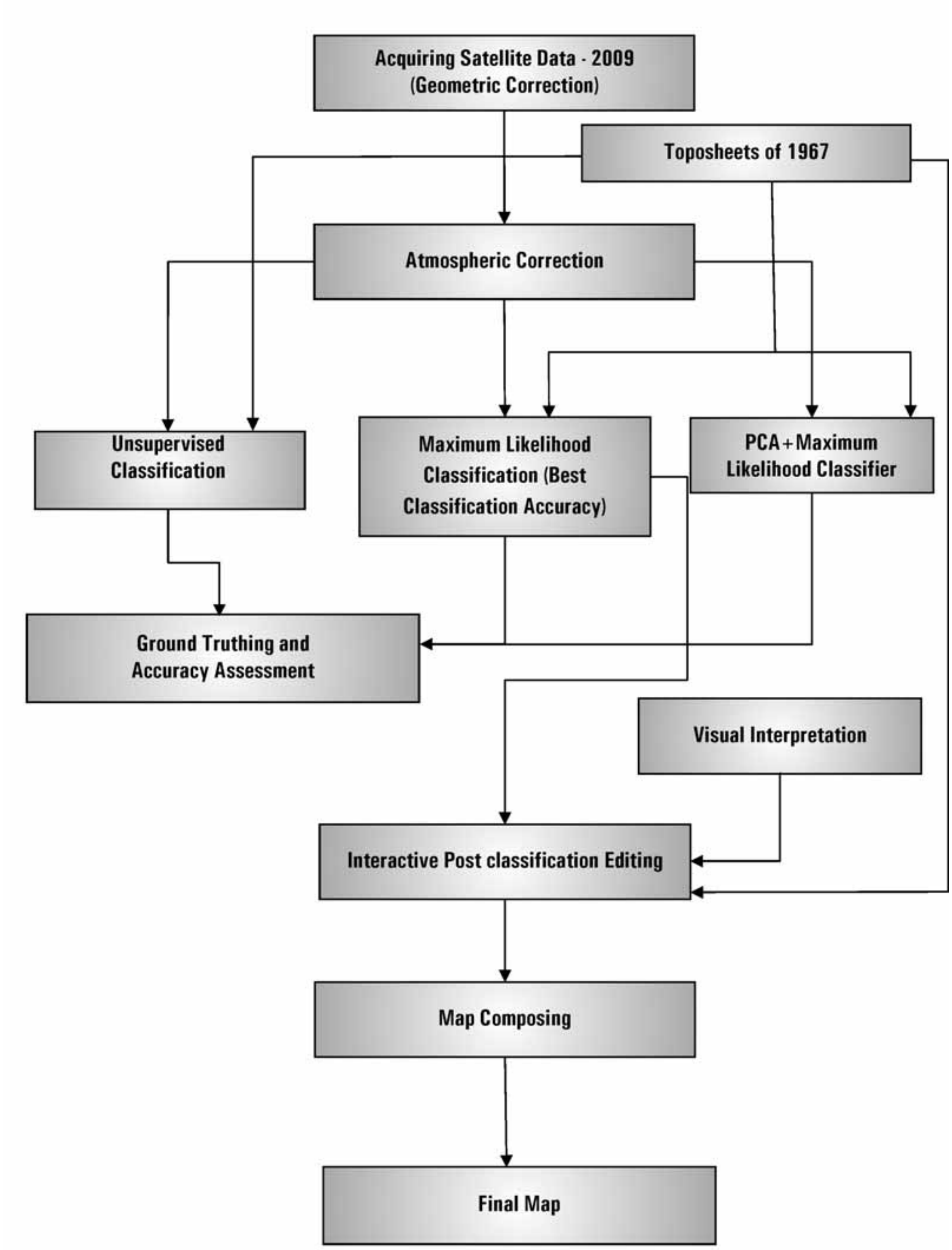

Figure 4.2 Flow chart for LULC Mapping

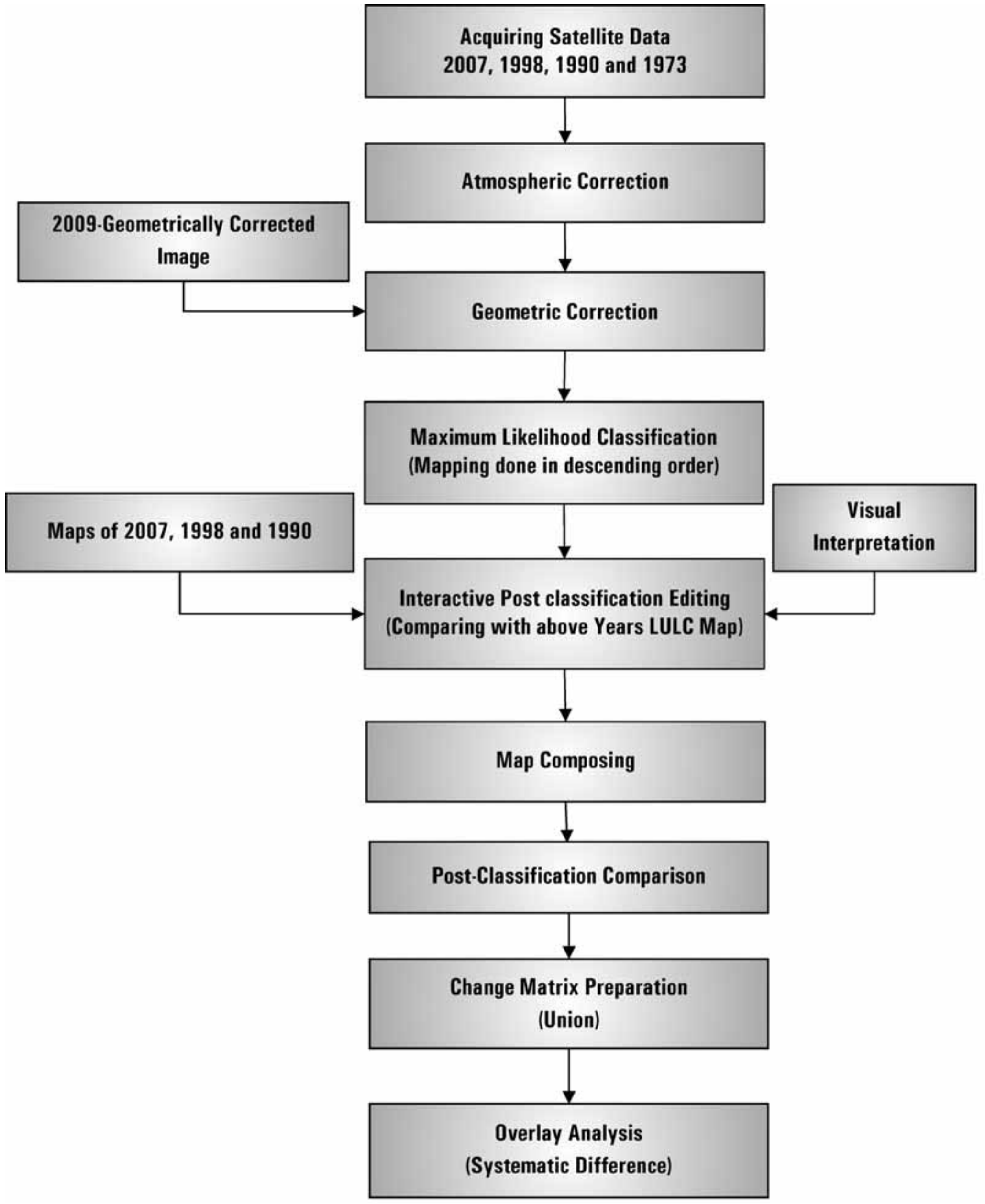

Figure 4.3 Flow chart for LULC Change Detection

4.2.9 Vulnerability (Reclamation) Mapping of Wetlands

Vulnerability Mapping was done for understanding which areas are more vulnerable to reclamation. Different vulnerability factors were identified and different scale values or points were assigned to these factors based on their degree of influence. These factors are described below. Since the Rivers and Estuary are currently less prone to encroachment by the public, they are excluded from this Vulnerability Mapping.

4.2.9.1 Vicinity from the City Centre

The studies of change detection and wetland changes reveals that reclamation is more rampant the City Centre. The city centre is identified by converting the Polygon LULC feature to Point Feature in Data Management tools available in ARC Tools in ArcGIS Environment. For vulnerability mapping, Multiple Ring Buffered Feature Class was prepared, starting from 1 km, 2 km... to 20 km. 95 Points were given for the first I km buffered area and for each km away from the city centre, 5 points were deducted. This feature Class Data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.2 Vicinity from National Highway

Vicinity from the National Highway is another very important factor for the reclamation of the wetlands. For the study the National Highway Map was prepared by digitising the 2011 LISS-III Imagery. For vulnerability mapping Multiple Ring Buffered Feature Class was prepared starting from 1 km, 2 km... to 10 km. 90 points were given for the first I km buffered area and for each further km 10 points were deducted. This feature Class Data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.3 Vicinity from State Highway and Important Roads

Vicinity from the State Highway and important roads is another important factor for the Reclamation of the Wetlands. For this study, the Map of State Highways and other important roads was prepared. For vulnerability mapping, Multiple Ring Buffered Feature Class was prepared starting from 1 km, 2 km... to 5 km. 80 Points were given for the first I km buffered area and for each further km 20 points were deducted. This feature Class Data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.4 Vicinity from Important Developmental Activities - ICTT.

Vicinity from the ICTT Vallarpadam is another very important factor for the reclamation of the Wetlands. For the study, ICTT Vallarpadam map was prepared by digitising the 2011 LISS-III Imagery. For vulnerability mapping, Multiple Ring Buffered Feature Class was prepared, starting from 1 km, 2 km ... to 20 km. 95 Points were given for the first I km buffered area and for each successive 1 km 5 points were deducted. This feature Class Data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.5 Vicinity from Important Developmental Activities - Smart City

Vicinity from the Smart City, Kakkanad is another critical factor for the reclamation of the wetlands. Hence, the Smart City Map was prepared by digitising the 2011 Imagery. For vulnerability mapping, Multiple Ring Buffered Feature Class was prepared, starting from 1 km, 2 km... to 10 km. 90 Points were given for the first one km buffered area and for each successive km 10 points were deducted. This feature Class Data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.6 Population Density

Population density is a very important factor affecting the reclamation of the wetlands. The scanned Map of Local Bodies collected from Ernakulam Collectorate was digitised and population of each Panchayath, collected from Directorate of Census Operations, Kerala was entered. Points given for the population density for the vulnerability mapping is given in the table below.

Table 4.5 Scale Values based on Population Density

Sl.No.	Population Density	Scale Values
1	3500+	90
2	3000-3500	80
3	2500-3000	70
4	2000-2500	60
5	1500-2000	50
6	1000-1500	40
7	Less than 1000	30

This feature class data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.7 Spatio-Temporal Changes in Built-up Areas.

Spatio-Temporal Changes of Built-up area is another indicator of the Wetland Reclamation. The LULC were mapped and clipped with the 39 Local Body boundary maps and 39 separate LULC maps were prepared. The percentage of increase of built-up area from1973-2011 was calculated and illustrated. Points given for the percentage of increase of Built-up area from 1973-2011 for the vulnerability mapping is given the table given below.

Table 4.6 Scale Values based on Percentage Increase of Built-up area

Sl.No.	% of increase of Built-up area	Scale Values
1	300+	90
2	250-300	80
3	200-250	70
4	150-200	60
5	100-150	50
6	100-50	40
7	Less than 50	30

This feature class data was then clipped with the Wetland feature Class. This clipped Feature Class was converted to Raster data with 30 m Pixels.

4.2.9.8 Overlay Analysis

The above-mentioned raster files were subjected to 'Weighted Sum overlay analysis' in ArcGIS. Weightages given for each vulnerability factor is given below.

Table 4.7 Weightages given for vulnerability factors

Sl.No.	Vulnerability Factors	Weightages in %
1	Vicinity from the City Centre	20
2	Vicinity from National Highway	20
3	Vicinity from State Highway and Important Roads	20
4	Vicinity from Important Developmental Activities-ICTT	10
5	Vicinity from Important Developmental Activities-Smart City	10
6	Population Density	10
7	Spatio-Temporal Changes of Built-up area	10

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Chapter- 5

RESULTS AND DISCUSSION

Contents

5.1 Land Use / Land Cover of 2011

In this study the Land use / Land cover (LULC) changes of the Cochin City and surrounding area were explored during the last 7 decades, for which the data used are given in Chapter 4. Due to absence of necessary precision, only estuary, Pokkali fields and Built-up area could be traced in the 1944 toposheet for comparison with the current scenario. All the 17 classes as described in Section 4.2.4.3 for the years 1973, 1990, 1998, 2007 and 2009 were compared with the current scenario (2011). It is found that the landscape has undergone drastic modifications and alterations, due to various reasons, which are described below.

5.1.1 Current Land Use / Land Cover (LULC) Scenario (2011)

The LULC pattern during 2011 is shown in Map 5.1 and as illustrated in Figure 5.1 shows that 33.35% of the total study area is covered with wetlands, which is a shrinkage of 11.76% compared to the 1973 situation (Annexure V).

The wetland decrease has contributed mainly to a proportionately large 111% increase in Built up area (from about 83.74 to 176.89 km^2).

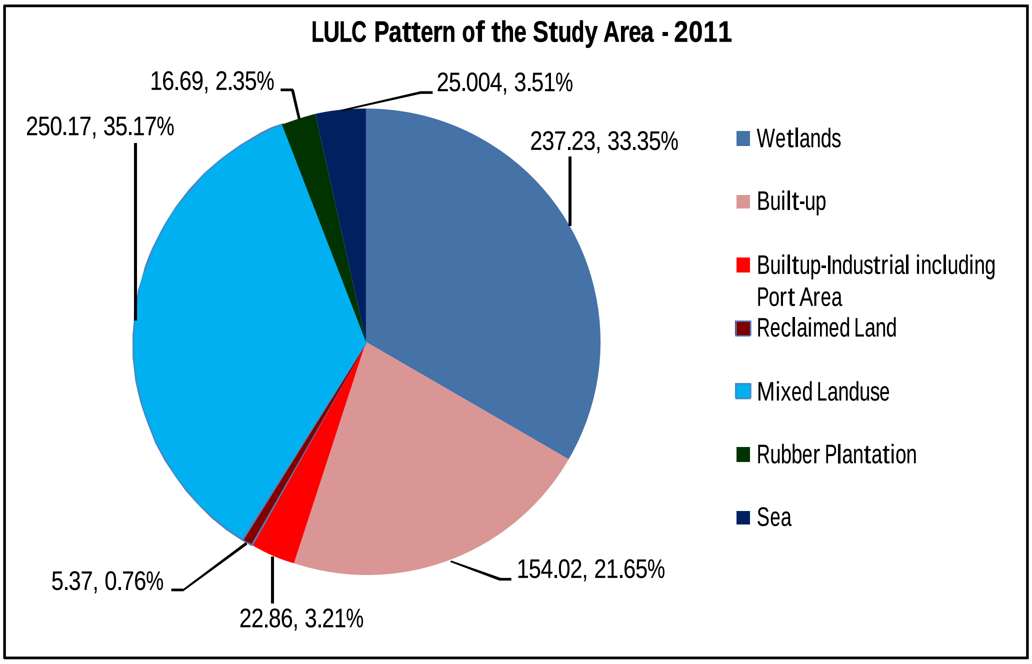


Figure 5.1 Land use / Land cover Patterns in 2011

Other than wetlands, of the total built-up area (24.86%), 3.21% is industrial area including the Cochin Port. 35.17% of the study area is of mixed land use, 2.35% is taken up by Rubber plantations, and 3.51% by sea and 0.76% is reclaimed area.

Of the wetlands (coverage = 33.35% of the total study area), 42.75% is covered by Estuary, 28.89% by Pokkali fields, 16.87% by Paddy fields and 5.15% by Rivers & Lake. Minor fractions (1.18%) are taken up by dense mangroves and 0.66% by sparse mangroves. Also, 1.4% of the wetland area is shared for aquaculture with coconut plantation, 1.4% for canals, 0.57% for

Sandy / Beach Area, 0.57% for clay mines and 0.38% is marshy areas. Detailed wetland types are illustrated in the Fig-5.2.

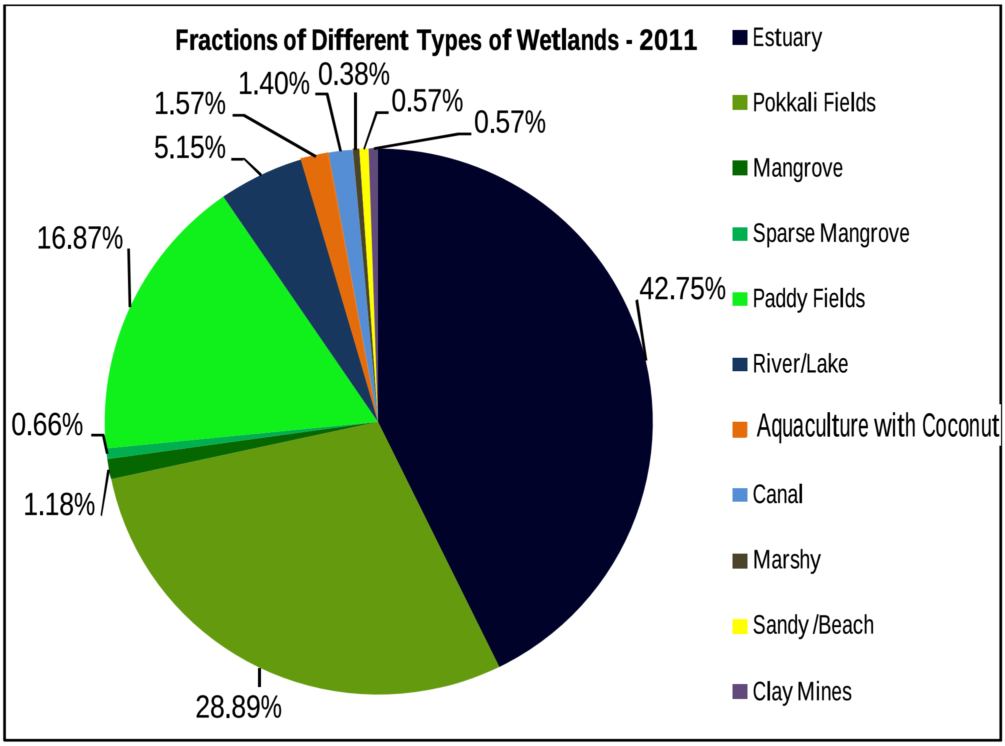


Figure 5.2 Fractions of Different Types of Wetlands - 2011

5.2 Change Detection Analyses

For detecting LULC changes the study area had witnessed during the period of study, i.e. for spatio-temporal analyses, the LULC Maps for 2009 (Map 5.2), 2007 (Map 5.3), 1998 (Map 5.3), 1990 (Map 5.4), 1973 (Map 5.5) & 1944 (Map 5.6) are shown below.

5.3 Spatio-Temporal Changes in the Study Area

The study reveals a drastic decrease in the coverage of wetlands, which contributed to a concomitant increase mainly in Built up area and activities to develop the necessary infrastructure to the growing populace, like roads, bridges, railways, etc., the details of which are listed in the sections 5.3.4 given below. The spatio-temporal changes, which the wetlands of the study area have undergone, are described in Figure 5.3 and the exact values of the area changes are listed in Annexure V. The periodic and spatial changes of the built-up area are given in detail in Section 5.3.4.

5.3.1 Spatio-Temporal Changes of the Major Wetland Constituents

In this study, the wetland comprises parts of Vembanad estuary, Pokkali fields as well as paddy fields. Rivers - Periyar and Muvattupuzha - are treated separately.

An estuary is a partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea. Estuaries form a transition zone between river environment and ocean environment and are subject to both marine influences, such as tides, waves and the influx of saline water and riverine influences, such as flows of fresh water and sediments. The inflow of both seawater and freshwater provide high levels of nutrients in both the water column and sediment, making estuaries the most productive among natural habitats in the world.

Pokkali rice fields are unique wetlands of Kerala, where paddy cum fish culture is practiced. Pokkali is a unique salinity and flooding tolerant rice variety cultivated organically in the water-logged coastal regions of Alappuzha, Thrissur and Ernakulam districts of Kerala in Southern India. [Pokkali Rice has got the Status of a Geographical Indication Species by Govt. of India under Section 13 of Geographical Indications of Goods (Registration and Protection) Act, 1999]. This paddy is cultivated from June to early November when the salinity level of the water in the fields is low. From mid-November to mid-April, when the salinity is high, prawn or fish farming takes over. But Pokkali cultivation is nearing extinction due to economic reasons and this area is now being used for aquaculture.

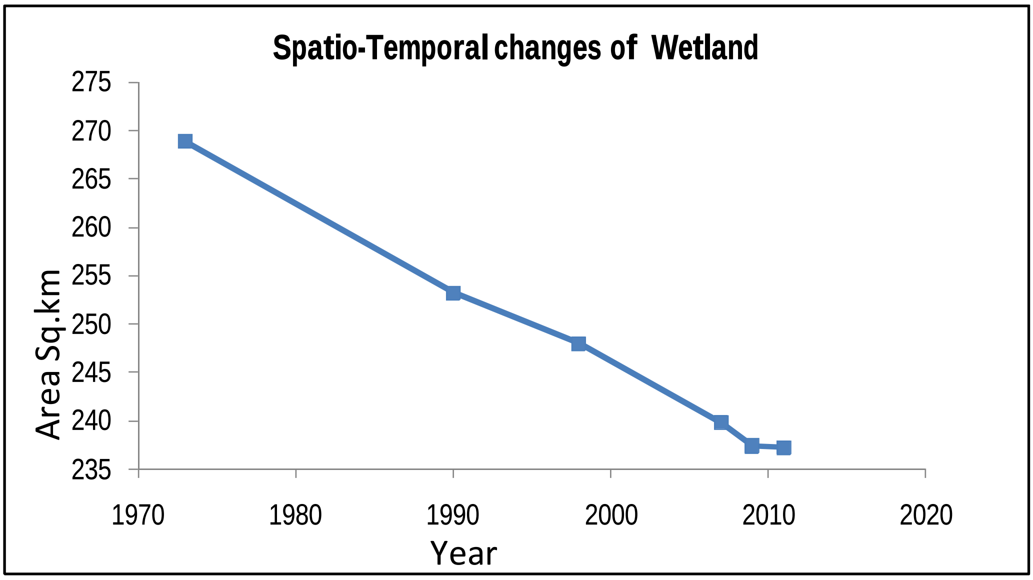
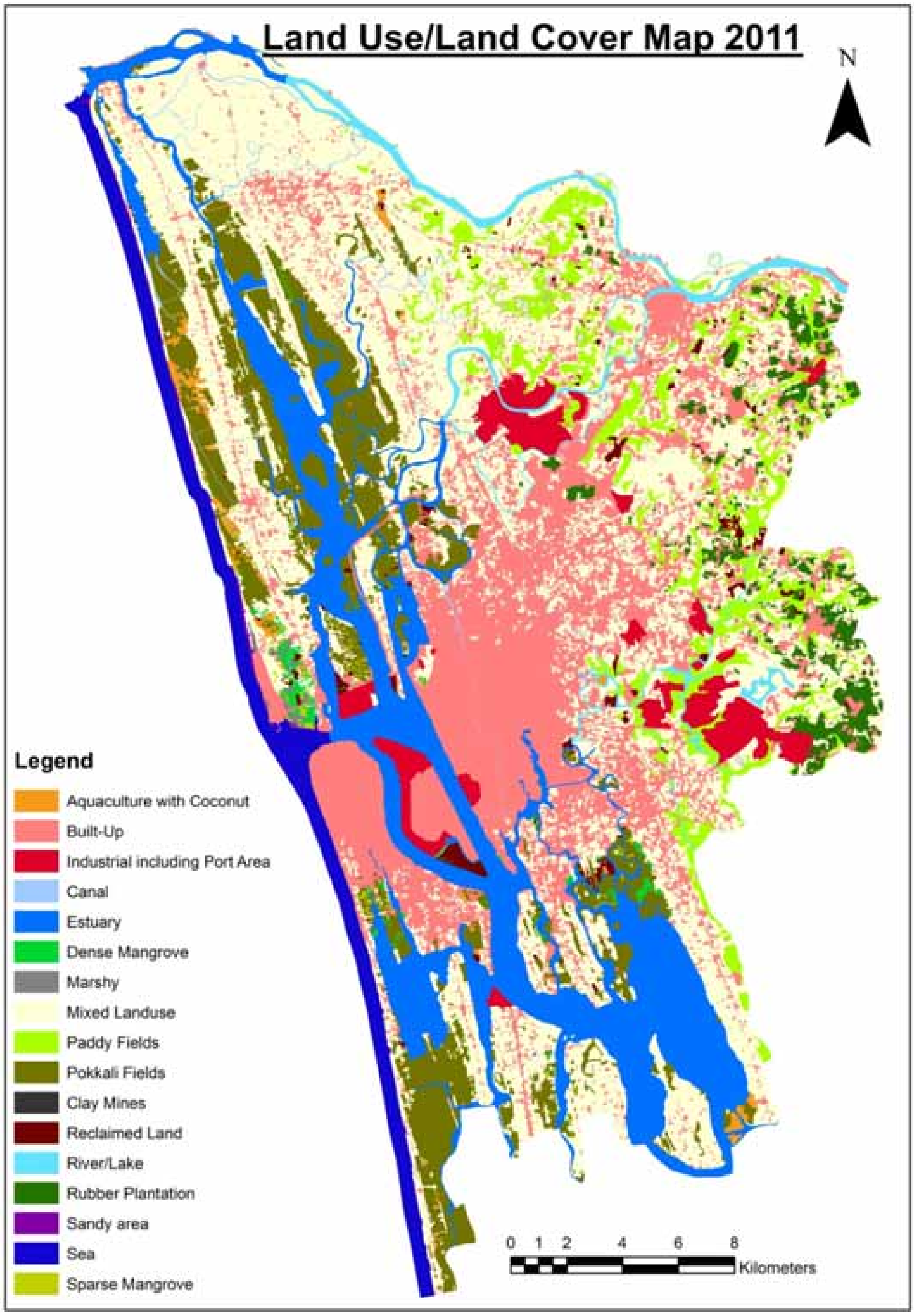
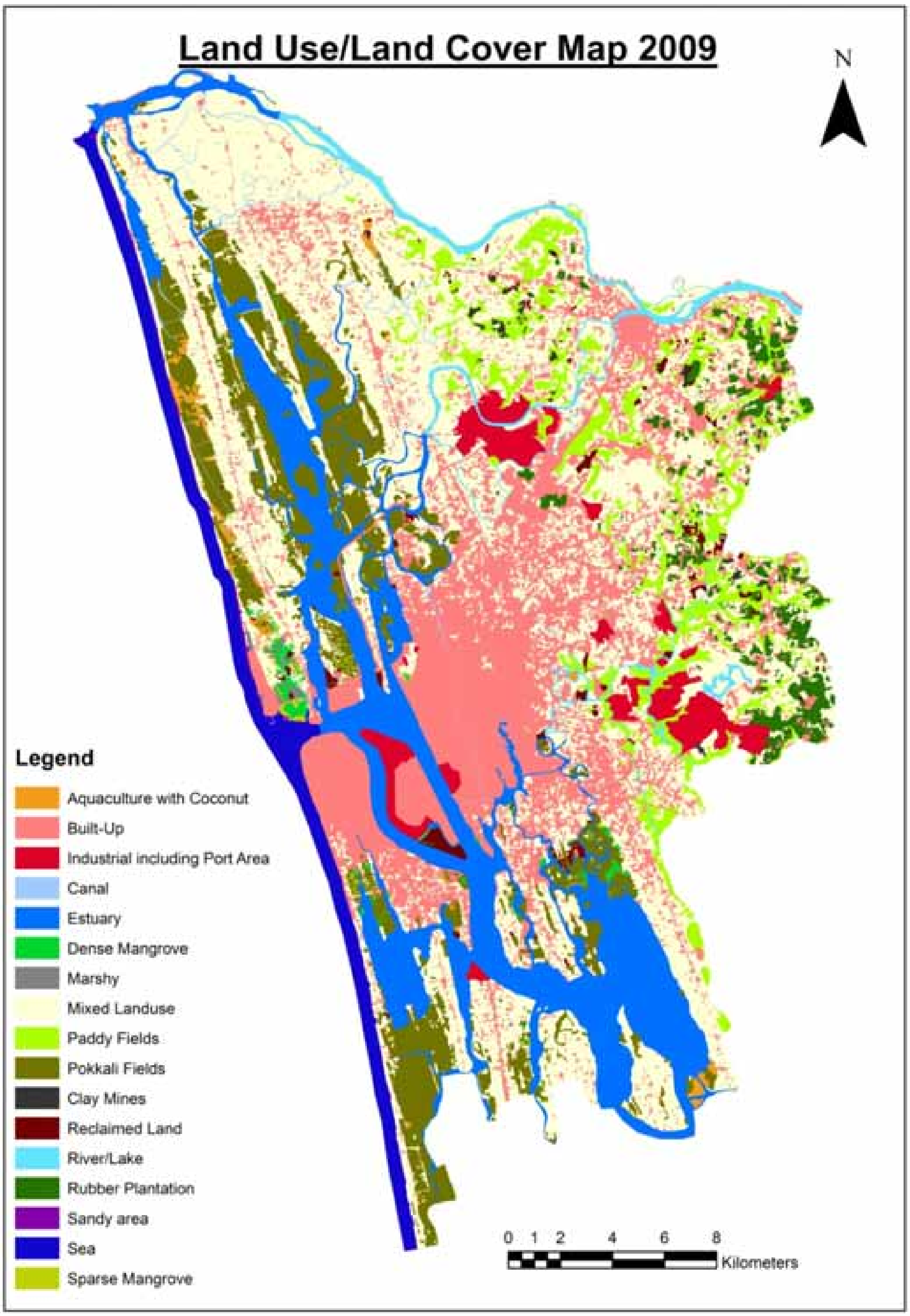


Figure 5.3 Spatio-Temporal Changes of Total Wetlands

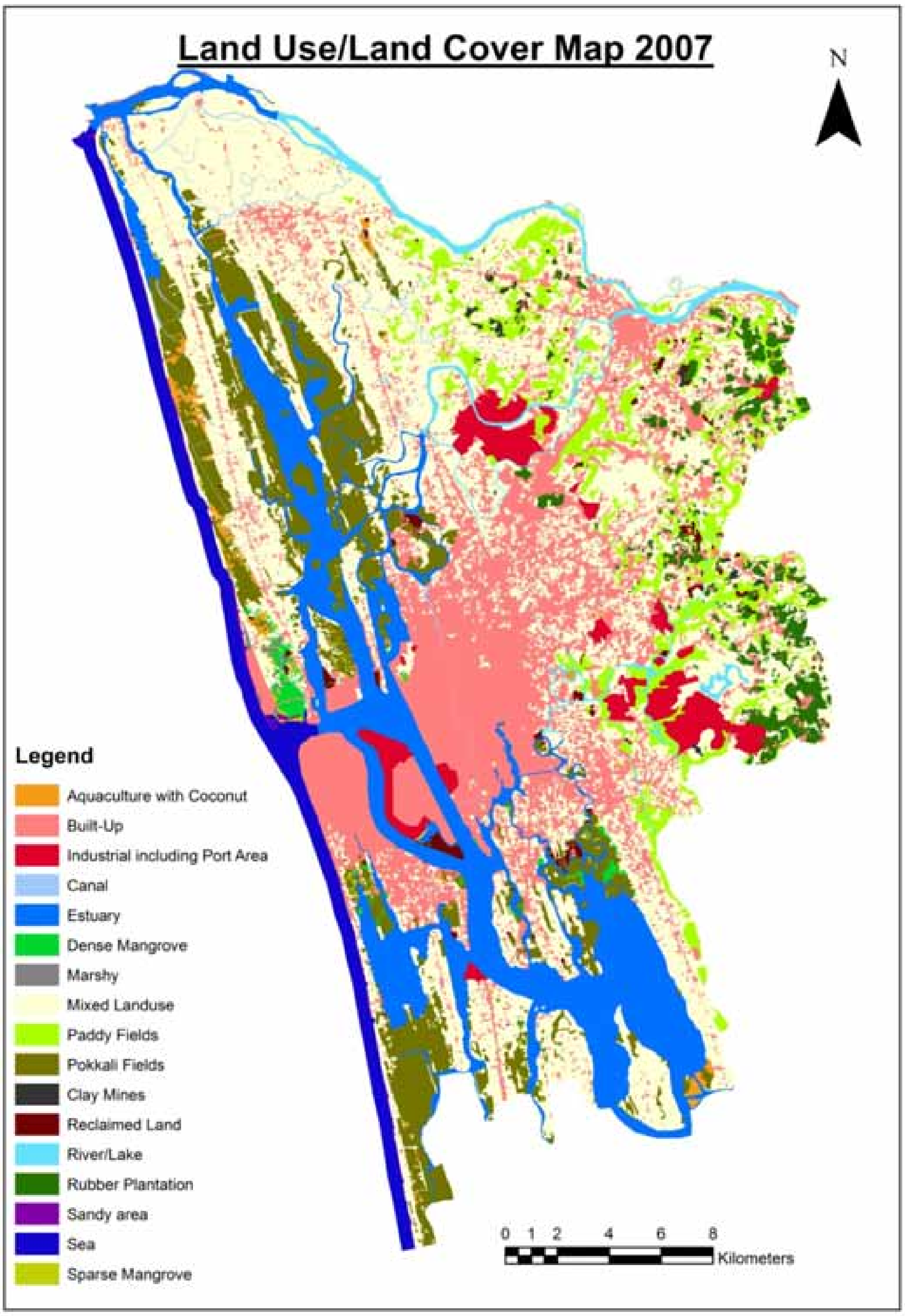
Wetland coverage is found to decrease continuously from 1973 to 2011 and about 11.76% of the wetlands were lost during this period as seen in Annexure -V.



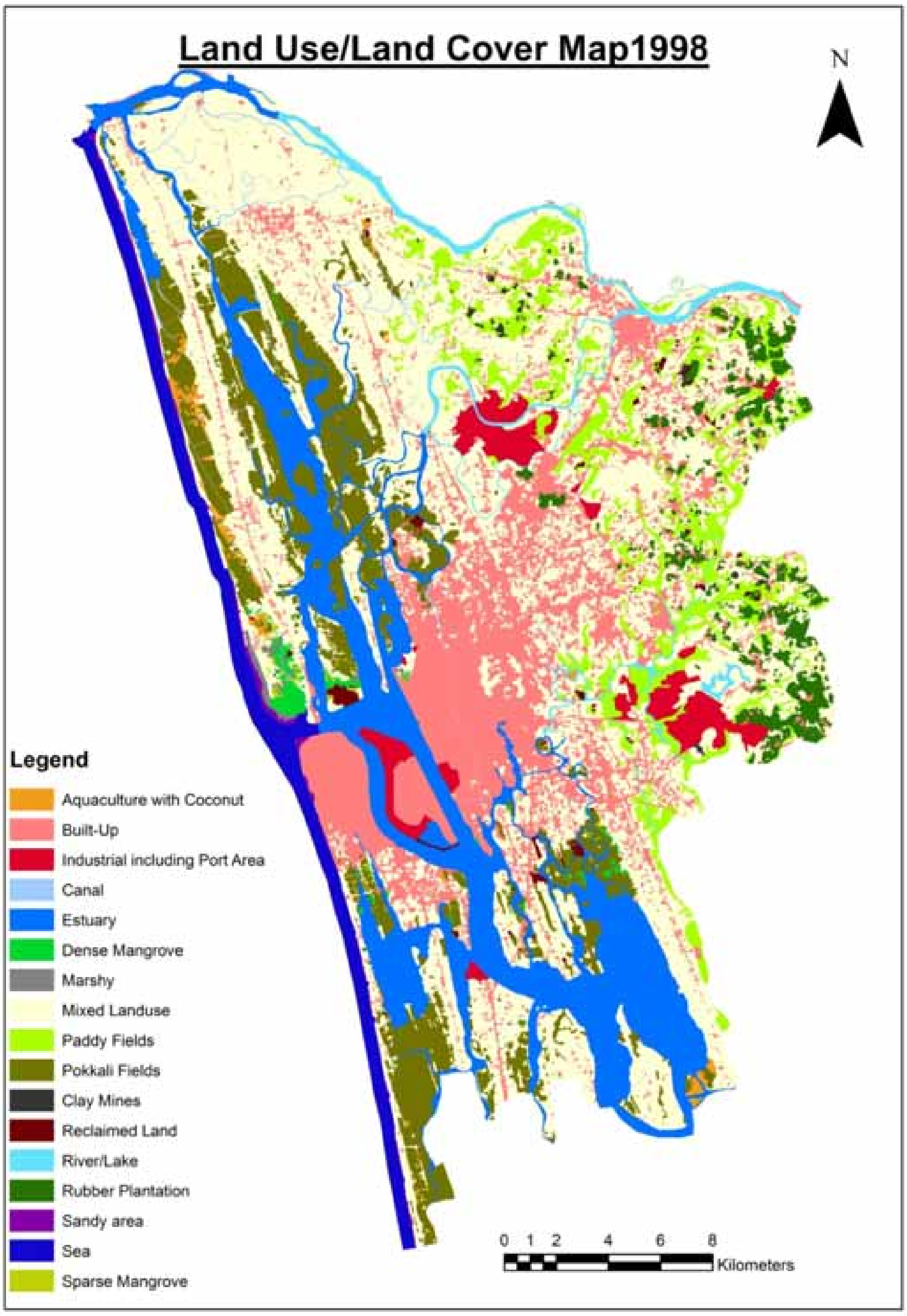
Map-5.1 Land Use/Land Cover Map 2011



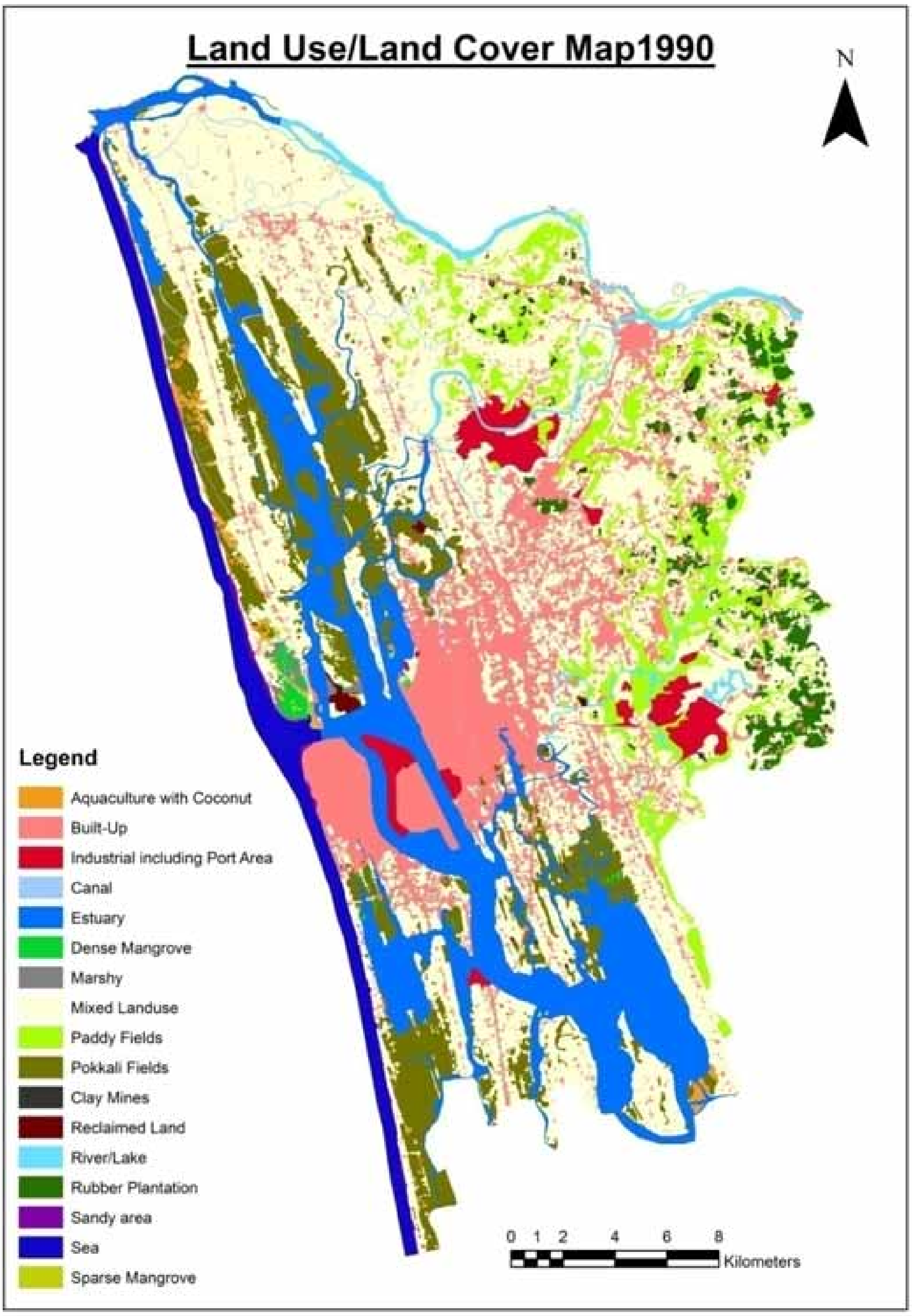
Map-5.2 Land Use/Land Cover Map 2009



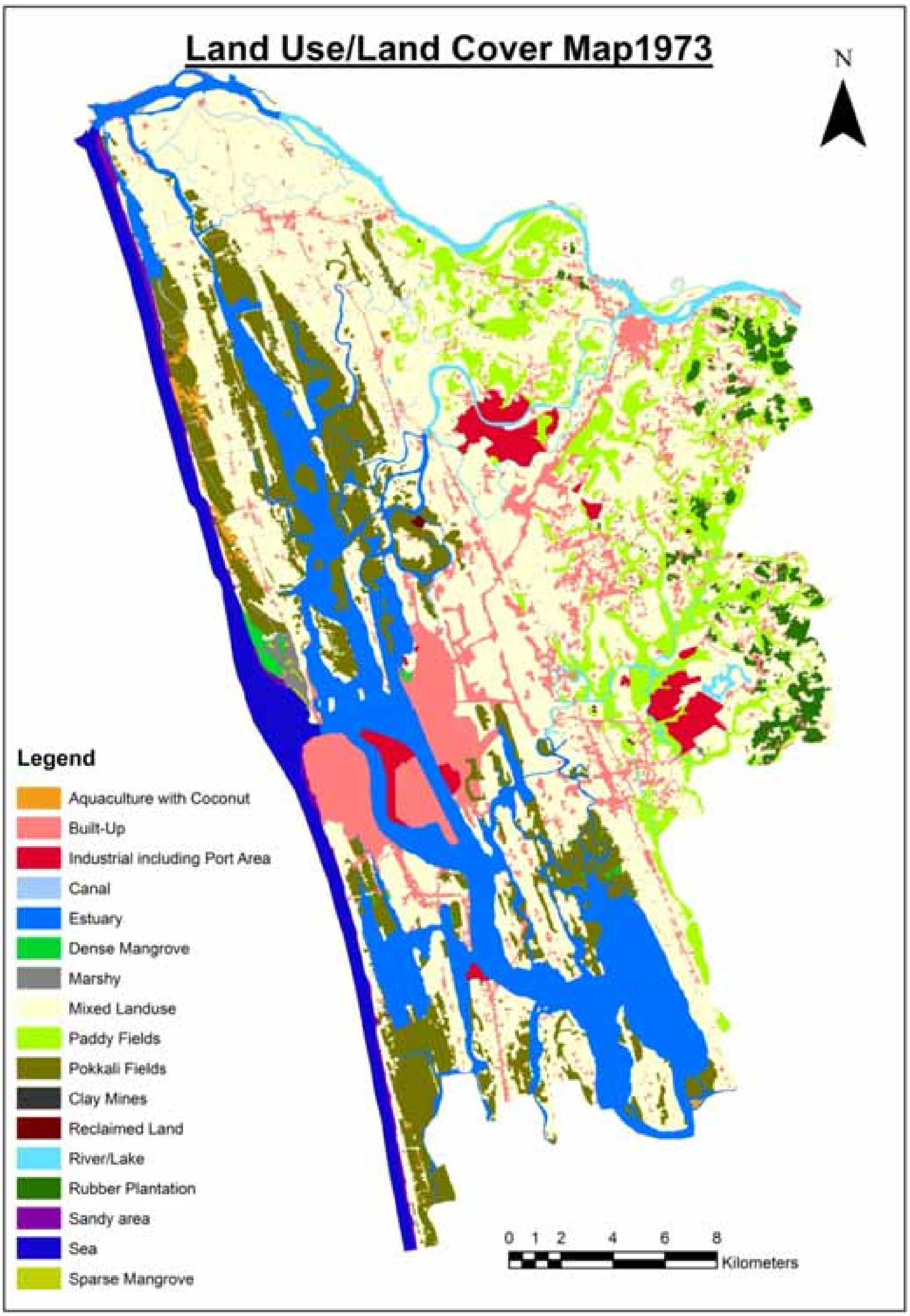
Map-5.3 Land Use/Land Cover Map 2007



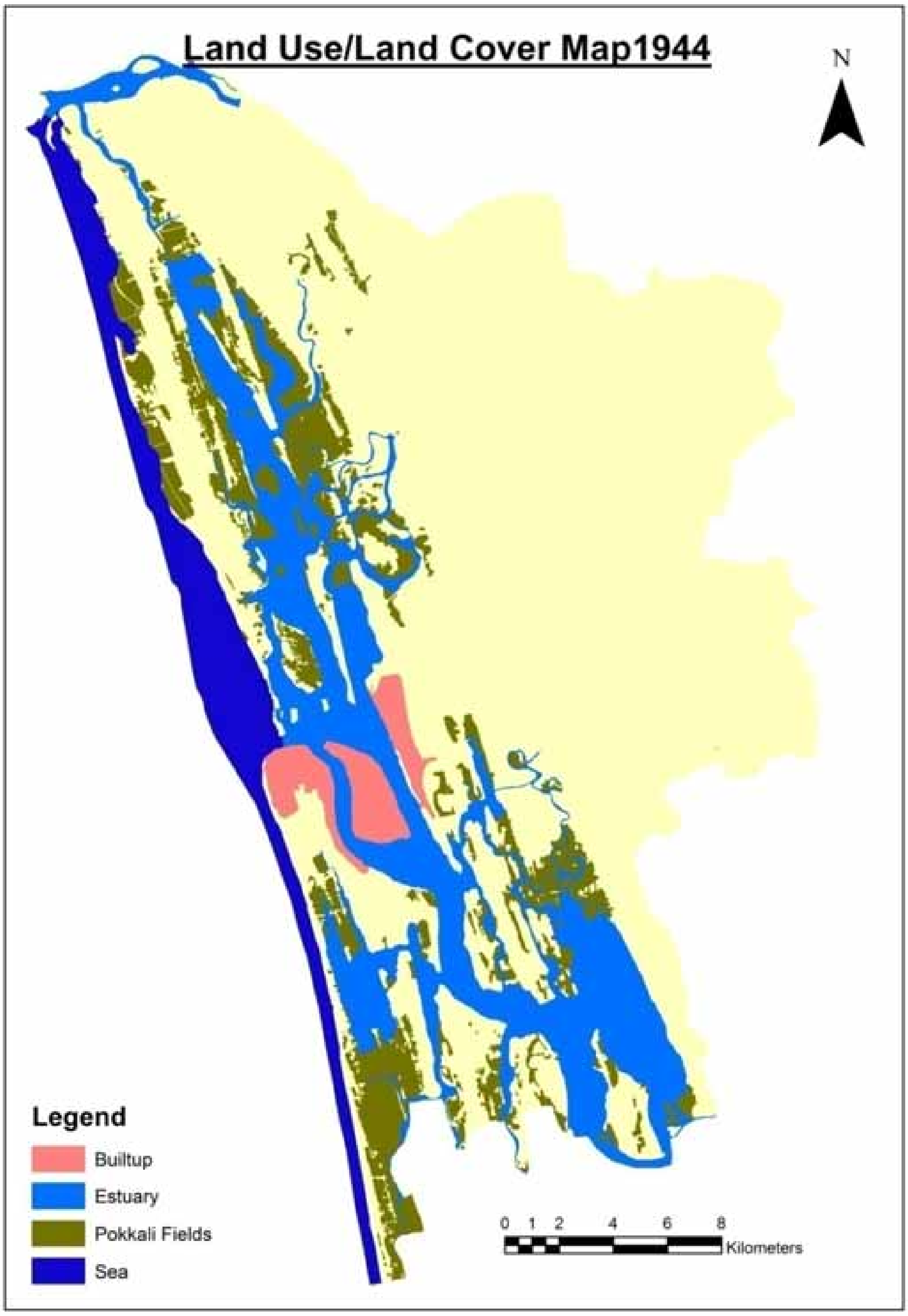
Map-5.4 Land Use/Land Cover Map 1998



Map-5.5 Land Use/Land Cover Map 1990



Map-5.6 Land Use/Land Cover Map 1973



Map-5.7. Land Use/Land Cover Map 1944

Table 5.1 Rate of Reduction of Total Wetlands

Period	Area Change km^2	Rate of reduction km^2 / year
1973-1990	15.645	0.9202
1990-1998	5.248	0.7497
1998-2007	8.193	0.8193
2007-2009	2.351	1.1755
2009-2011	0.205	0.205

Similarly, all the components of estuary, Pokkali fields and paddy fields (Figs 4 and 5) also have shrunk in coverage due to population pressures as well as urban sprawl. Table-5.1 indicates that after the first period, the reduction rate of wetland coverage has increased till 2009, which was very high between the period 2007-2009, a result of rapid urbanisation. During the years 2009 to 2011, the shrinkage of wetlands has decreased due to the new Conservation of Paddy land and Wetland Act, 2008 implemented by Government of Kerala.

5.3.1.1 Spatio-Temporal Changes of Estuary

The estuarine area in the present study is a part of Vembanad Estuary. Cochin backwaters and Cherai Estuary is included in the study area. During the period, 1944 to 2009, it is found that the overall decline of the estuarine area is 12.96% (15.11 km^2) as seen in Annexure –V.

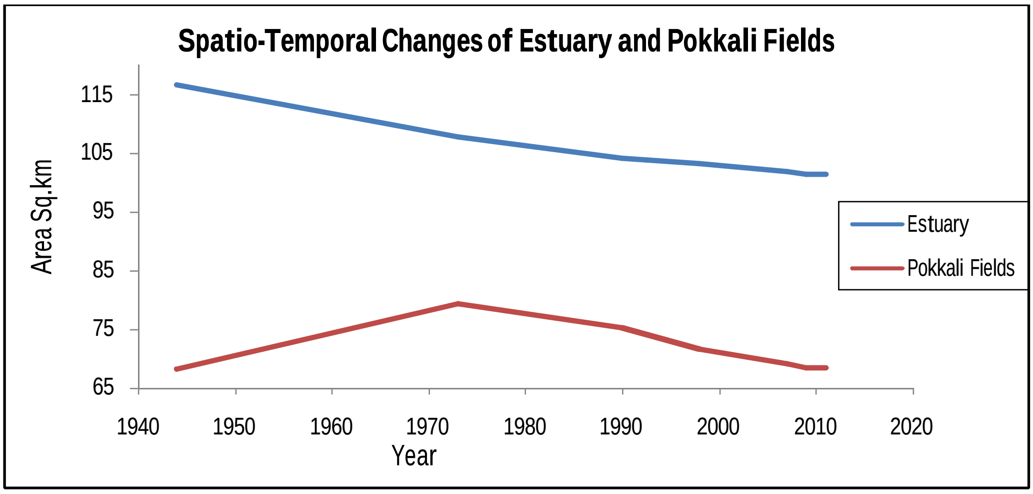
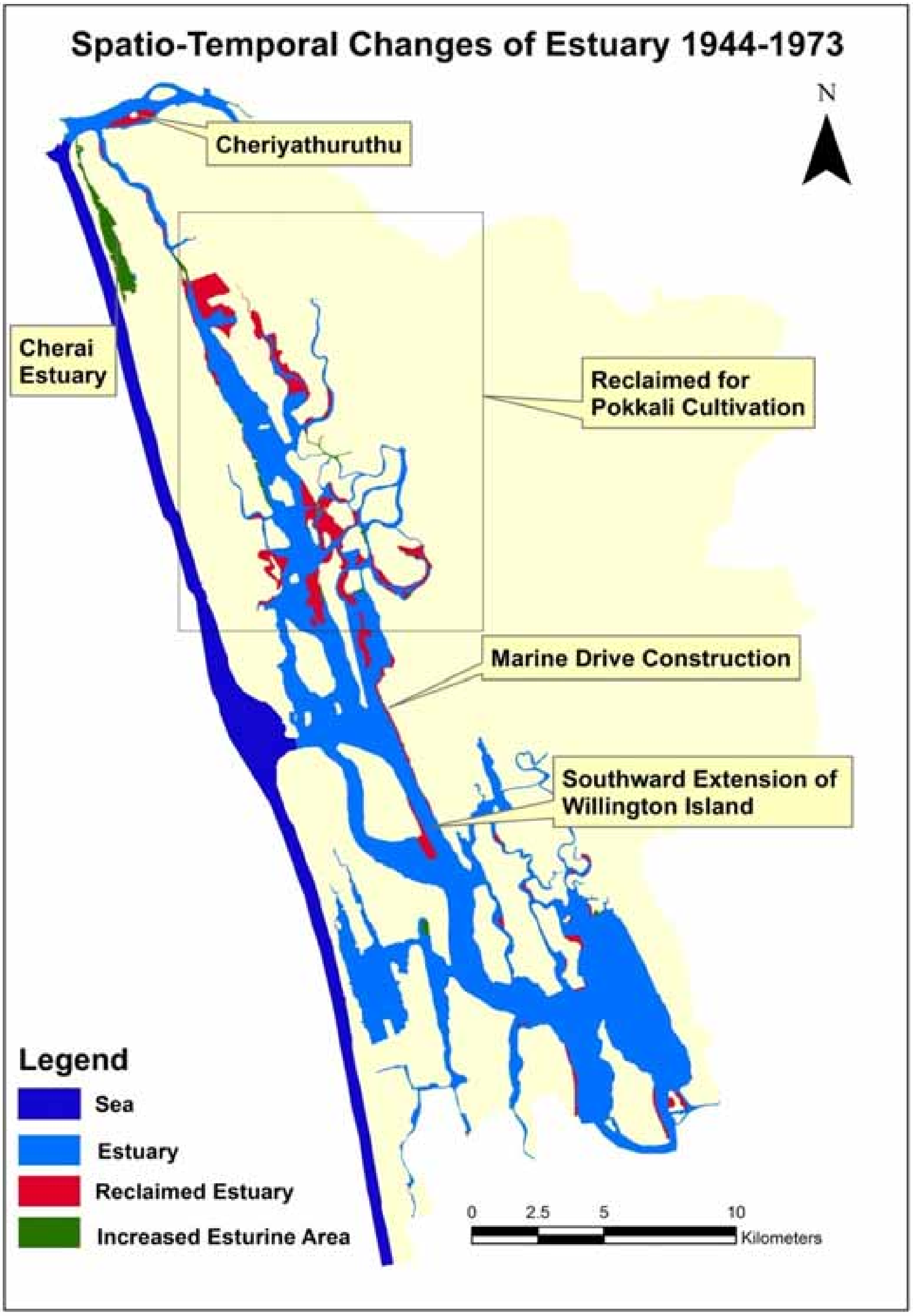


Figure 5.4 Spatio-Temporal Changes of Estuary and Pokkali Fields



Map-5.8 Spatio-Temporal Changes of Estuary 1944-1973

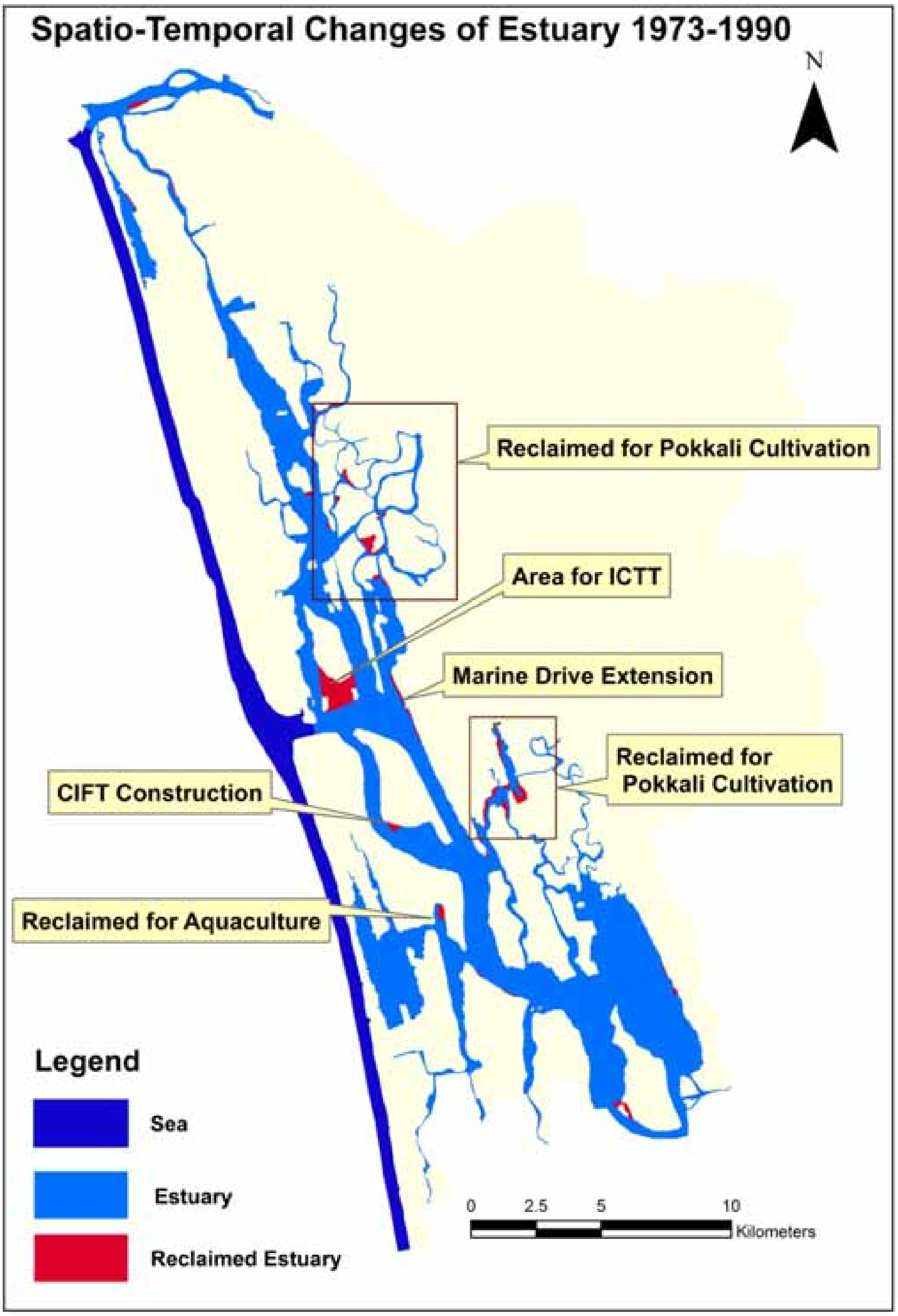
Table 5.2 Rate of Spatio-temporal Changes in Estuary Coverage

Period	Area Change km^2	Rate of change km^2 / Year
1944-1973	8.668	0.298
1973-1990	3.723	0.219
1990-1998	0.998	0.142
1998-2007	1.396	0.140
2007-2009	0.308	0.154
2009-2011	0.02	0.02

Fig 5.4 illustrates the slow decrease of the estuarine expanse and Table 5.2 reveals the reclamation rate during each period. During the first two periods, the reduction rate was very high due to the extensive conversion of estuary to Pokkali fields. The reduced rate during 2009-2011 was due to the Govt. of Kerala Act.

Table 5.3 Conversion of Estuary to other Land Use / Land Cover
(From Change Matrix Table given in the Annexure VIII-XIV)

Period	Pokkali Fields	Built Up	Built-up Industrial including Port	Reclaimed	Mixed Land use	Mangrove	Sp.Mangrove	Marshy
1944-1973	8.29	0.897	0.028		2.384			0.0345
1973-1990	1.233	0.547	0.141	0.805	0.509	0.032	0.046	0.462
1990-1998	0.044	0.224	0.36	0.15	0.17	0.028		
1998-2007		0.553		0.625	0.141	0.019	0.045	
2007-2009		0.182		0.21				
2007-2011				0.024				
1944-2011	9.567	2.403	0.529	1.814	3.204	0.079	0.091	0.4965



Map - 5.9 Spatio-Temporal Changes of Estuary 1973-1990

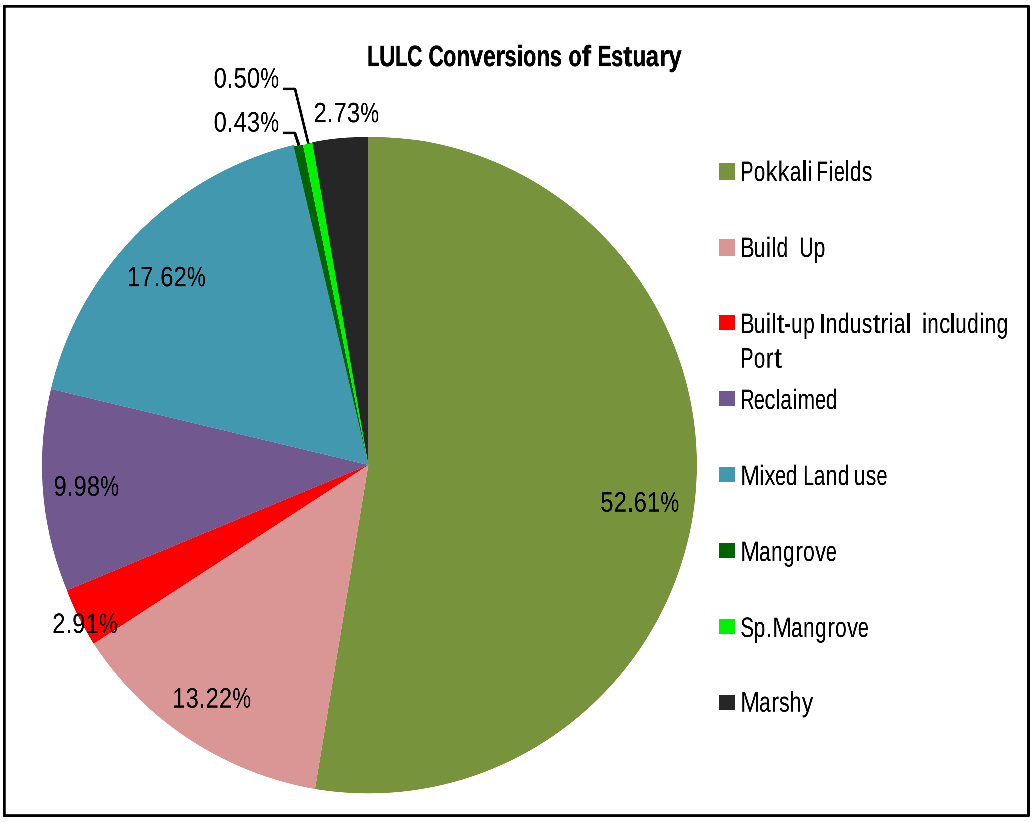


Figure 5.5 Fractions of Land Use/Land Cover converted from Estuary

Table 5.3 and fig-5.5 indicates that approximately 52.61% of the estuary was converted to Pokkali Fields and 16.13% to built up area (including industries).

The estuary has shrunk by 7.43% (8.668 km^2) from 1944 to 1973 (Annexure V). The environmental impact of this reduction in estuarine area was somehow minimized by the addition of estuarine patches at some other places. To the existing estuary, an area of 3.068 km^2 was added, in which an area of 2.047 km^2 was due to the formation of a new estuary patch near Cherai due to sand deposition off the sea coast with its ensuing separation from the Arabian sea.

During this period (1944 - 1973), an area of 8.29 km^2 has reduced due to conversion by the native population for the Pokkali cultivation, but still retaining some of its wetland characteristics (Annexure V). An area of 3.309 km^2 was reclaimed as land from which 0.5 km^2 was lost by the formation of a new island (Cheriyathuruthu) near Munambam bar mouth, whereas 0.28 km^2 and 0.513 km^2 respectively were lost due to construction of Marine Drive and southward extension of Willington Island by Greater Cochin Development Authority (GCDA). Illegal public encroachment devoured 2.016 km^2 by converting the estuary to land area. Spatial changes during this period are given in Map 5.8.

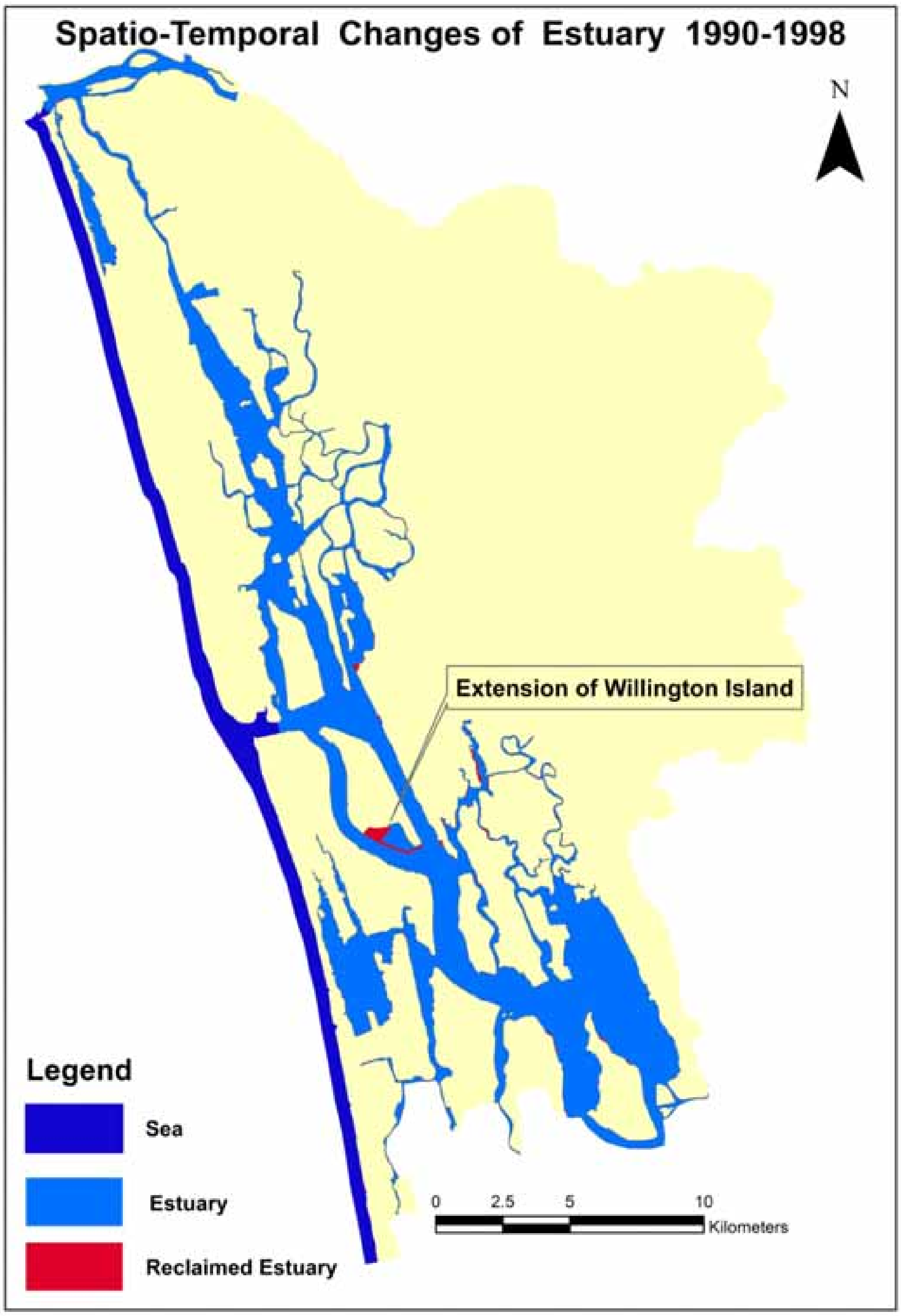
During 1973 to 1990, the estuary has gradually decreased in area by 3.44% (3.723 km^2) (Annexure V), of which 1.233 km^2 was reclaimed for Pokkali cultivation and a 1.32 km^2 -sized land strip was created by the Cochin Port Trust(CPT) by dumping of silt dredged for deepening the ship channel near Vallarpadam Island. This land is now being used for the International Container Trans-shipment Terminal (ICTT). 0.114 km^2 was lost due to the extension of Willington Island for Central Institute for Fisheries Technology (CIFT) - related constructions and 0.158 km^2 was lost by reclamation for the extension of Marine Drive. 0.41 km^2 was lost due to illegal conversion of the estuary to land area by the public. Spatial changes during this period are given in Map 5.9.

During 1990 - 1998, the estuary got reduced by 0.95% (0.998 km^2) (Annexure V), of which a big portion of the estuary (0.506 km^2) was lost near Willington Island for increasing the container storage area for the CPT. 0.09 km^2 was lost due to constructions at Ernakulam Boat jetty area, construction of new Thevara - Willington Island bridge and reclamation at the northern end of Marine Drive. An area of 0.158 km^2 was lost from the estuary due to encroachment and land filling by the native population and 0.04 km^2 was encroached upon the estuary for aquaculture activities by the native population. Spatial changes during this period are given in Map 5.10.

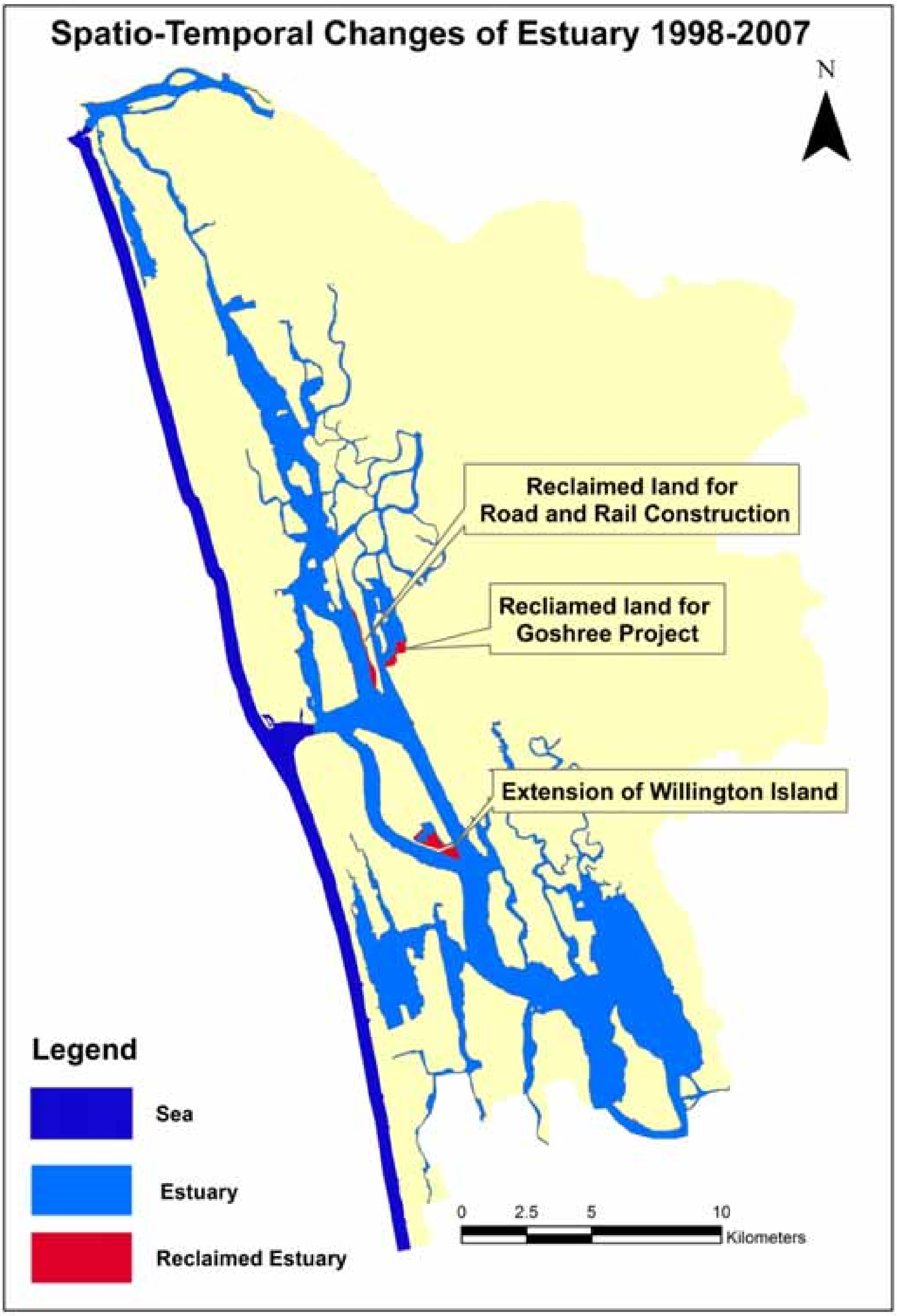
During 1998 to 2007, the estuarine coverage reduced by 1.3% (1.396 km^2) (Annexure V). During this period 0.219 km^2 was lost due to Rail and Road construction for Vallarpadam ICTT Project. An area of 0.379 km^2 was lost for the extension of Willington Island and 0.288 km^2 was lost by public encroachment and land filling. An area of 0.433 km^2 was reclaimed and traded to meet the expenses of Goshree Bridge construction. Spatial changes during this period are given in Map 5.11.

After 2007, during a 2-year period, the estuarine coverage has decreased by 0.308 km^2 (Annexure V), of which 0.182 km^2 was devoted to rail and road construction for Vallarpadam ICTT Project. 0.126 km^2 was lost due to extension of Willington Island. Spatial changes during this period are given in Map 5.12.

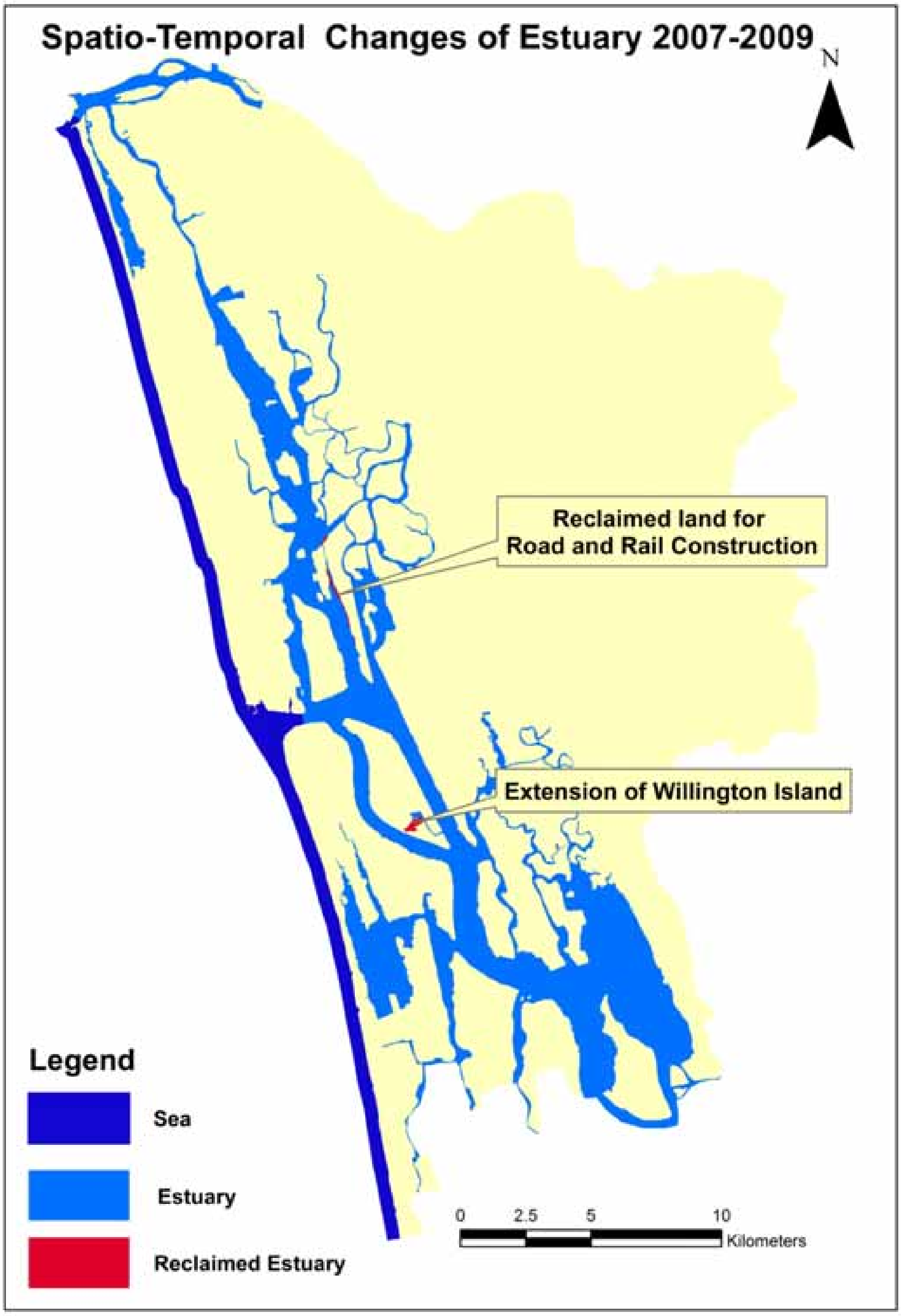
During 2009 to 2011, the estuarine coverage reduced only very little - 0.02 km^2 (Annexure V).



Map-5.10 Spatio-Temporal Changes of Estuary 1990-1998



Map-5.11 Spatio-Temporal Changes of Estuary 1998-2007



Map-5.12 Spatio-Temporal Changes of Estuary 2007-2009

5.3.1.2 Spatio-Temporal Changes of Pokkali Fields

From this study, it is found that the overall decline of the Pokkali fields during 1973-2011 is 13.72% (10.844 km^2). But during 1944 to1973, there was an increase of 16.45% (11.224 km^2) as seen in Annexure V. Pokkali coverage changes during these seven decades (1944-2009) are shown in the Fig 5.4 and the details given in Table 5.4.

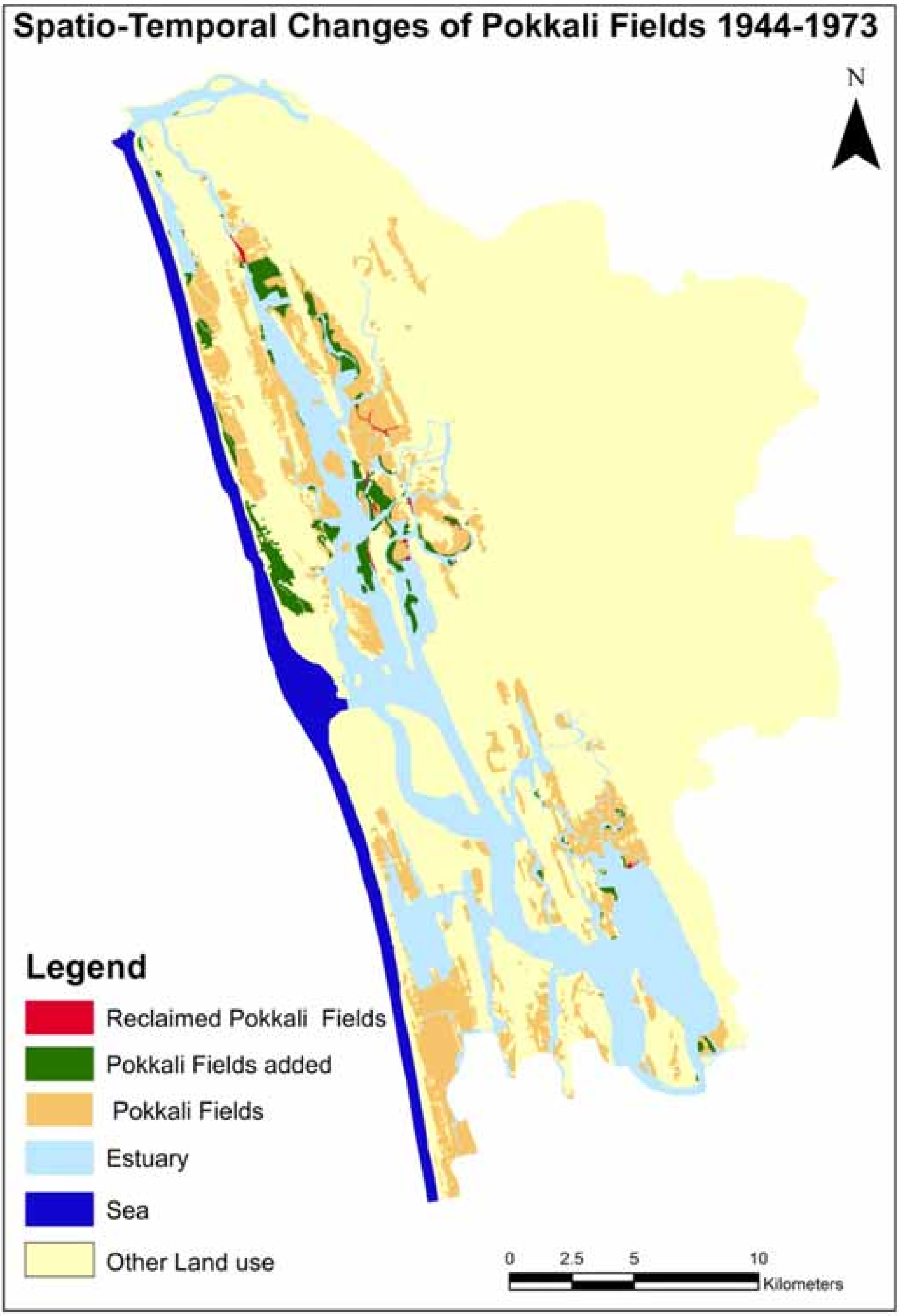
Table 5.4 Rate of Spatio-temporal Changes in Pokkali Coverage

Period	Area Change km^2	Reduction Rate km^2 / year
1944-1973	11.224	+0.387
1973-1990	4.056	-0.238
1990-1998	3.792	-0.542
1998-2007	2.445	-0.245
2007-2009	0.604	-0.302
2009-2011	0.003	-

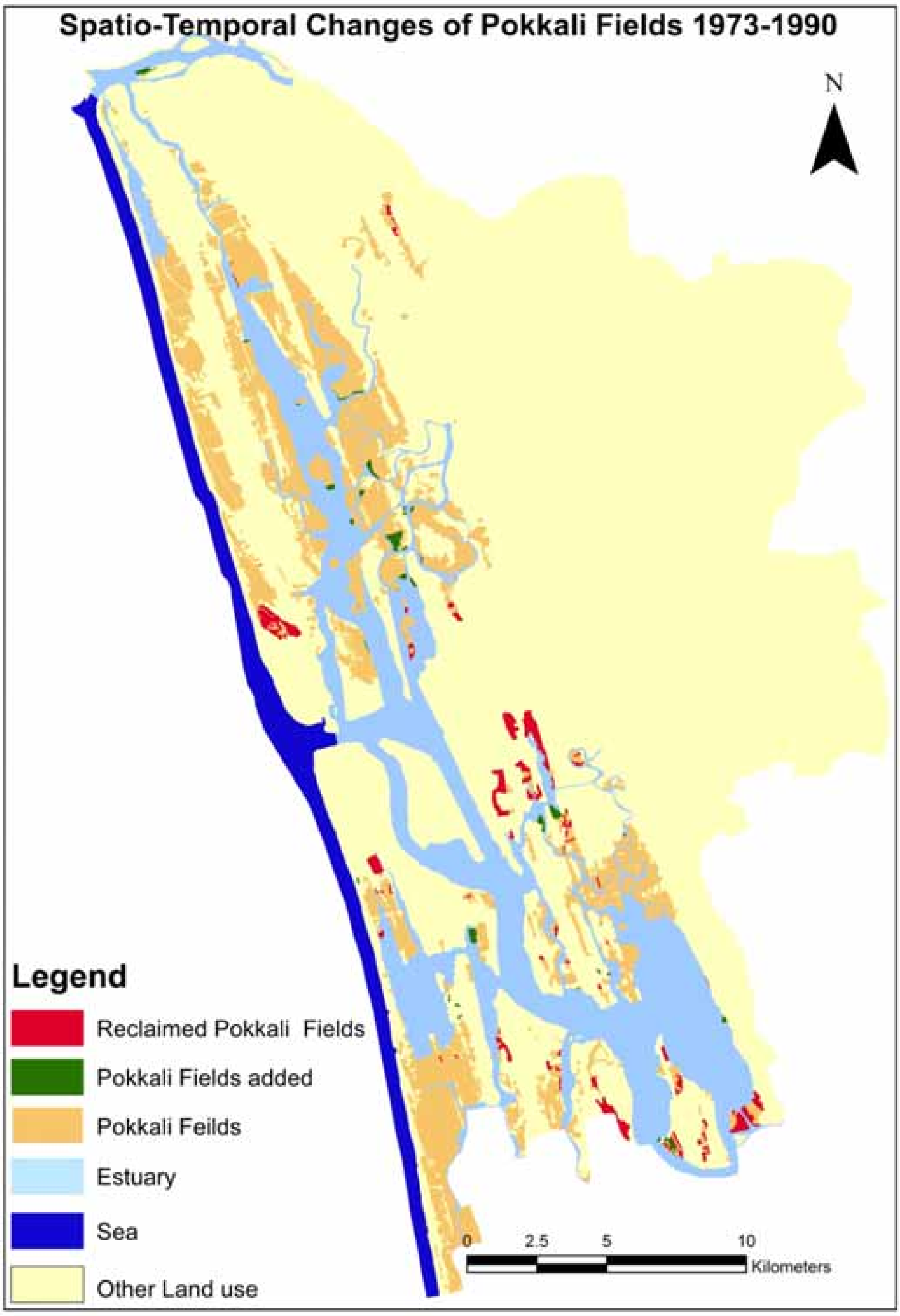
Table 5.4 indicates that during 1990 to1998, the reduction rate was very high due to the NH-47 Bye-pass construction from Edappally to Aroor, mainly at the Maradu - Nettoor Area. After 2009, the wetland reclamation has drastically decreased like for reasons mentioned above.

Table 5.5 Pokkali Conversions to other Land use / Land cover
(From Change Matrix Table given in the Annexure VIII-XIV)

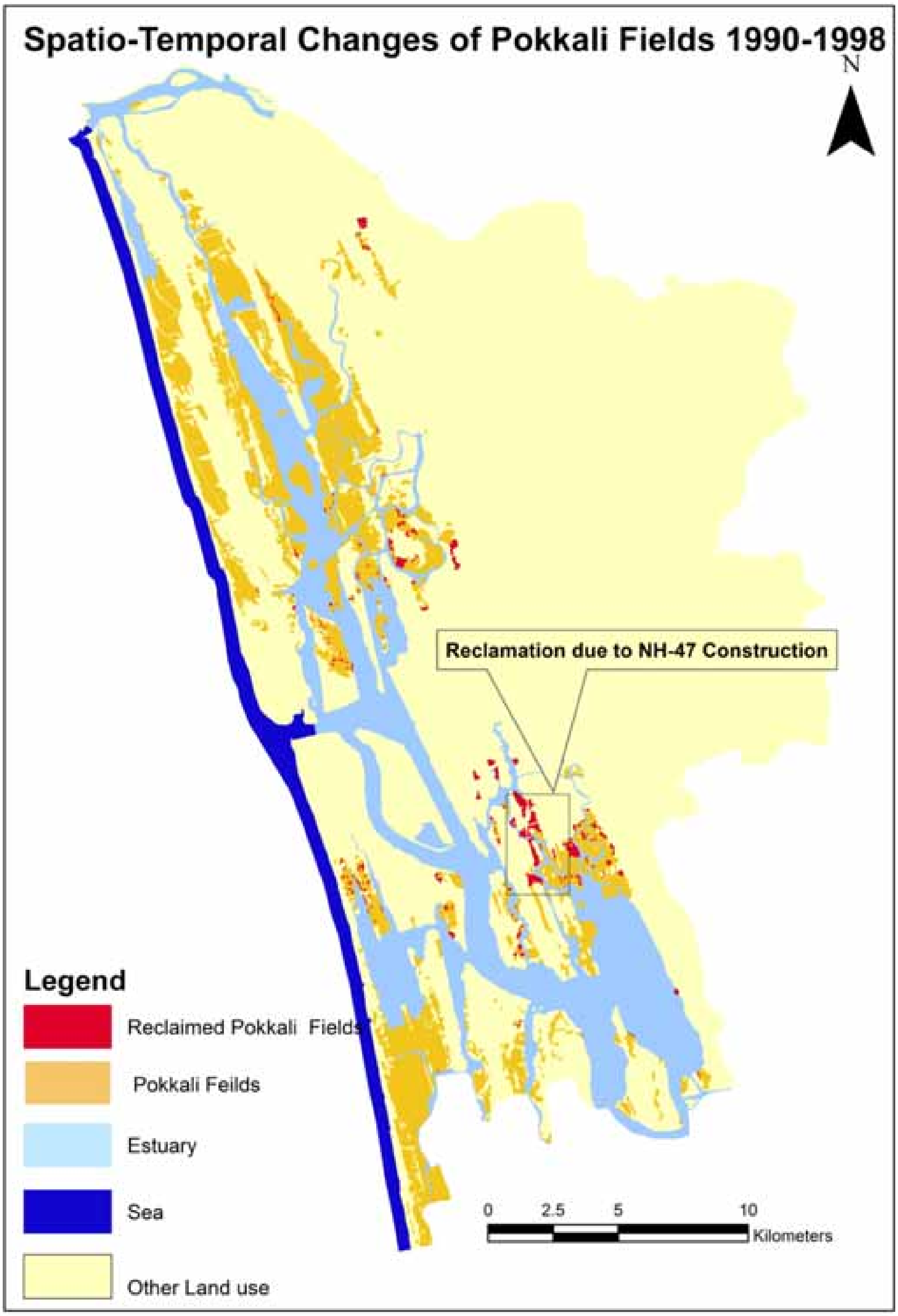
Period	Built Up	Aquaculture with Coconut	Mixed Land use	Reclaimed	Dense Mangrove	Sp. Mangrove
1973-1990	2.088	0.858	1.975	0.169	0.129	0.162
1990-1998	1.193	0.238	0.75	0.719	0.479	0.465
1998-2007	0.57	0.198	0.78	0.362	0.336	0.445
2007-2009	0.317	0.027	0.096	0.145	0.061	0.076
2009-2011			0.012	0.094	0.007	0.018
1973-2011	5.002	1.307	2.879	1.054	0.995	0.854



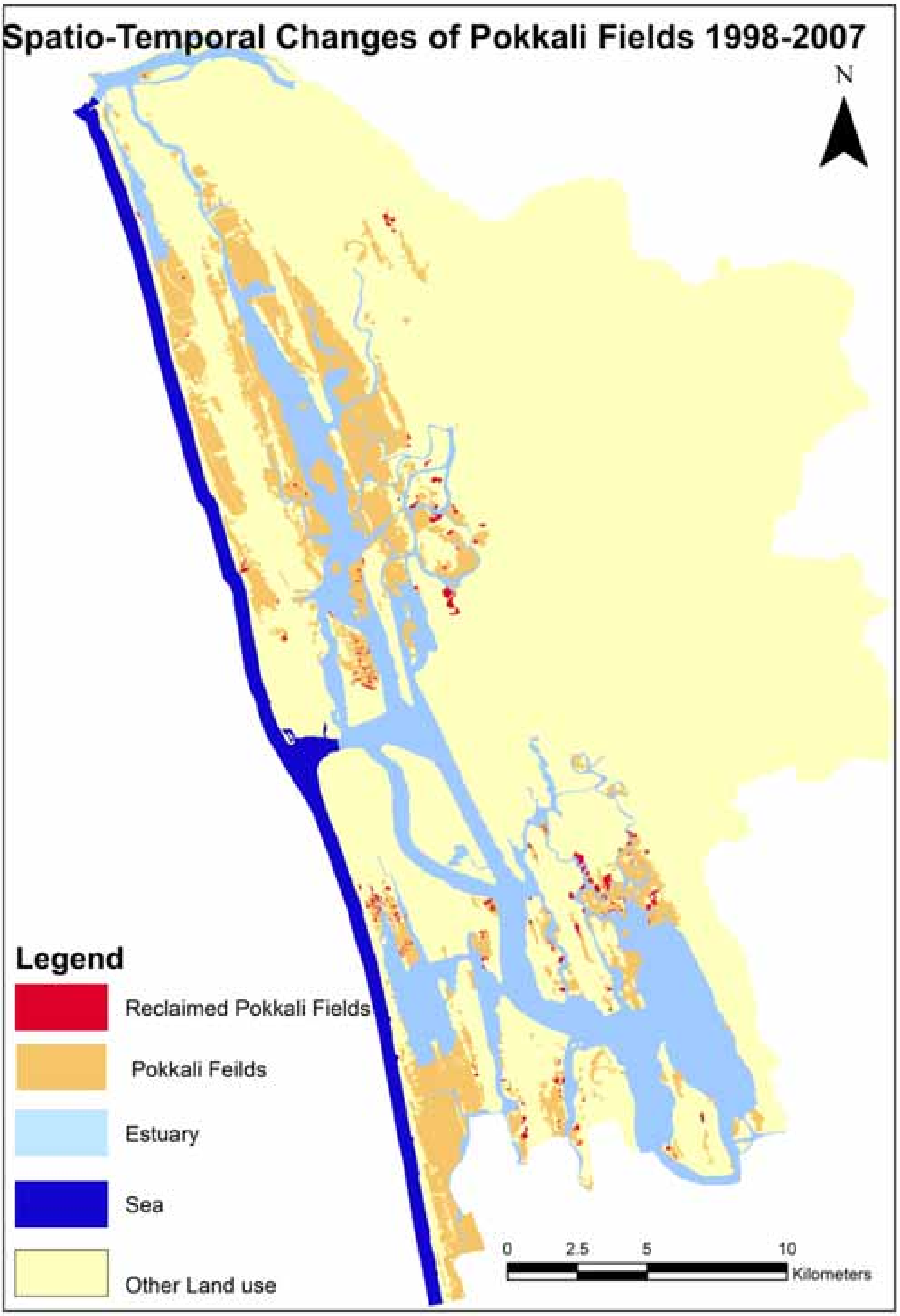
Map-5.13 Spatio-Temporal Changes of Pokkali Fields 1944-1973



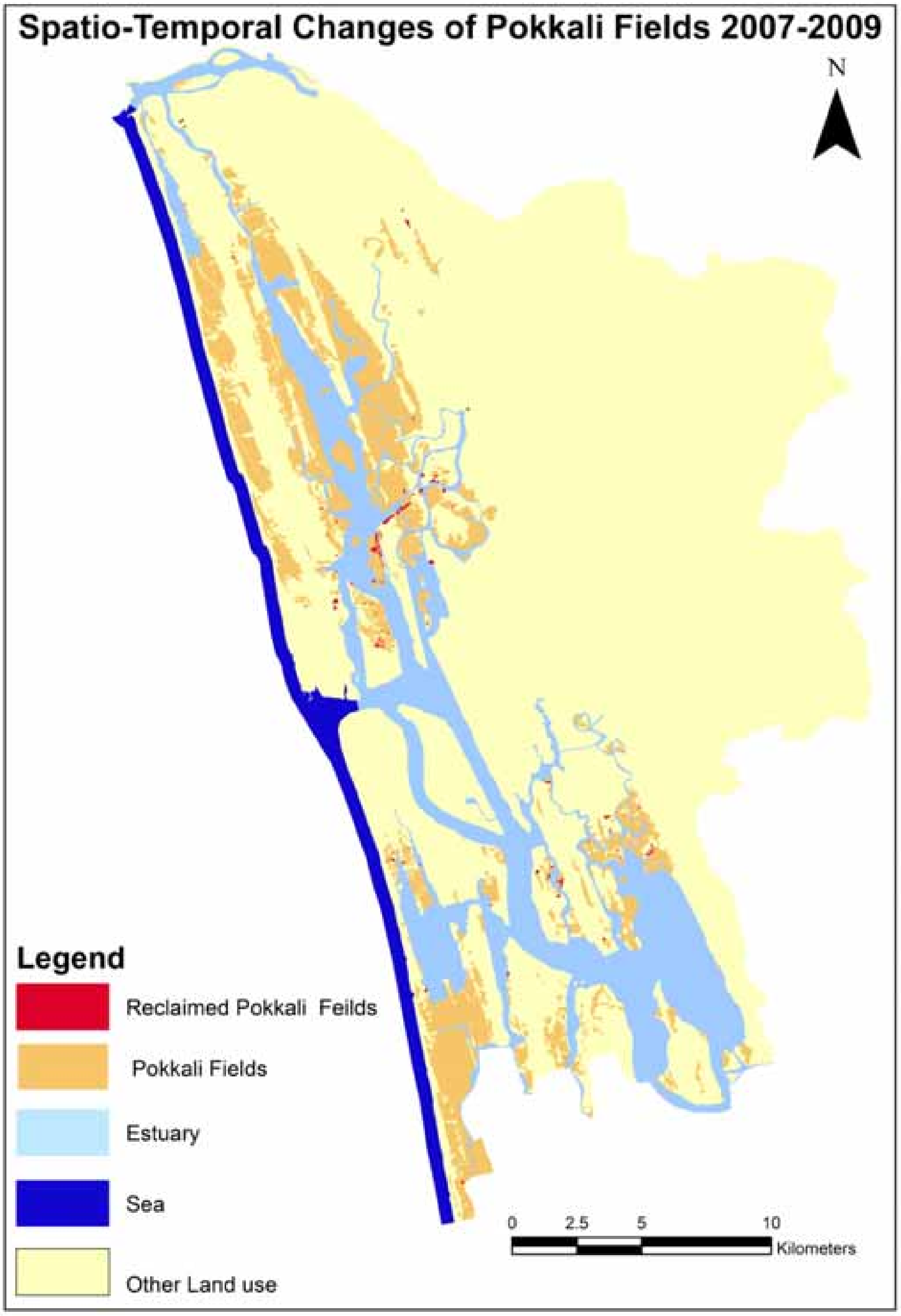
Map-5.14 Spatio-Temporal Changes of Pokkali Fields 1973-1990



Map-5.15 Spatio-Temporal Changes of Pokkali Fields 1990-1998



Map-5.16 Spatio-Temporal Changes of Pokkali Fields 1998-2007



Map-5.17 Spatio-Temporal Changes of Pokkali Fields 2007-2009

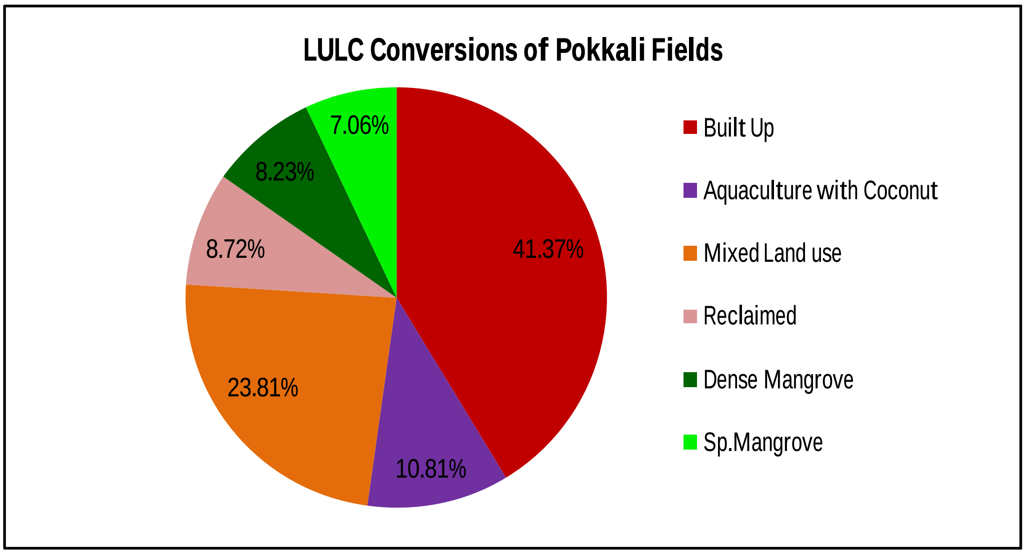


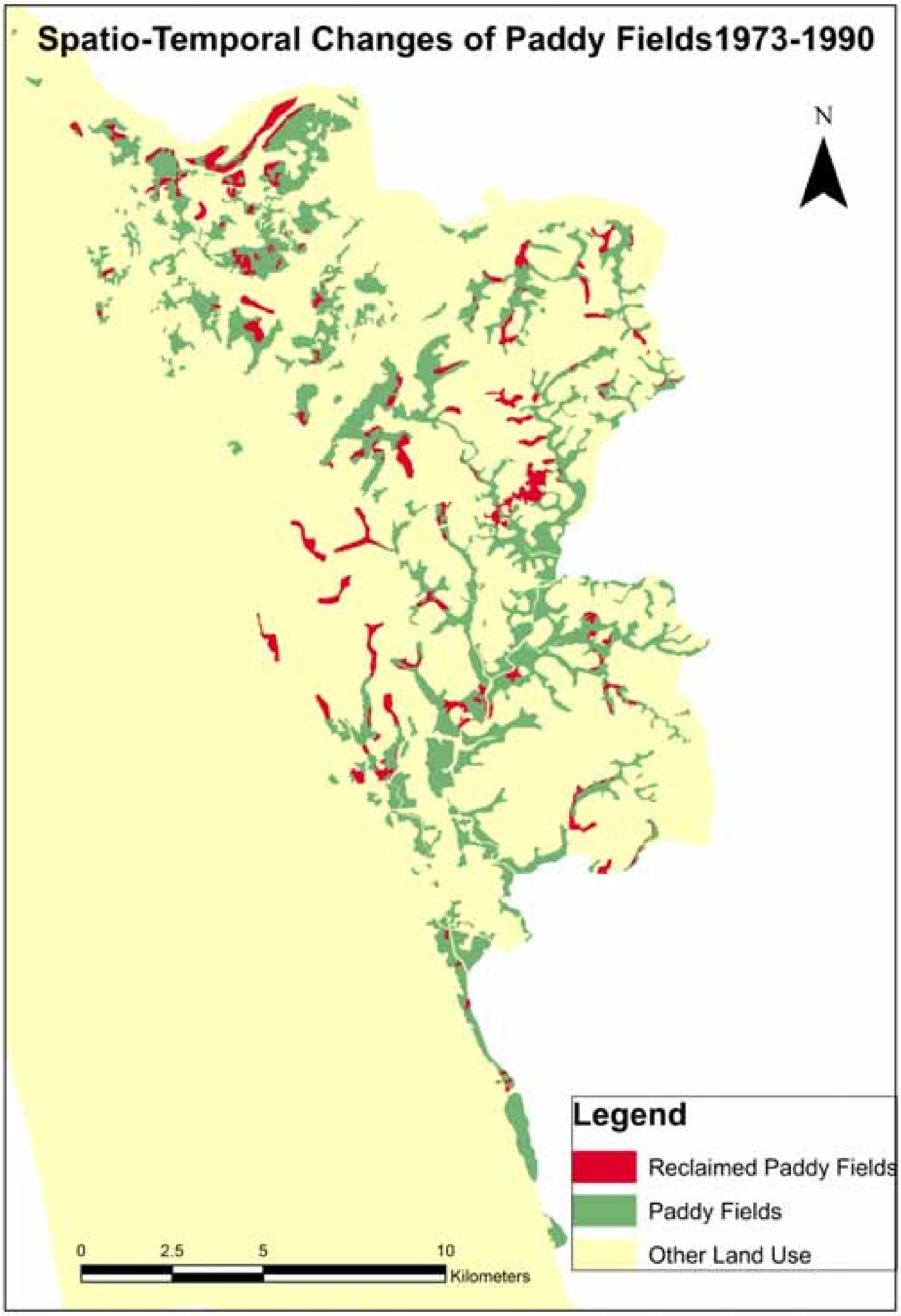
Figure 5.6 Fractions of Land Use/Land Cover converted from Pokkali Fields

Table 5.5 and Fig-5.6 indicate that from the total area of Pokkali fields reclaimed, a good part (15.29%) was naturally encroached by mangroves because of leaving the Pokkali fields fallow. Of the total area reclaimed, 41.37% was converted to Built up area.

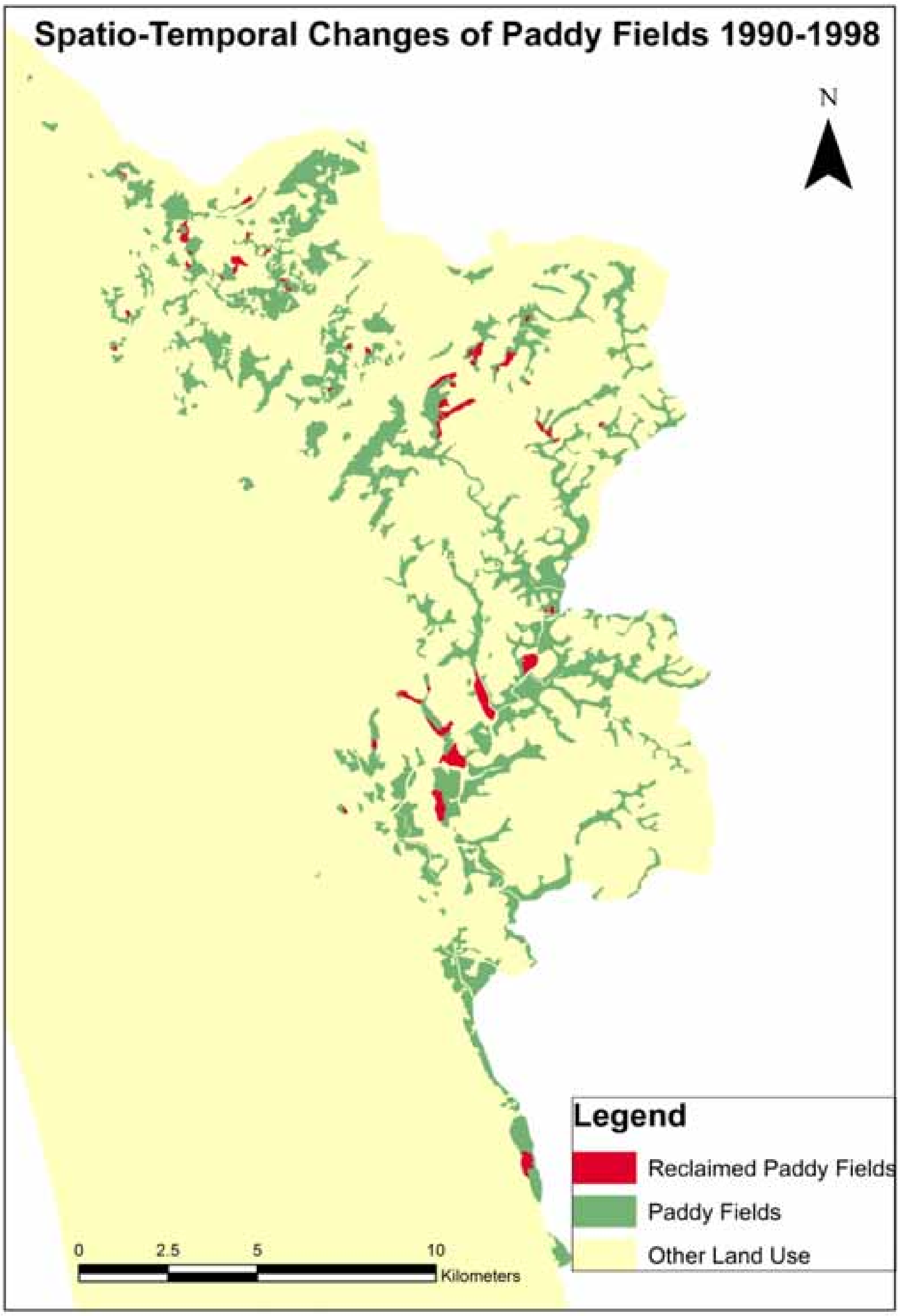
Spatio-temporal changes of Pokkali fields during the periods 1944-1973 is given in Map 5.13, 1973-1990 in Map 5.14, 1990-1998 in Map 5.15, 1998-2007 in Map 5.16 and 2007-2009 in Map 5.17.

5.3.1.3 Spatio-Temporal Changes of Paddy Fields

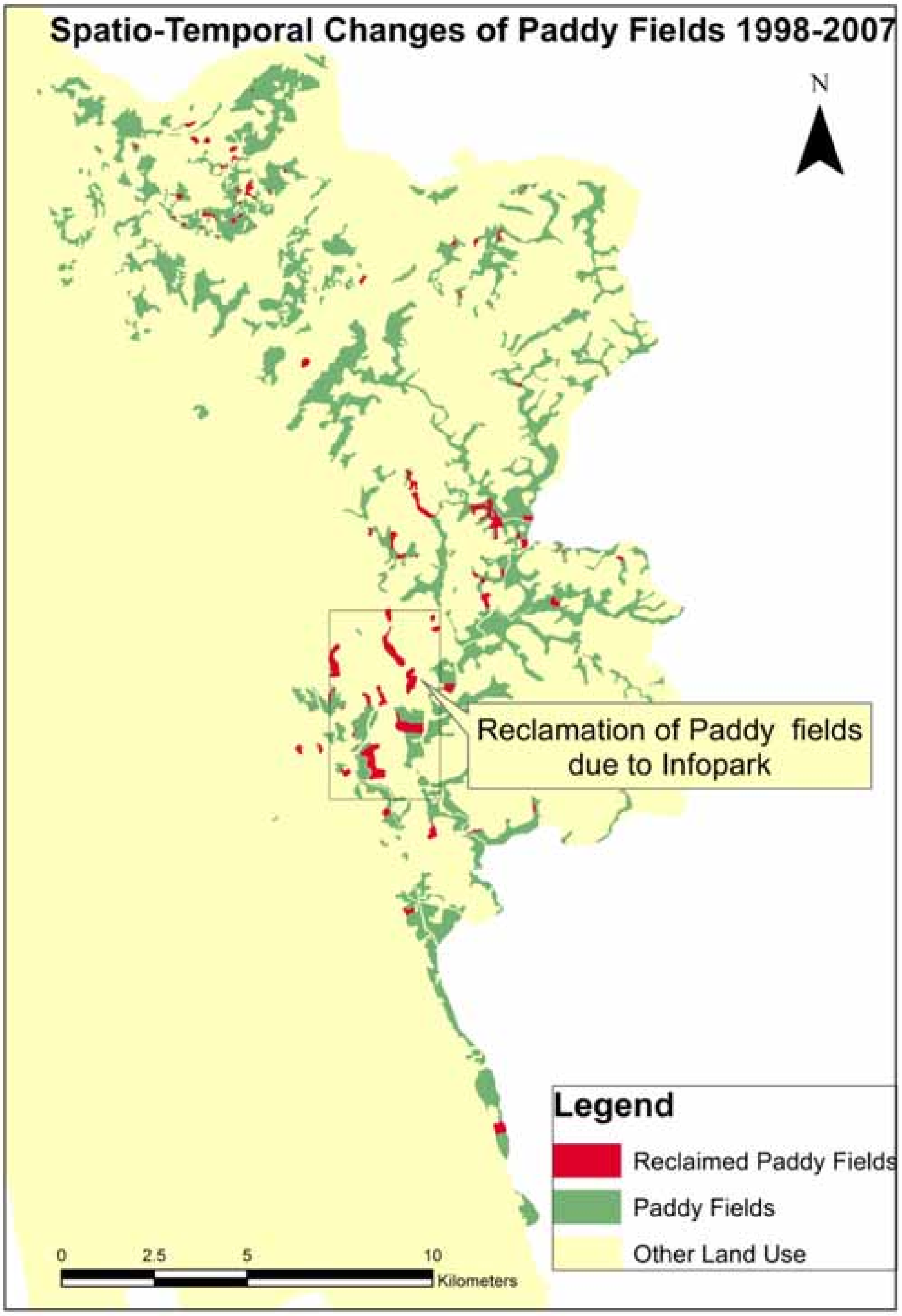
From this study, it is found that the overall decline of the Paddy fields during 1973-2011 is 13.72% (15.001 km^2), as shown in Fig 5.7, the details of which are given in Annexure V.



Map-5.18 Spatio-Temporal Changes of Paddy Fields 1973-1990



Map-5.19 Spatio-Temporal Changes of Paddy Fields 1990-1998



Map-5.20 Spatio-Temporal Changes of Paddy Fields 1998-2007

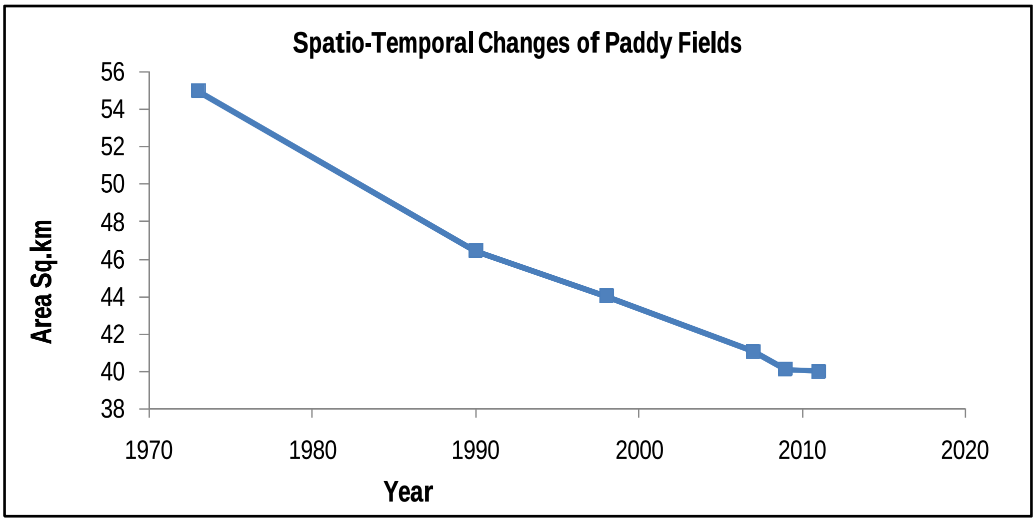


Figure 5.7 Spatio-Temporal Changes of Paddy Fields

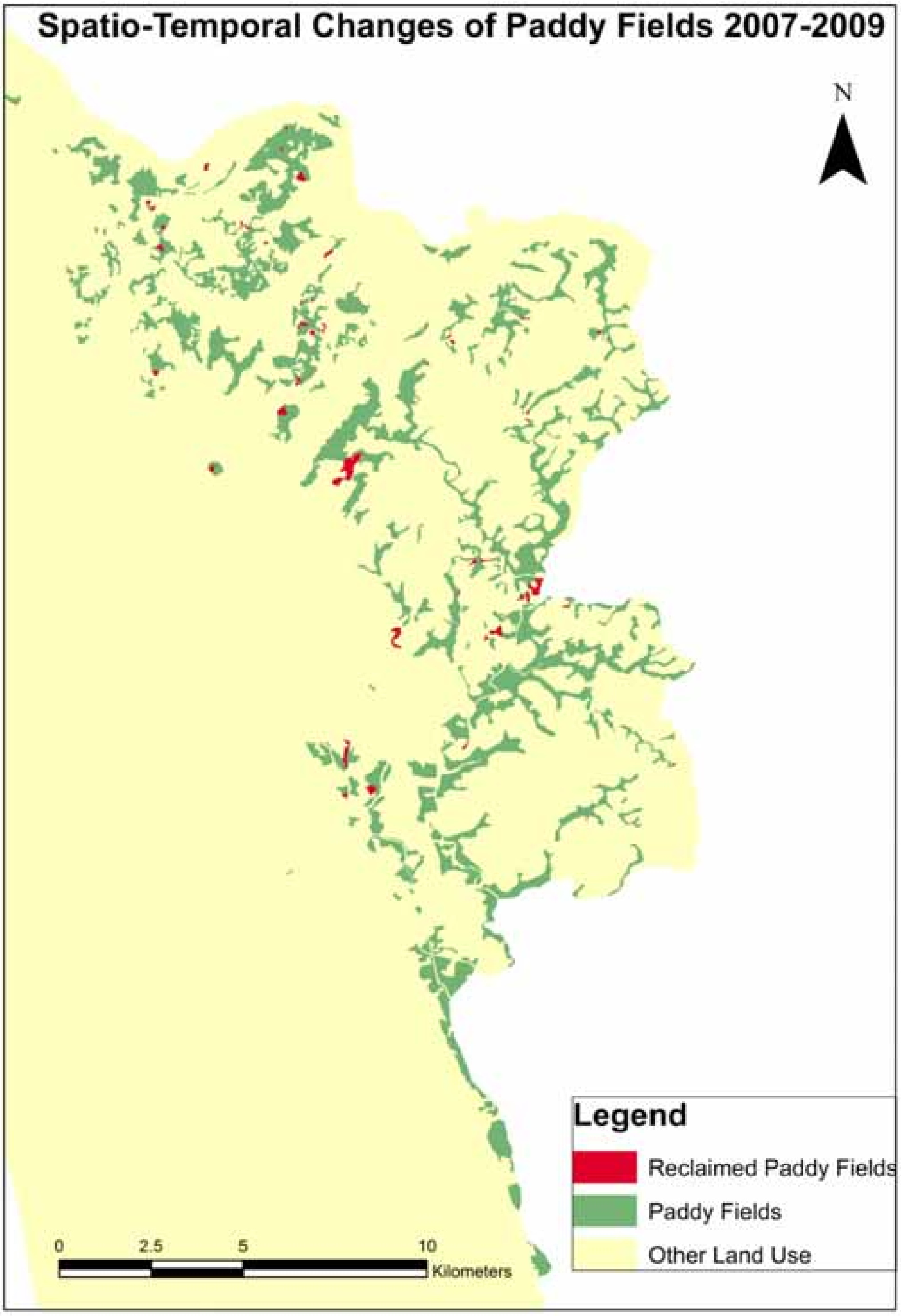
Table 5.6 Rate of Spatio-temporal Changes in Paddy Fields

Period	Area Change km^2	Rate of change km^2 / year
1973-1990	8.569	0.504
1990-1998	2.419	0.345
1998-2007	2.95	0.295
2007-2009	0.962	0.481
2009-2011	0.1	0.1

During 1998-2007, the reclamation of paddy fields was mainly concentrated around Infopark, Kakkanad (Map 5.20). During the subsequent 2-year period, the reclamations reduced in that area, but increased very much in far off regions resulting in an overall 0.481 km^2/year reduction (Map 5.21). After 2009, the reclamation has reduced considerably (Table 5.6).

Table 5.7 Paddy Field Conversions to other LULC
(From Change Matrix Table given in the Annexure VIII-XIV)

Period	Built up Area	Built-Up Industrial Area	Mixed Land use	Reclaimed	Clay Mines
1973-1990	2.296	0.399	5.277		0.49
1990-1998	0.865	0.204	0.895	0.356	0.216
1998-2007	0.834	0.797		0.732	0.1
2007-2009	0.073		0.134	0.792	0.023
2009-2011	0.014			0.086	0.018
1973-2011	4.387	1.191	6.306	2.404	0.819



Map-5.21 Spatio-Temporal Changes of Paddy Fields 2007-2009

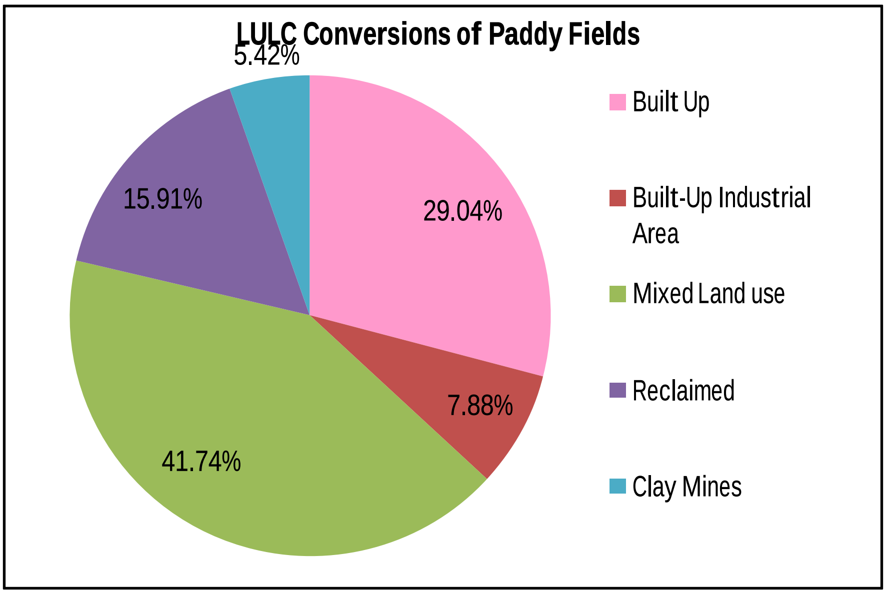


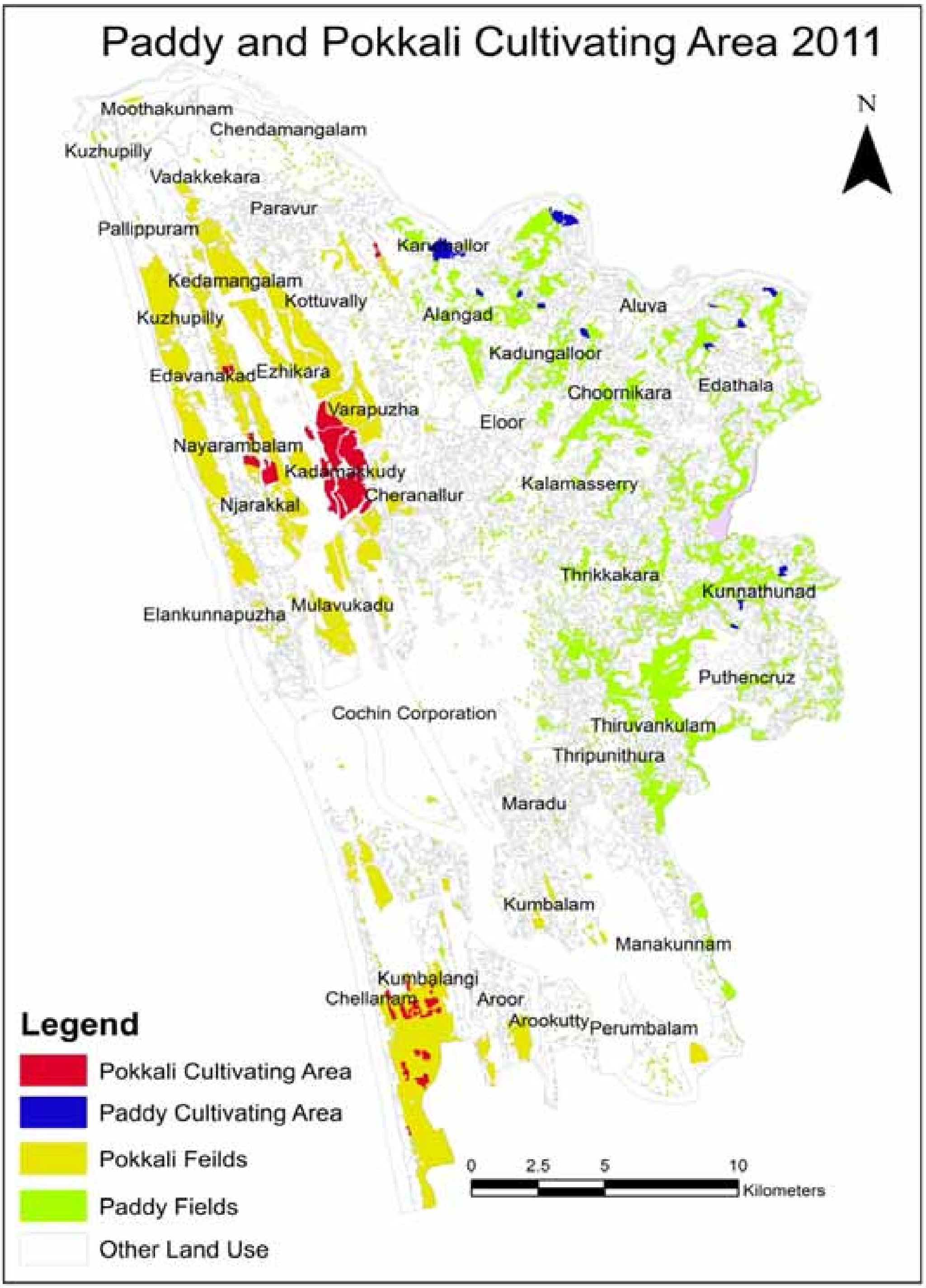
Figure 5.8 Fractions of Land Use/Land Cover converted from Paddy Fields

Table-5.7 and Fig-5.8 indicate that, of the total area of paddy fields reclaimed, a major portion (36.92%) was converted to built up area (including Industrial Area) and 5.42% of Paddy fields was converted to clay mines catering the needs of brick-kilns required for a booming construction business.

Spatio-temporal changes of paddy fields during the study period are given in Maps 5.18, 5.19, 5.20 and 5.21.

5.3.1.4 Present Pokkali and Paddy Cultivation Scenario

Of the total currently available paddy and Pokkali fields, only 10.09% of Pokkali fields and 4.25% of Paddy fields used for cultivation (Map 5.22). Traditional Pokkali cultivation is still continuing in parts of Kadamakkudy, Nayarambalam and Chellanam Panchayaths. Also, a few Pokkali farms have been started in parts of Kumbalangi and Chellanam Panchayaths. Large patches of paddy cultivating areas at Karumallor Panchayath and several small patches can be seen throughout the study area from the above-mentioned Map.



Map-5.22 Pokkali and Paddy Cultivating Area 2011

5.3.2 Spatio-Temporal Changes of Mangroves

Mangroves are salinity-tolerant plants which grow in tropical and subtropical intertidal regions of the world. The specific regions where these plants flourish are termed as 'mangrove ecosystem', which are highly productive but extremely sensitive and fragile. Besides mangroves, this ecosystem is also the habitat for several plant and animal species. Mangrove forests are one of the most productive and bio diverse wetlands on earth.

Not only the mangroves prevent soil erosion, but they also aid in the building up of land in the following way. Some early successional species of the water-ward side extend even to a depth of about 1 meter into the water. The intermeshing of prop-roots of these trees along with the pneumatophores (breathing roots) collect suspended particles in water and result in the gradual formation of land. The thick mesh of roots prevent any chances of erosion also. Also, the shallow water protected by the intertwining prop roots of the mangrove trees forms an ideal nursery ground for young fishes where it can escape easily from predators. Mangrove trees have a significant role in the production of food for fishes in coastal waters. It is estimated that (Odum and Heald, 1975) mangrove trees produce about 1 metric ton of dry organic matter / hectare / year in the form of leaves which fall into the water and slowly disintegrate to form food for small fishes and other small aquatic animals, which in turn form food for large fishes. Also, the mangrove ecosystem forms ecotone with edge effect resulting in the maximum productivity of aquatic life and species diversity. Mangrove forests form a protective zone in the shallow areas in the backwaters which is an ecological edge.

In the wetlands near Cochin, 10 dominant species of mangroves are identified (Sunil,1993). They are given in the Table 5.8.

Table 5.8 Mangroves in Cochin area

No.	Mangroves	Family
1	Rhizophora mucronata	Rhizophoraceae
2	Rhizophora apiculata	Rhizophoraceae
3	Avicinnia officinalis	Verbenaceae
4	Acantus ilicifolius	Acanthaceae
5	Bruguiera sp.	Rhizophoraceae
6	Acrostrichum aureum	Fern
7	Clerodendron inerme	Verbenaceae
8	Cerebra odollom	Apocyanaceae
9	Derris trifoliata	Leguminosae
10	Sonneratia apectala	Sonneratiaceae

In this study, the Mangrove-covered areas are divided into 2 types - Dense and Sparse mangroves according to the Coastal Classification of Space Application Centre, (SAC), Ahmadabad (George, 2005). Dense mangroves are areas with the grown up, thickly or densely packed mangrove trees and Sparse mangroves are the areas with young mangrove trees, mangroves at the ridges of Pokkali fields and other sparsely growing mangrove areas.

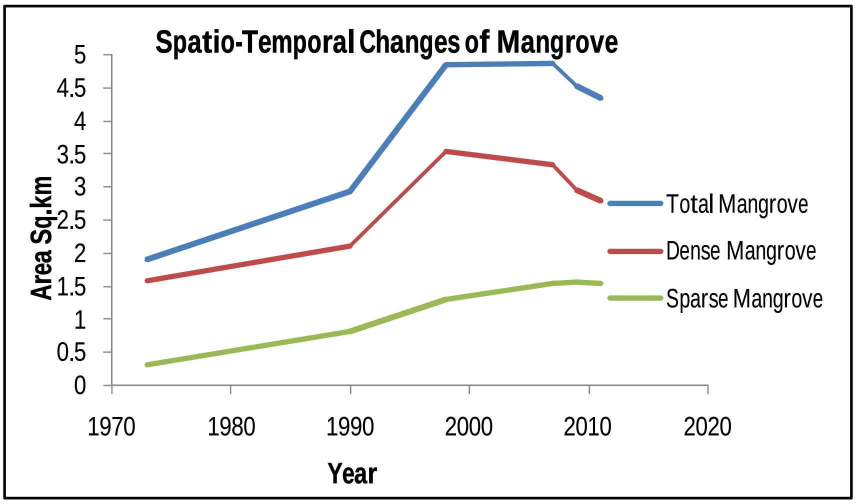
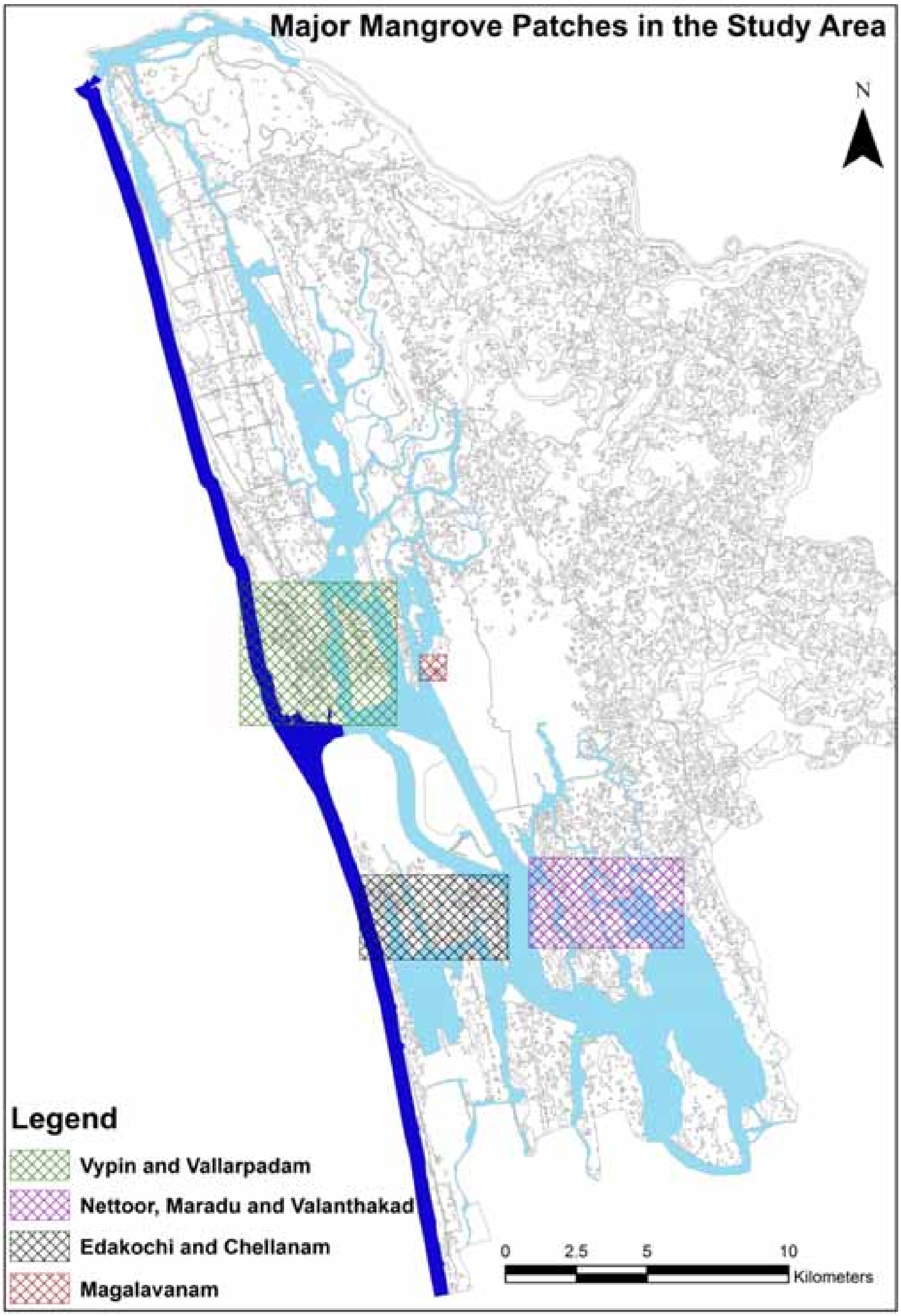


Figure 5.9 Spatio-Temporal Changes of Mangroves

Figure-5.9 shows that the total Mangrove coverage increased from 1973 to 1998 by about 155.39% (Annexure V). During this period the Pokkali cultivation and the mangrove spread appears to be inversely proportional. But since 2007, in spite of the decrease in Pokkali as well as paddy farming, a reduction in mangrove coverage (10.84%) is seen, an obvious consequence of urbanisation.



Map-5.23 Major Mangrove Patches in the Study Area

During the study period, the Dense mangrove coverage closely followed the pattern of Total mangrove coverage, but the Sparse mangrove appear to spread almost uniformly (Fig 5.10). Such a difference is attributable to the spreading of mangrove siblings to the Pokkali fields being left fallow; an increasing tendency in the face of failing economic returns.

From the Annexure V it can be seen that the Dense Mangroves have increased from 1973 to 1998 by about 123.11% and reduced (21.39%) by 2011.

It is seen that in the study area, mangroves are mainly located in 4 sites (Map 5.23), which are:-

1. Vypin and Vallarpadam
2. Nettoor, Maradu and Valanthakad
3. Edakochi and Chellanam
4. Mangalavanam

Even though mangroves are concentrated mainly on these 4 main locations, there are a few isolated small patches of mangrove stands in the study area. Of the above 4 locations, Vypin and Vallarpadam area have the maximum extent of mangroves.

In general, the spatio-temporal changes in the mangrove coverage reveal distinct influence of urbanisation and related developmental activities. The spatio-temporal behavior of these 4 different mangrove stands reveal different trends depending mainly on the proximity to city centre and other areas of commercial as well as industrial activities. They are discussed in detail in sections given below:

5.3.2.1 Vypin - Vallarpadam Area

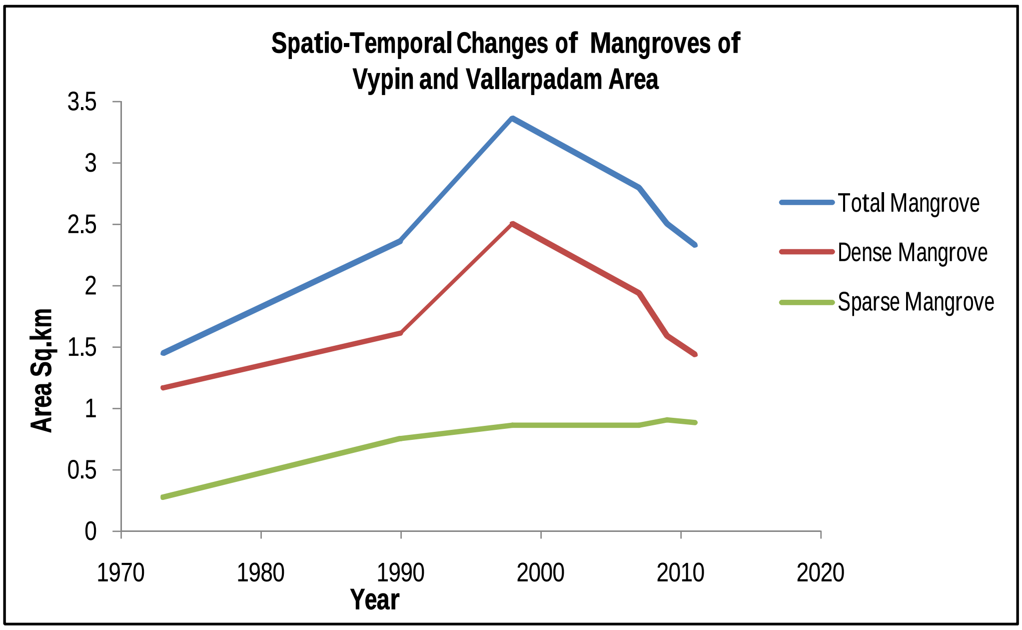
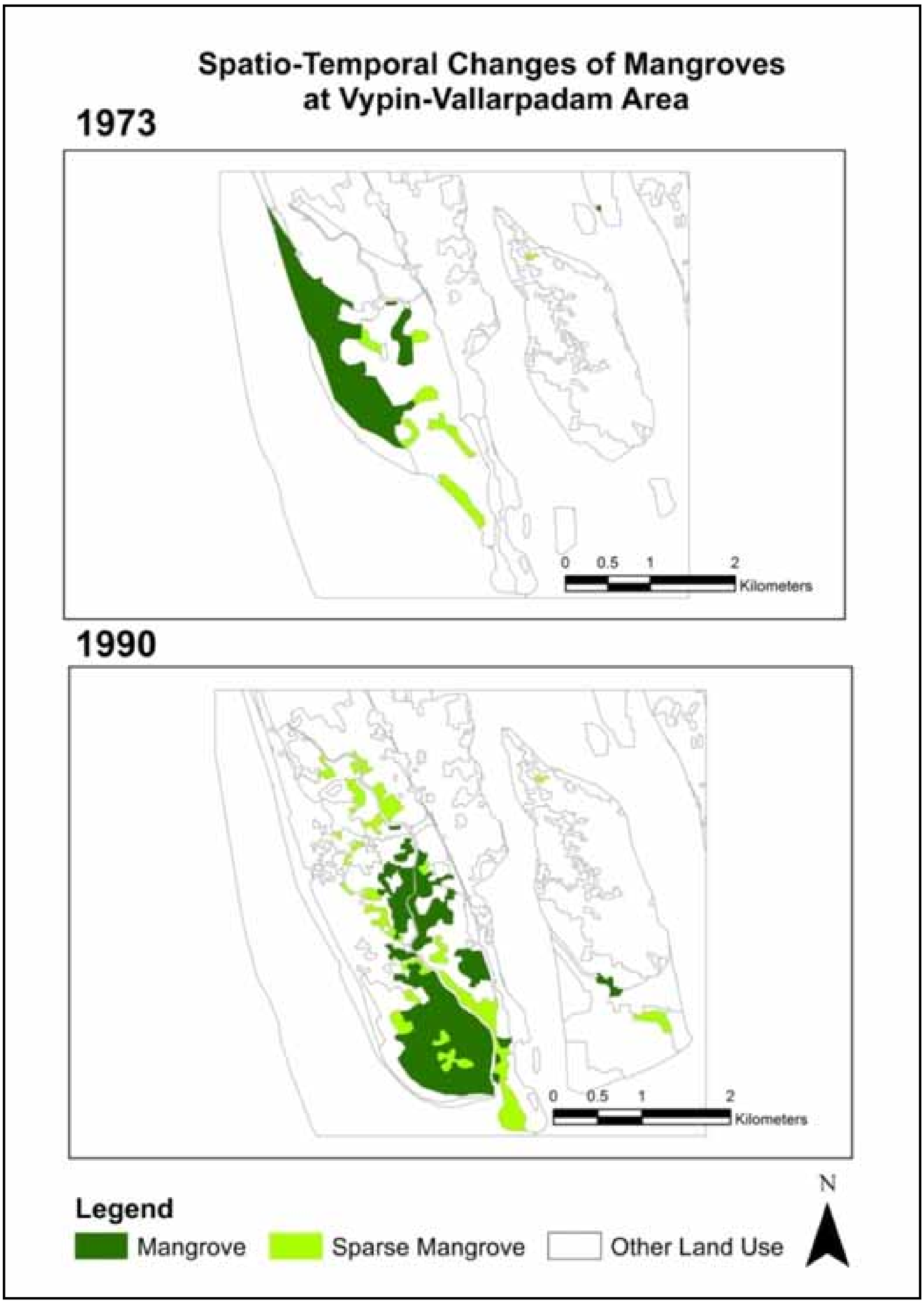
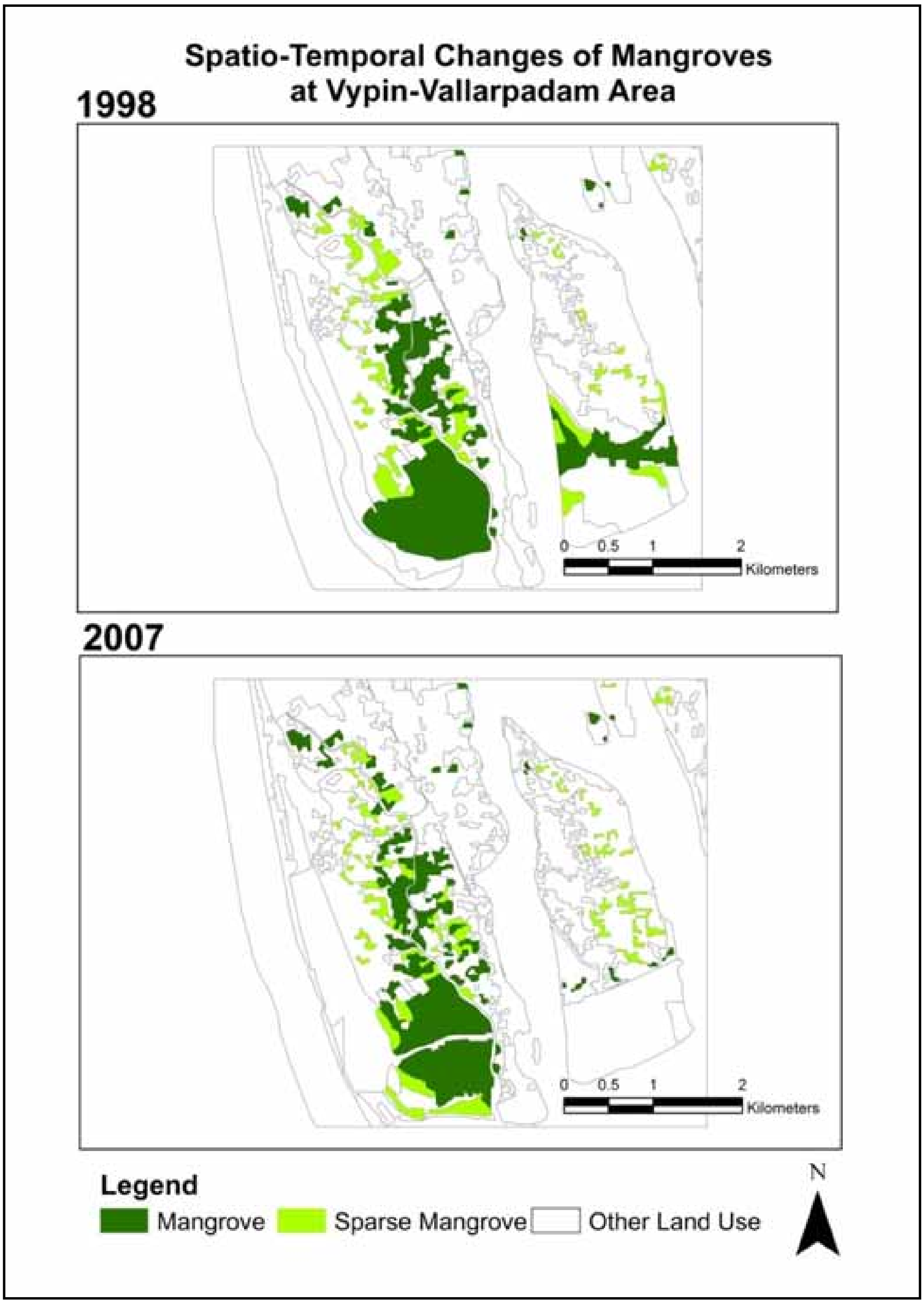


Figure 5.10 Spatio-Temporal Changes of Mangroves of Vypin - Vallarpadam Area

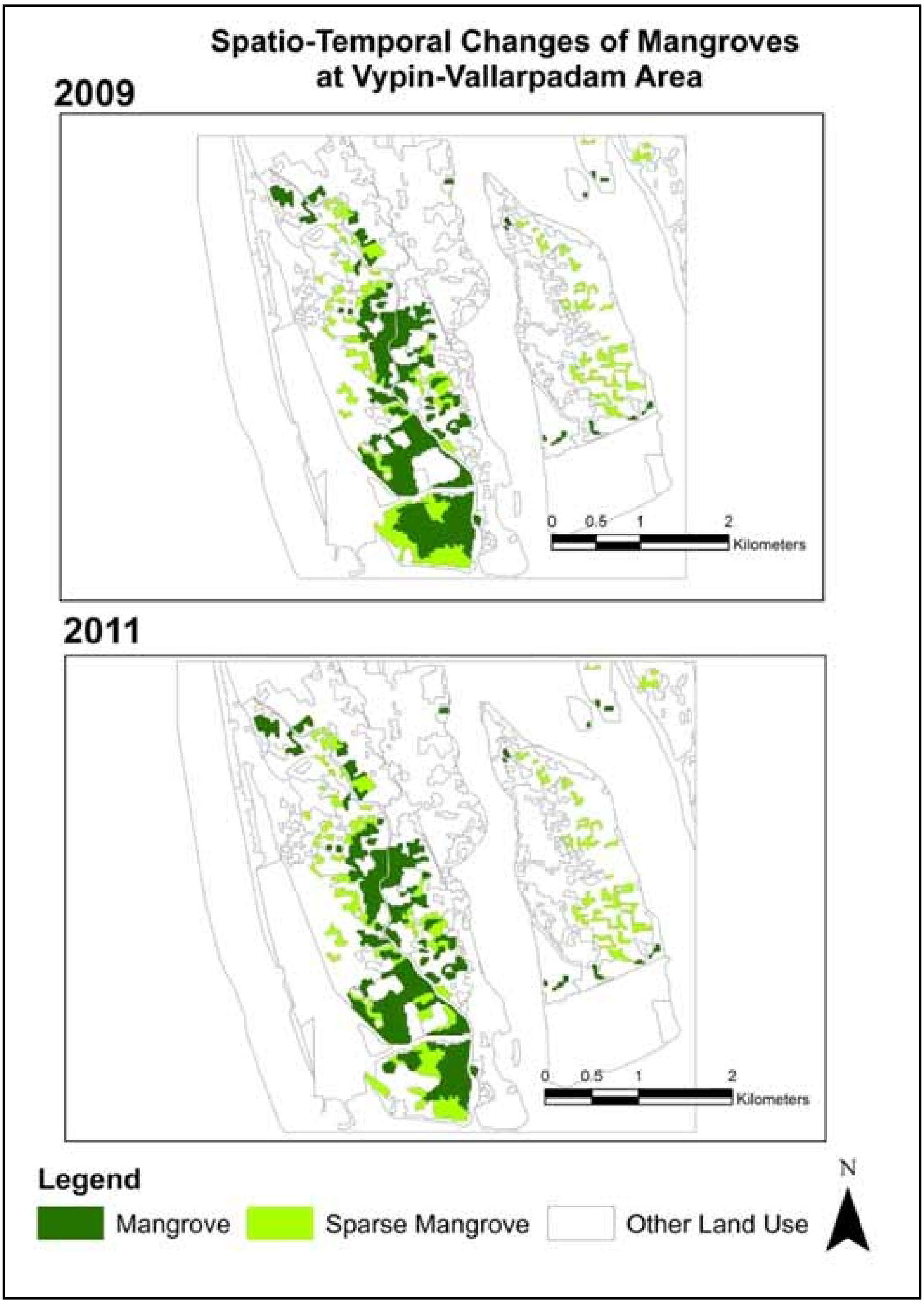
Figure 5.10 and Maps 5.24, 5.25 and 5.26 indicate that the total as well as dense mangroves were increasing during 1973 to 1998 at the rate of 131.2% and 113.2% respectively, which may be due to the increase in land area by soil deposition from the sea. But after that period, the total and dense mangroves decreased till 2011 at the rate 30.85% and 42.57% respectively (Annexure VI). This decrease was due to the construction of International Container Trans-shipment .Terminal (ICTT), Goshree bridge construction and connecting roads as well as the Liquid Natural Gas Terminal (LNGT) at Puthuvypin. Also, the above figure and maps indicate an increasing trend in sparse mangrove coverage, which is due to the rejuvenation of felled grown up mangroves.



Map-5.24 Mangrove Coverage at Vypin and Vallarpadam Area, 1973 and 1990.



Map-5.25 Mangrove Coverage at Vypin and Vallarpadam Area 1998 and 2007



Map-5.26 Mangrove Coverage at Vypin and Vallarpadam Area 2009 and 2011

5.3.2.2 Nettoor, Maradu and Valanthakad Area

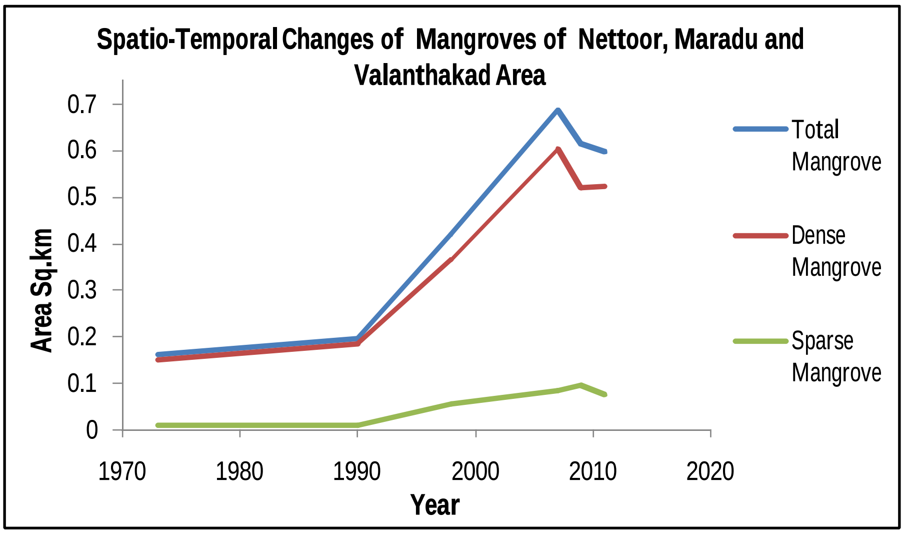
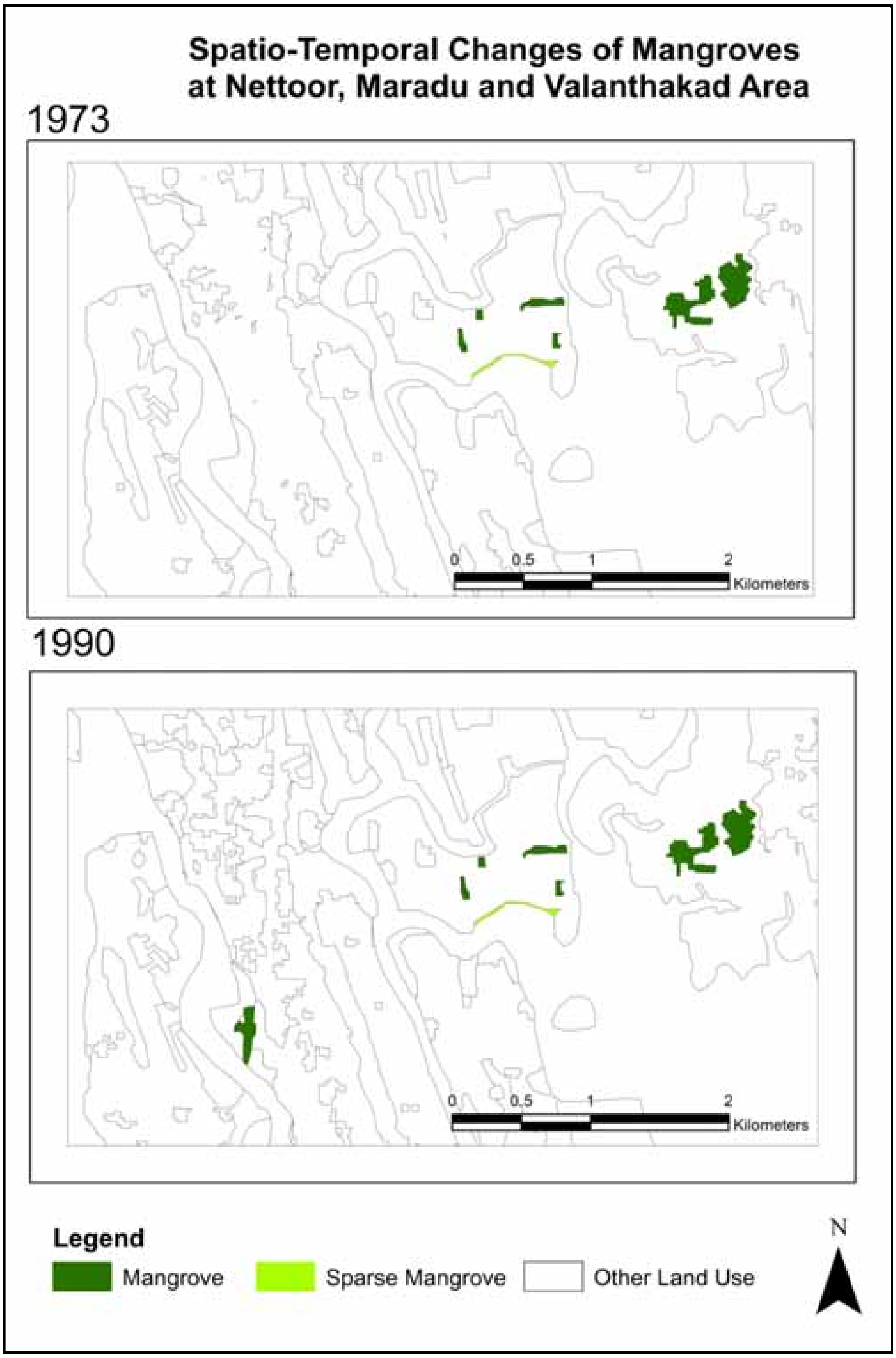


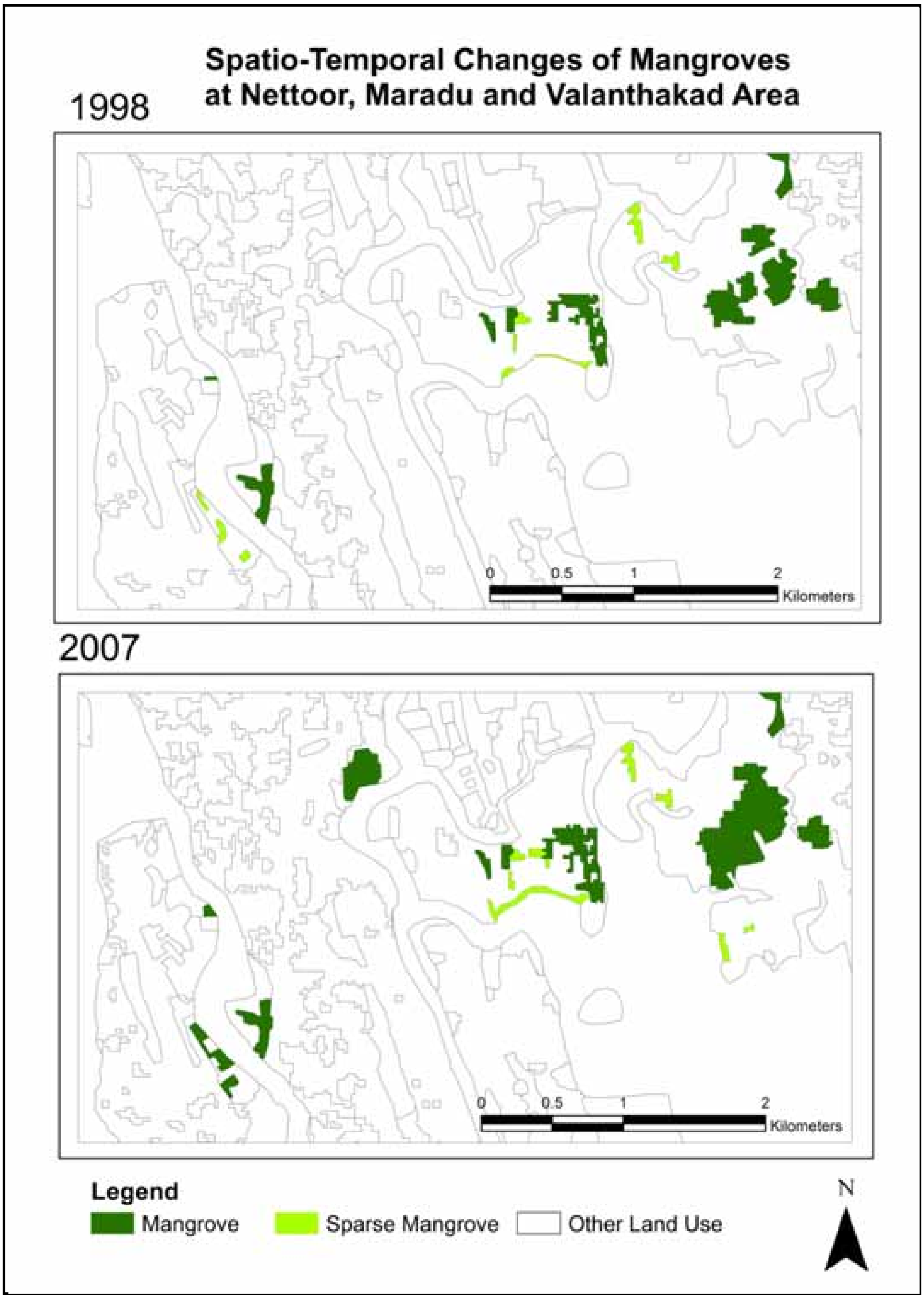
Figure 5.11 Spatio-Temporal Changes of Mangroves of Nettoor, Maradu and Valanthakad Area

Earlier, the mangroves were considered as a nuisance and hence were cut down to make way for Pokkali cultivation resulting in a decrease in mangrove coverage proportionate to the increase in Pokkali Farming. But, the farming lost its economic importance in the 1990s and was replaced to a certain extent by intensive fish farming, which required only less manpower. But most of the Pokkali fields were left fallow since 1990s, which were replaced by mangroves.

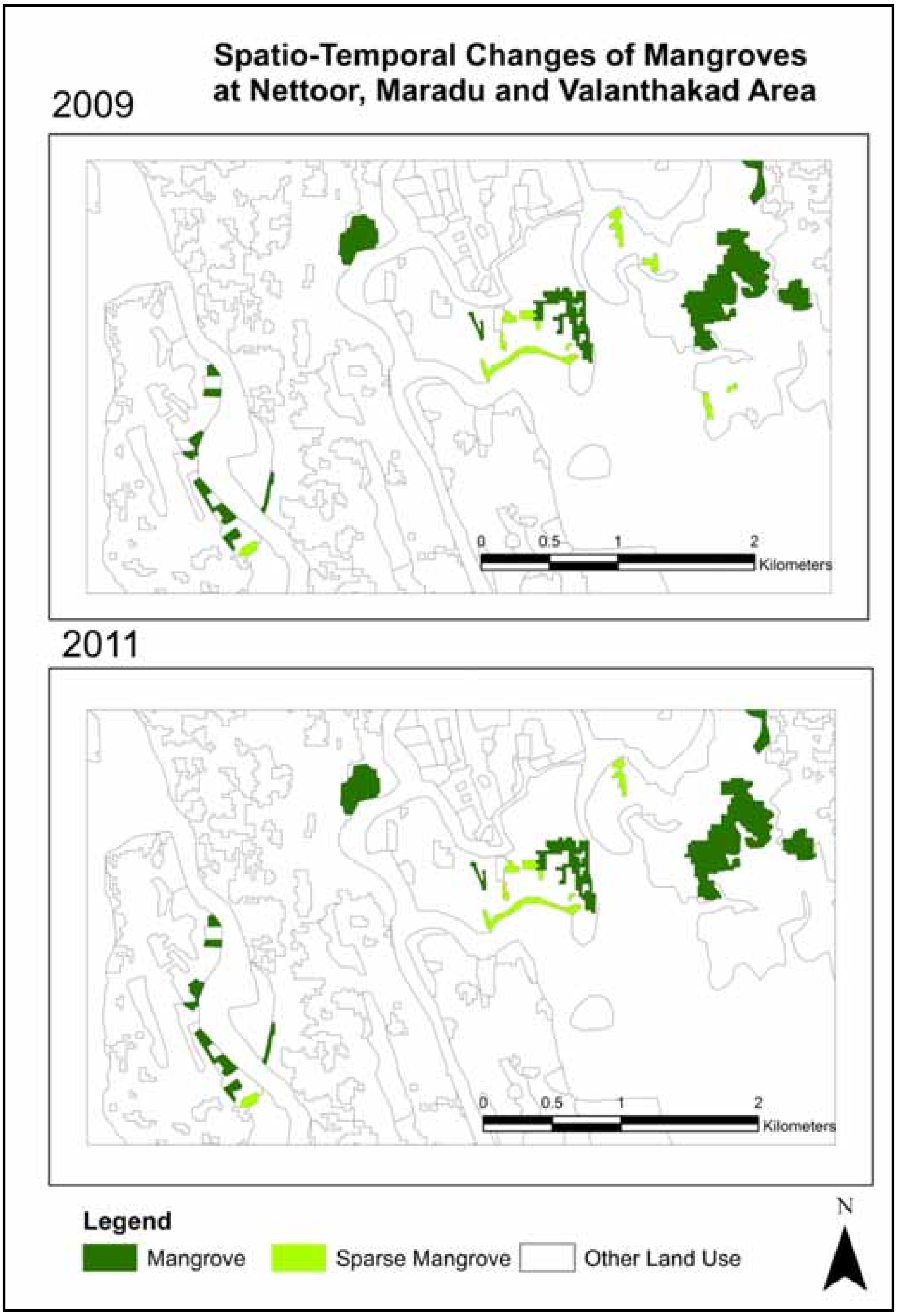
Figure 5.11, Maps 5.27, 5.28 and 5.29 and Annexure VI indicate that the total and dense mangroves increased from 1973 to 2007 at the rates of 321.4% and 296.7% respectively. But after 2007, the total and dense mangroves were decreasing at the rates of 12.81% and 13.27% respectively, partially due to the pre-construction mangrove clearance during 2007 and 2009, for the proposed Sobha City. Sparse mangroves also show a similar trend.



Map-5.27 Mangrove Coverage at Nettoor, Maradu and Valanthakad Area, 1973 and1990



Map-5.28 Mangrove Coverage at Nettoor, Maradu and Valanthakad Area, 1998 and 2007



Map-5.29 Mangrove Coverage at Nettoor, Maradu and Valanthakad Area, 2009 and 2011

5.3.2.3. Edakochi - Chellanam Area

Of all the 4 prominent mangrove stands in the study area, Edakochi-Chellanam area has seen the least developmental activities and is reflected in their periodic variation.

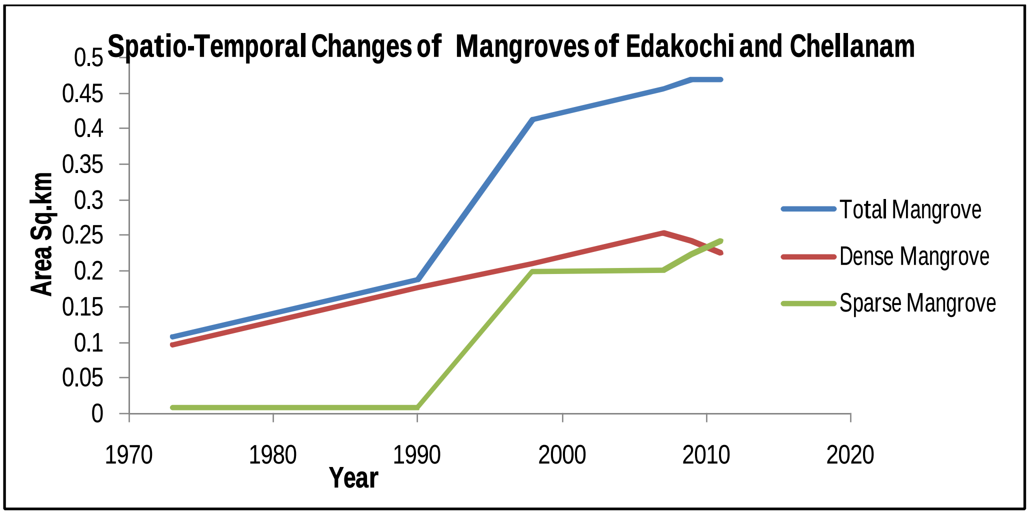
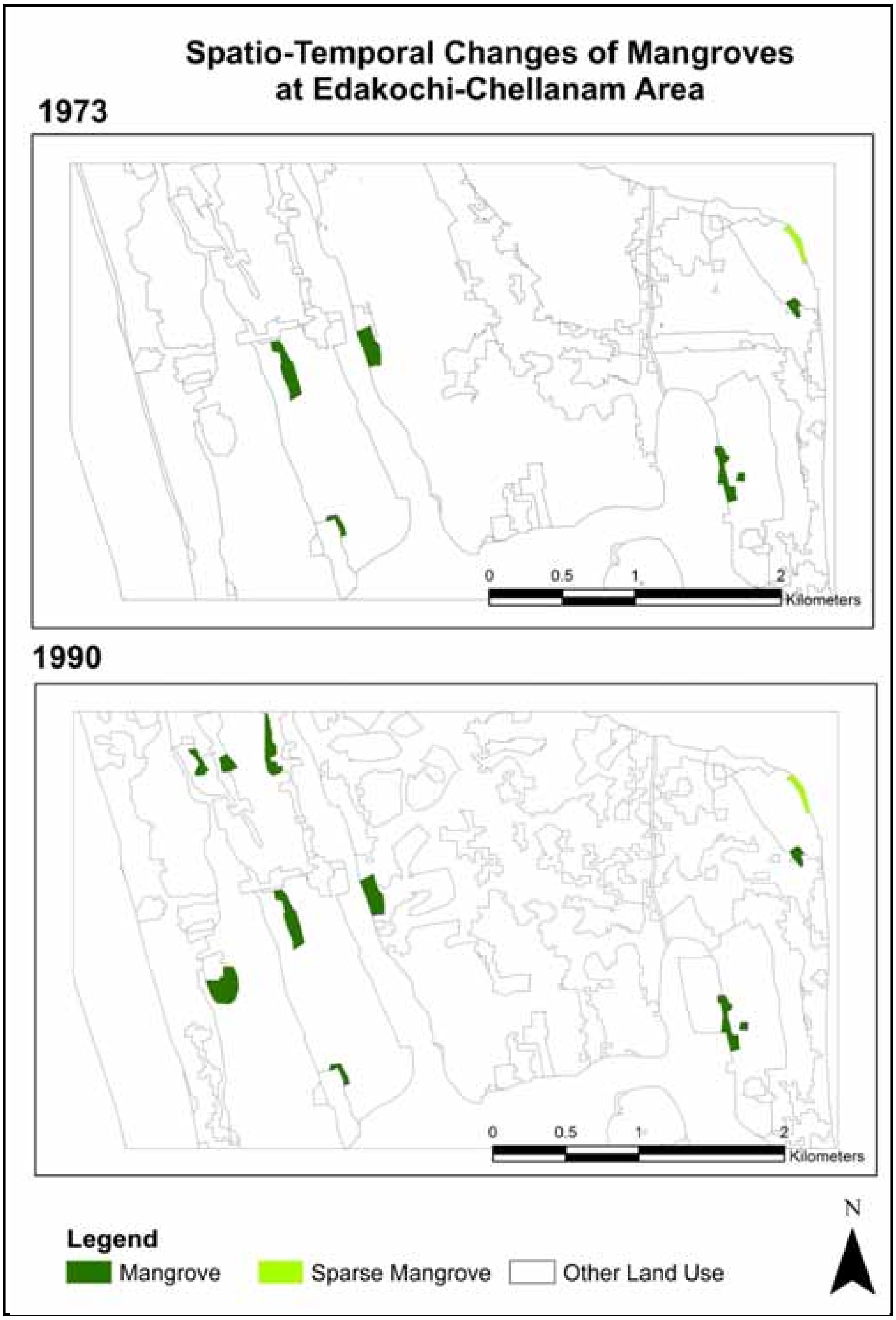
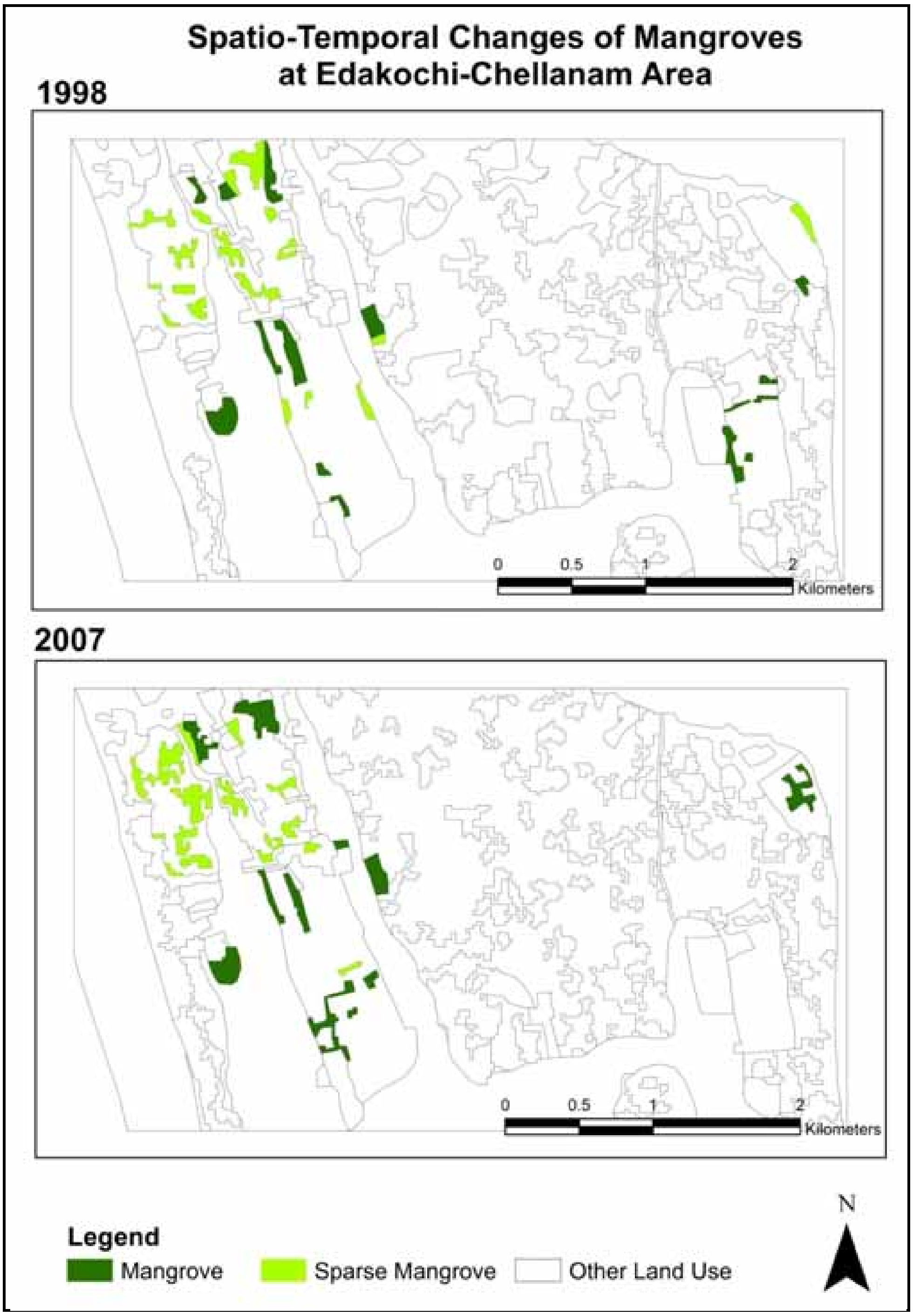


Figure 5.12 Spatio-Temporal Changes of Mangroves of Edakochi - Chellanam Area

Figure 5.12 and Maps 5.29, 30 and 31 indicates an increase of 335.2% (Annexure VI) in the Total Mangrove from 1973 to 2011, but Dense Mangroves increased by 160.2% from 1973-2007 and a decrease of 10.98% by 2011. During 2009-2011, a patch of Dense Mangrove was cut down at Edakochi for the construction of a now-aborted Cricket Stadium Construction project. However, the Sparse Mangrove has increased slowly after 1990 due to decreased Pokkali farming.



Map-5.30 Mangrove Coverage at Edakochi - Chellanam, 1973 and 1990



Map-5.31 Mangrove Coverage at Edakochi - Chellanam, 1998 and 2007

Map-5.32 Mangrove Coverage at Edakochi and Chellanam 2009 and 2011

5.3.2.4 Mangalavanam

Unlike the other 3 Mangrove stands, Mangalavanam area is protected as a bird sanctuary, and hence least interrupted by human activities.

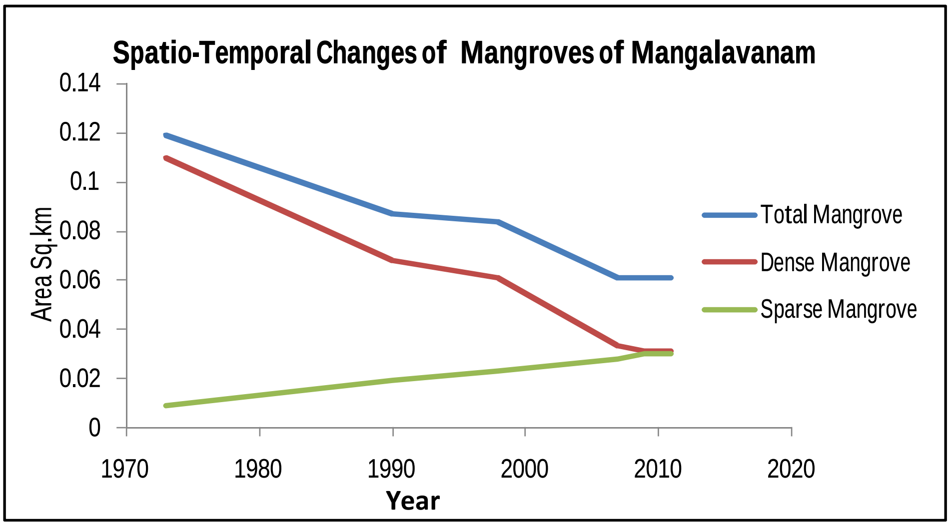


Figure 5.13 Spatio-Temporal Changes of Mangroves of Mangalavanam

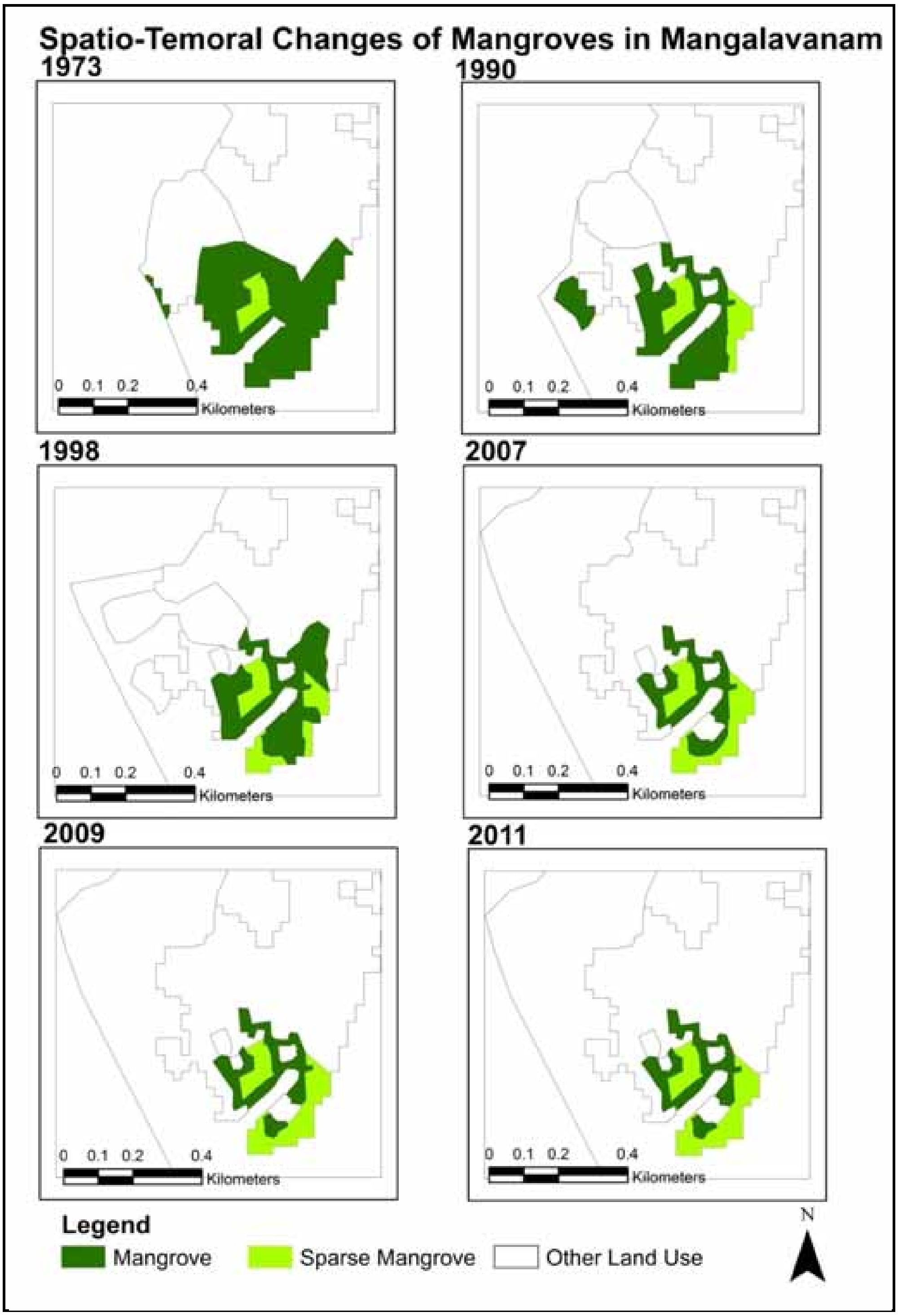
Fig 5.13 shows that in Mangalavanam, in spite of the protection status, the total (48.74%) as well as dense mangrove (17.81%) coverage have decreased from 1973 to 2007 and has remained constant afterwards (Annexure VI). This decrease was mainly due to the construction of CMFRI and NIO in the 1990s. The subsequent continuous decrease may be the increasing pollution, since that area is protected. However, sparse mangrove coverage is increasing steadily.

Map 5.32 Spatio-Temporal Changes of Mangroves at Mangalavanam

5.3.3 Spatio-Temporal Changes of Other Wetland Constituents

Other constituents of the Wetland Class under this study, with their proportionate representation are given below:-

A. Areas coming under - Rivers / Lake - 5.15% of the wetlands
B. Aquaculture with coconut trees 1.4%,
C. Sandy Beach - 0.57%
D. Clay Mines - 0.57%
E. Marshy Areas - 0.38%



Map 5.33 Mangrove Coverage at Mangalavanam, 1973-2011.

The study area includes the rivers Muvattupuzha and Periyar as well as the artificial fresh water body found inside the FACT, Ambalamugal area and is termed as "Rivers / Lake", a part of the contiguous wetland ecosystem, according to Ramsar classification system. Since this class occupies only 5.15% of the wetland area under study (Fig.5.2), it is barely visible in the Maps. However on analysis, it is seen that from 1973-2007 there was a decrease of 5.91% (Fig 5.14, Annexure V)., which was due to the encroachment of native population living on the riverbanks. Such encroachment has ceased after 2007.

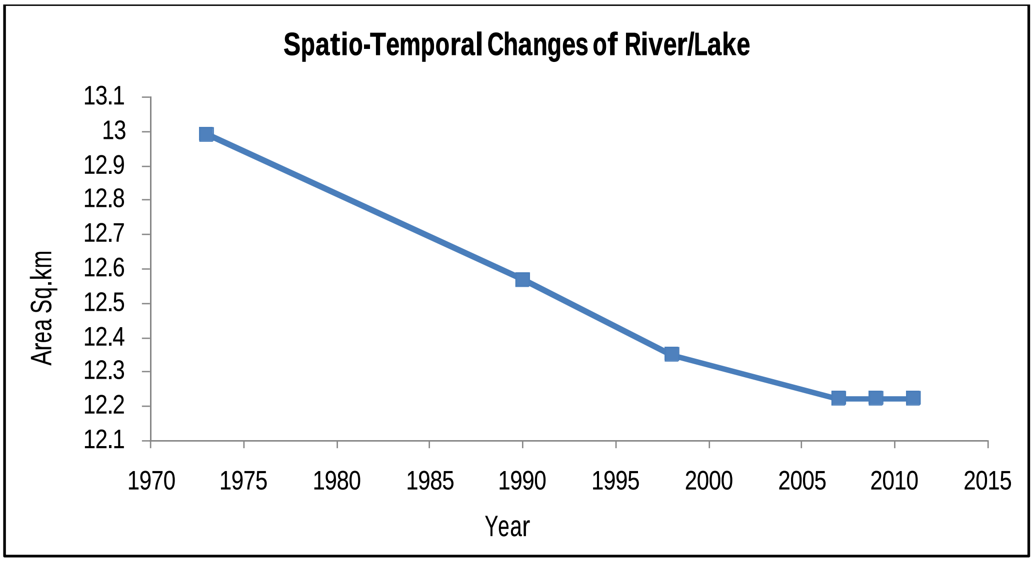


Figure 5.14 Spatio-Temporal Changes of Rivers / Lake

Peculiar to Vypin, large low-lying areas were partitioned with bunds, which were strengthened with coconut trees and were used for aquaculture traditionally. Recently, as agriculture has turned out to be uneconomical, more and more Pokkali farms are also being transformed to this land use pattern, where intensive fish farming is practiced. Such practices are seen to be increasing (51.07%) continuously since 1973 till 2011 (Fig 5.15 and Annexure V).

The sandy beaches of the study area form only a very minute fraction of the study area, but are of much environmental significance. Beaches are influenced by various factors such as deposition, erosion, beach protection projects, population pressures etc. The beach area coming under the present study seems to have periodically varied under the influence of all the above-mentioned causative factors (Fig 5.15). From 1973 to 2011 the beach area has reduced by about 63.86% (Annexure V).

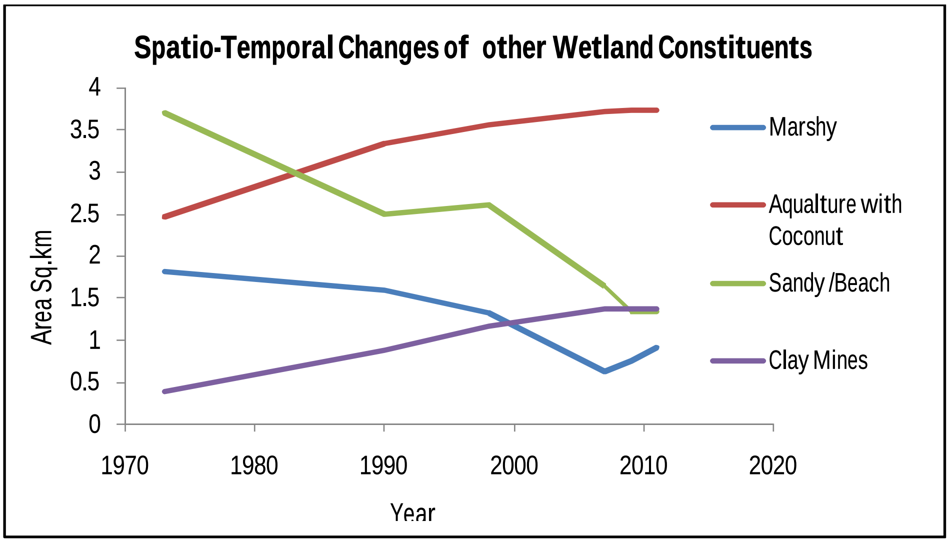


Figure 5.15 Spatio-Temporal Changes of other Wetland Constituents

In the study area, there is one granite quarry, a few laterite quarries and several clay mines. Several paddy fields on the eastern fringes of the study area were converted to clay mines to feed the brick kilns, which became more economically rewarding in the context of a booming construction industry (Fig 5.15), i.e., an increase of 257.1% (Annexure V).

Marshy areas are considered in this study as those areas lying in between the mangrove stands and aquaculture areas mainly in the Vypin locality. Such areas are found to have decreased from 1973 to 2007 (65.98%). After 2007, increase of 46.5% is seen in this land cover pattern, may due to the wide spread destruction of mangroves (Fig 5.15 & Annexure V).

5.3.4 Spatio-temporal Changes of Built up Areas

Built up area coverage during 2011 is about 24.86% of the total study area in which 3.21% is dedicated to industrial activities (Fig 5.1). Total built up area has increased by about 2989% from 1944 to 2011, while 111% increase was from 1973 and industrial area including Cochin Port has increased by about 59.48% (Annexure V). In general, most of the study area has witnessed a constantly accelerating pace of urbanisation, but as mentioned earlier, at the cost of wetlands. The specific pockets of increase in built up areas and the reasons for such developments are discussed below.

During the 3 decades from 1944 the built up area increase was about 1362% (Table 5.9). During this period, Mattancherry, the earlier hub of business activity, which lies at the western fringes of the study area has developed at a fast pace. Other expansions were - an eastward spreading of residential areas in Ernakulam and other scattered developments in Alwaye and Kalamasserry area, which had road access. Gradually, the commercial importance of Mattancherry drastically decreased, as a result of which the spread of human settlements slowed down in that area.

The industrial activities of the Cochin area are concentrated in Eloor and Ambalamugal area, which are situated near the banks of Periyar and Movattupuzha rivers. Not only the built up-industrial area has developed at those areas, but residential and other industry related commercial activities also started flourishing as can be visualized in Maps 5.6 and 5.7.

During 1973-1990, a 49.5%(Table 5.9) increase in built up area can be seen (Maps 5.6 and 5.5) as a result of spreading human habitation at Edakochi, Edappilly, Kalamasserry and Aluva Region as well as a small urban agglomeration at Thripunithura, and Paravur area. By, 1990, the residential areas have already spread to northern and eastern suburbs of Ernakulam. Also, the M.G.Road area witnessed the proliferation of several commercial activities, which was later followed by the Marine Drive area at Ernakulam.

During 1990-1998 the increase of built up area is 11.2%(Table 5.9). The city further spread to the suburbs of Edakochi, Edappally, Kalamasserry, Aluva, Paravur and Thripunithura region to accommodate the continuously increasing city population, thus straining the already insufficient infrastructure facilities. With the new addition of the NH-47 bypass, built up area rapidly devoured more and more wetlands at Maradu and Nettoor areas (Maps 5.5 and 5.4).

During 1998-2007, the increase in built up area was 19.51% (Table 5.9). Almost the same trend is seen in all the areas mentioned above, except a rapid expansion of built up area at Vallarpadam and Puthuvypin area due to construction of ICTT and LNGT. Also observed is a fast increase in residential, commercial and industrial built up areas around the Infopark at Kakkanad (Maps 5.3 and 5.4). Moreover, during 2007-2009 and 2009-2011, the built up area increased by 3.8% and 2.32% respectively, a direct aftermath of the expanded port activities at Vallarpadam after the commissioning of ICTT.

Table 5.9 Rate of Increase of Built up area

Period	Area Change km^2	Rate of Increase km^2 / Year	% of Increase
1944-1973	78.014	2.69	1362
1973-1990	41.415	2.436	49.42
1990-1998	14.038	1.403	11.21
1998-2007	27.172	2.717	15.27
2007-2009	6.465	3.233	3.89
2009-2011	4.027	4.027	2.32

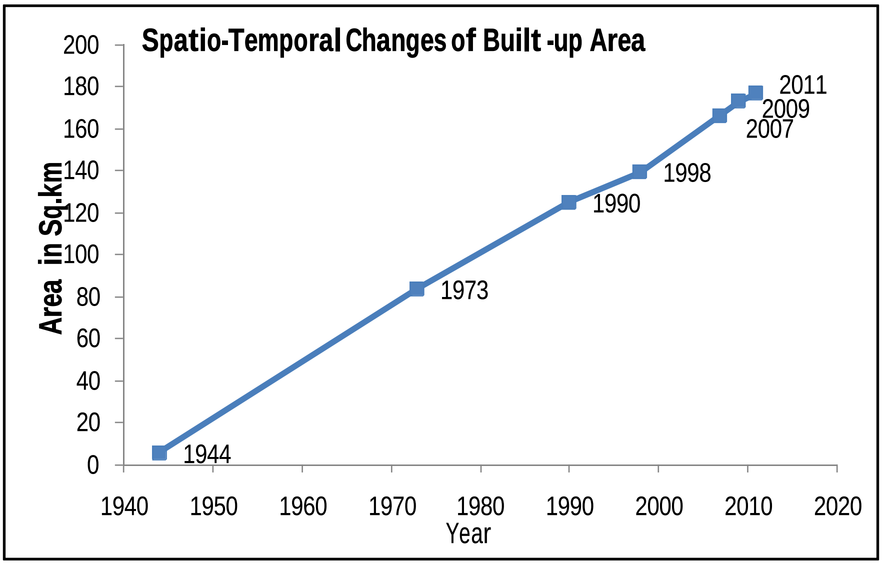


Figure 5.16 Spatio-Temporal Changes of Built -up Area

5.4 Vulnerability Mapping of the Wetlands

Vulnerability Mapping was done for understanding which wetland areas are more vulnerable to reclamation. Different vulnerability factors were identified and appropriate values or points were assigned to these vulnerability factors depending on the proximity to City Centre, National Highways and important roads, vicinity form developmental activities, etc as mentioned in Chapter 4. Since the Rivers and Estuary are currently less prone to encroachment by the public, they are excluded from this Vulnerability Mapping.

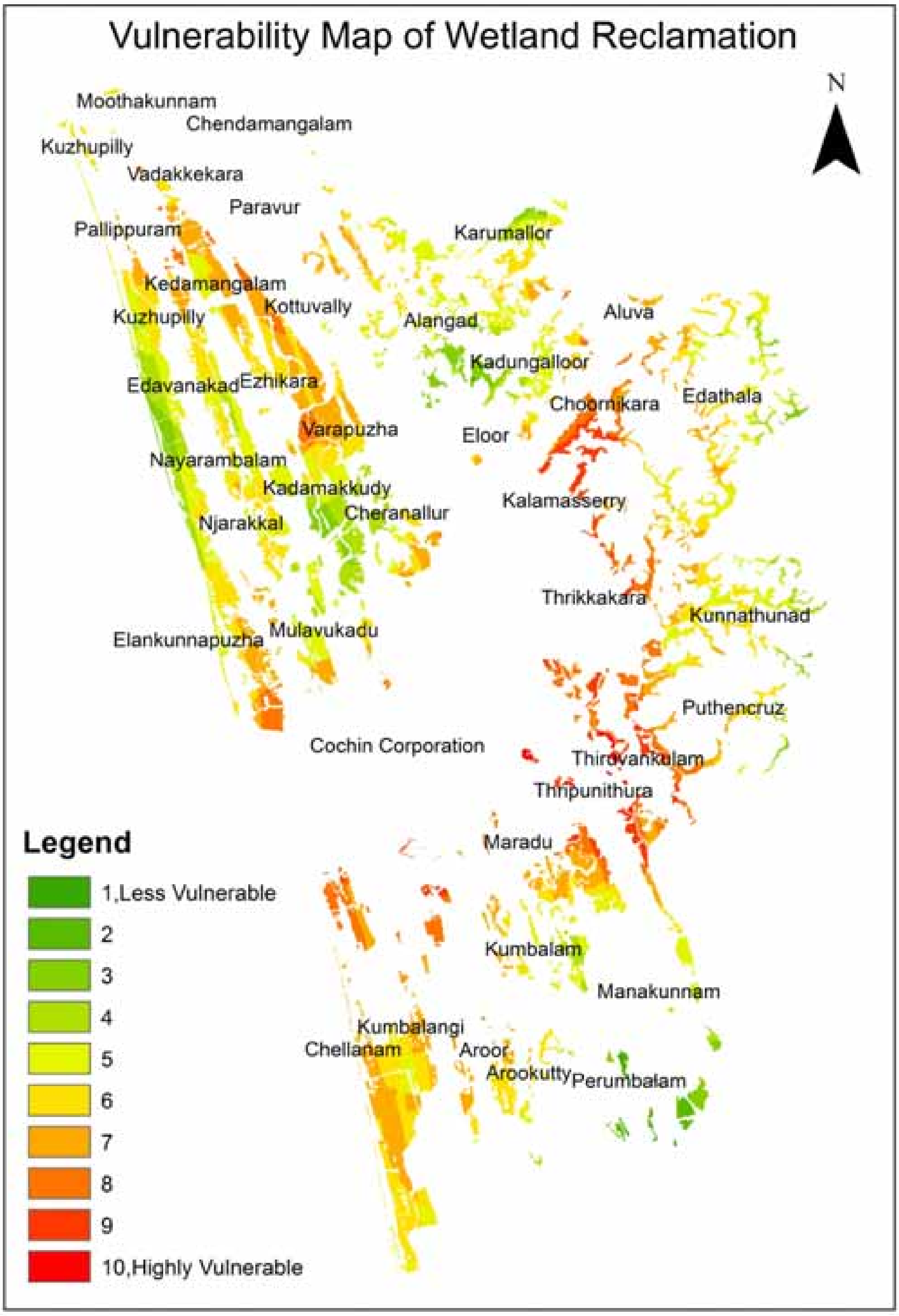
From Map 5.34, it can be observed that the highly vulnerable wetland areas are located at Maradu, Edakochi, Thrikkakara, Kalamasserry, Choornikara and Puthuvypin etc in the order of their vulnerability indices.

5.5 Reasons for Reclamation of Wetland

During the time period of this study, i.e. about 7 decades, the study area has undergone tremendous changes, in its LULC pattern, an inevitable consequence of unplanned urban proliferation. Built up areas had spread out at the cost of the wetlands in general and the traditional farmlands, in particular. The identified causes for such changes are discussed below.

5.5.1 Urbanisation and Population Increase

Like in other developing countries, Kochi is rapidly urbanising, mostly in an unregulated way, which itself is the prime culprit for the reclamation of wetlands. Increase of built-up areas and population increase (Fig 5.16 and 5.17) are the major indicators of urbanisation. Ignorance of the general public about the environmental consequences of these conversions, as well as the absence of proper farsightedness in the governing authorities act complementary to each other.



Map-5.34 Vulnerability Map of Wetland Reclamation

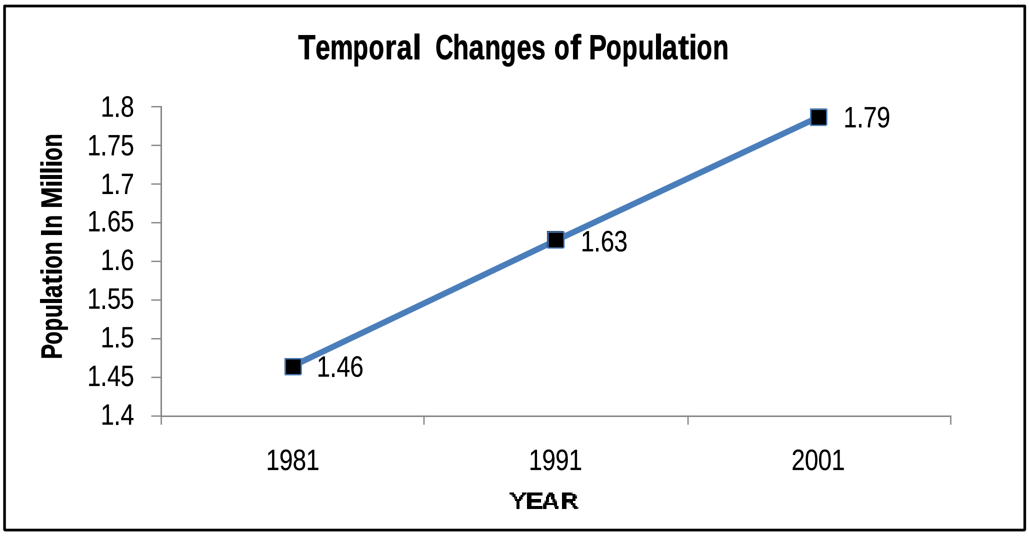


Figure 5.17 Temporal Changes of Population

The change matrix indicates that the total area reclaimed from estuary is 16.13%, Pokkali fields 41.37% and Paddy fields 36.92%, which were converted to built up area as mentioned earlier (Annexure VIII-XIV).

5.5.2 Developmental Activities

Reclamation of the wetlands are due to either direct or indirect effect of the developmental activities, i.e. rapid industrial and commercial developments or spread of human settlements in the proximity of wetland areas has led to their degradation. Local Panchayaths, Municipalities or Corporations are rather unconcerned about the environmental and infrastructural consequences of promoting economic and developmental activities, which will infringe upon the precious wetland ecosystem. Even specialized agencies with mandate for urban development is found to follow a similar laxity in this matter.

Official Reclamations for Developmental Actives occurred after 1944 in estuary are listed in the Table 5.10 given below.

Table 5.10 Developmental Activities and area of reclamation

Developmental Activities	Area in km^2
Construction of Marine Drive	0.280
Extension of Marine Drive	0.158
Extension of Willington Island	1.556
Goshree Bridge Construction	1.320
International Container Transshipment Terminal construction (ICTT)	0.433
Rail and Road construction for ICTT	0.401

Indirect effects of developmental activities can be observed at Maradu-Nettor area, which resulted in the extensive reclamation of Pokkali fields (Maps 5-15) after the Vytilla-Aroor by pass road (NH-47). Similarly, rapid reclamation of Paddy fields near Kakanad after the construction of Info Park can be seen (Map.-5-20).

5.5.3 Booming of Real Estate

A rapid real estate boom, which the last few years has witnessed, resulting in a speculative increase of 5 to 10 times of the land cost has prompted the few land owners left in the periphery of the study area to stop agriculture and fill the wetlands particularly Pokkali and paddy fields and exchange them for a temporary financial benefit. Those farmers either move away to far off places to continue their agricultural activities, or join the urban populace to work as unskilled laborers.

5.5.4 Abandoning of Paddy or Pokkali Cultivation

Within the last few decades, paddy cultivation has changed to a non-profitable profession due to various socio-economic factors. During this time, paddy cultivation gradually gave way to intensive aquaculture, or clay mines or fallow wetlands or reclaimed land areas. Some of the prompting factors for such an evolution are given below.

- Non-availability of workers and high labour costs.
- Lack of necessary support from the authorities to the paddy farmers
- Unpredictable crop failures due to pest infestations or vagaries of climate
- High input costs of seeds, fertilizers, pesticides etc.
- Availability of other lucrative options.

5.5.5 Problems faced by Aquaculture Farming

Problems Facing Aquaculture Farms are

- Increasing Pollution
- Increasing Input costs
- Pestilence and other viral attacks affecting fish populations
- Availability of better economic options

5.5.6 Absence of Environmental Awareness in importance of Wetlands

Common people are unaware about the significance of mangroves or wetlands in general. Due to lack of awareness, wetlands have been indiscriminately and deliberately destroyed with a short sighted outlook for instant gains. The condition of wetlands in India is not different than the other countries. For example, 60 % of wetlands worldwide and up to 90 % in Europe have been destroyed over the past century, due to agriculture, pollution, development of dams, canals, groundwater pumping, urban development and peat extraction

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Chapter- 6

CONCLUSION

Contents

Cochin city and its neighbouring environs has witnessed major Land use / Land cover (LULC) changes during the last few decades similar to any other cities in the developing countries. Unplanned growth to accommodate the necessities of a fast developing metropolis not only brings irreparable damage to the environment but also exhaustion of life-sustaining natural resources. Added to that is the overstraining of bare infrastructural facilities, which threatens the very social fabric of a civil society.

Cochin, being a tropical coastal city was endowed with a unique wetland ecosystem, which has borne the brunt of developmental activities, whether planned (legal) or unplanned (illegal). A gist of the most important LULC changes, the study area has undergone during the past few decades are described below. All the 17 classes as described in Section 4.2.4.3 for the years 1973, 1990, 1998, 2007 and 2009 were compared with the current scenario (2011). The obvious changes are:-

- At present, about one third of the total study area is covered with wetlands, which has shrunk by more than 10% compared to the 1973 situation.
- The wetland decrease has contributed mainly to a proportionately large (111%) increase in built up area (from about 83.74 to 176.89 km^2) and

activities to develop the necessary infrastructure like roads, bridges, railways, etc.

- Of the wetlands, 42.75% is at present covered by estuary, 28.89% by Pokkali fields, 16.87% by paddy fields and 5.15% by rivers and lake. Minor fractions (1.18%) are taken up by dense mangroves and 0.66% by sparse mangroves. Also, a minor fraction of the wetland area is shared for aquaculture with coconut plantation, canals, sandy beach areas, clay mines, marshy areas etc.
- During 1944 to 2009, it is found that the overall decline of the estuarine area is more than 15 km^2. About half of it was converted to Pokkali Fields and more than 15% to built up area (including industries). The impacts of this reduction in estuarine area was somehow minimized by the addition of estuarine patches at Cherai and some other places due to sand deposition off the sea coast and subsequent separation from the Arabian sea.
- Also, legal reclamations like construction of Marine Drive and southward extension of Willington Island by GCDA, Port Trust, ICTT etc. devoured sizable parts of the estuary, complementing the illegal public encroachment claiming its own share.
- Pokkali rice fields are unique wetlands of Kerala, where paddy cum fish culture is practiced. Pokkali is a unique salinity and flooding tolerant rice variety cultivated in the water-logged coastal regions of Alappuzha, Thrissur and Ernakulam districts of Kerala during June to early November when the salinity level of the water in the fields is low. From mid-November to mid-April, when the salinity is high, prawn or fish farming takes over. But Pokkali cultivation is nearing extinction due to economic reasons and this area is now being used for intensive aquaculture or real estate development. Pokkali and paddy fields have

shrunk in coverage due to population pressures, lack of economic returns as well as urban sprawl. This shrinkage was very high between 2007 to 2009, as a result of rapid urbanisation. After that, the shrinkage has decreased due to the Conservation of Paddy land and Wetland Act, 2008 implemented by Government of Kerala.

- Mangrove coverage is found to increase during the early periods when the declining trend in Pokkali cultivation was observed. But later urbanization pressures and real estate requirements brought a fast reduction in the mangrove population till the enforcement of Wetland protection rules. The mangrove vegetation in the study area is under severe threat due to extensive backwater reclamations by land developers and agriculturists. Hence, there should be not only legislative measures for the preservation of existing mangroves but also mangroves should be grown in low-lying wastelands adjoining backwaters.
- The current built up area coverage is about one fourth of the total study area. It is seen that the urban sprawl is rapidly and randomly spreading to peripheral areas of the city usually without adequate provision of infrastructure. Such a rapid expansion of the ecological footprint of a metropolis is environmentally unsustainable even in the short run. Ignorance of the general public about the environmental consequences of these LULC conversions, as well as the absence of proper farsightedness in the governing authorities act complementary to each other.
- Vulnerability mapping was done for understanding which wetland areas are more vulnerable to reclamation. Different vulnerability factors identified are proximity to the City Centre, National Highways and important roads, vicinity from developmental activities etc. The highly vulnerable wetland areas are found to be located at Maradu, Edakochi,

Thrikkakara, Kalamasserry, Choornikara and Puthuvypin etc. For the continued existence of a healthy wetland ecosystem, proper management policies should be implemented, a few of which are given below.

6.1 Strategies for a Sustainable Wetland Management

- Educating the native population about the ecological and economic importance of wetlands as well as the serious consequences of reclamation of wetlands. This can be done with the help of educational institutions, neighborhood groups (NHG), NGOs and various Govt. organizations.
- Encroachment to rivers and estuary must be stopped with proper formulation and implementation of rules as well as constant monitoring.
- Kerala Government has implemented wetland and Paddy Protection rules in 2008. By this rule the government has banned the reclamation and conversion of wetlands and paddy fields. This rule as well as the CRZ rules should be implemented and followed strictly.
- Also, for the health of the wetland ecosystem, industries should be made to tow in line with the various Pollution Control Laws.
- Other aspects affecting the health of the wetland ecosystem, which require urgent legal proceedings are the following:-
    - Uncontrolled use of agricultural fertilizers, weedicides and pesticides.
    - Urban discharges and illegal dumping of sewage, poultry wastes, fish processing wastes etc.
- If possible, the wetlands (including paddy cultivation) should be avoided for future developmental activities. In the absence of any other

alternatives, proper EIA, Monitoring should be done and suitable Environmental Management Plans (EMPs) should be formulated.

- Appropriate Action plans should be prepared by each Local Bodies and locally relevant management options should be formulated and implemented.
- A detailed land use plan related to wetlands should be prepared for the whole Kerala State for implementing various Land and Water management activities.

6.2 Protection of Paddy and Pokkali Cultivation

Pokkali and paddy cultivations as well as aquaculture practices are part of the rural culture and economic sustenance, the knowledge of which were handed down over generations. An urban cultural invasion should not be allowed to erase such a rich heritage. A few immediate steps to be taken in that direction are the following:-

- To face the decreasing labour availability, and climatic vulnerability, timely supply of agricultural machinery including harvesting machines must be assured with the help of farmers' societies, government institutions and other organizations.
- Development of special harvesting machines that can stand the water-logged, unstable farmlands.
- Extent financial supports to the farmers by subsidies and/or an adequate supporting price rates.
- Include Pokkali Cultivation and paddy under the neighbourhood groups like Kudumbashree and Self Help Groups as well as various national rural employment schemes.
- All the activities related to paddy cultivation and wetland protection carried out by different agencies should be integrated.

- Popularize new methods of farming which is more profitable to the farmers (e.g., Organic and Integrated Farming methods, which combines paddy cultivation with horticulture, aquaculture, animal husbandry, poultry etc.).

6.3. Protection of Sea Coasts and Inland Waterways

During the monsoon months, strong winds from the west along with high water level increase the strength of waves which erode a large extent of beach at Munambam and Chellanam areas causing considerable destruction to land and properties. This is a major environmental problem in the coastal zone of Cochin. Even though, in the past, sea walls were extensively constructed along the coast, in many places it failed to check the rage of the waves as is evident from the disappearance of sea wall at several places in Munambam and Chellanam area.

There are good many plants, both native and alien species that withstand the fury of the nature to a great extent in the coastal area. Vegetation will considerably solve the coastal management problems like beach protection by binding the soil particles with their roots in areas prone to water and wind erosion. The vegetative cover (trees) also provides windbreaks against strong winds which frequent the coastal areas. Only, man has to imitate the natural protection system by planting appropriate species in the respective zones.

For the prevention of backwater shore erosion and fisheries protection, mangrove replanting should be done along with the conservation of existing patches. Removal of this protective zone for developmental purposes, as was done in most of the backwater shorelines of Cochin, has caused serious erosion problems and might have contributed substantially to the decline of fish productivity. Also, these stands of mangrove trees, with their prop-roots protect coastal area from severe storms. The mangrove trees also provide fire wood if selective cutting is permitted without upsetting the system.

The shorelines of the inland waterways of Cochin are prone to erosion due to the removal of mangrove forests which once protected the shorelines from erosion. The stabilization of the shore is important both to prevent loss of land by erosion and also for prevention of silting up of waterbodies which affect water navigation particularly in the case of tidal canals.

6.4 Scope for Future Studies

The study has focused on the spatio-temporal changes that have occurred due to various factors in and around the Cochin city during the past seven decades with special emphasis to wetlands. This study is one among the foremost attempts to bring out a clear picture of the various scenarios at the study area. This study can form the baseline for various future studies and meta-analyses which may help the planners to formulate a viable EMP, so as to have a sustainable development in future. Some of the fields which require immediate attention are detailed below.

a) Changes in biodiversity:

The study showcased the evolution of LULC changes of the region, which is one of the main factors seriously affecting the fauna and flora of the region. This can be added to future studies which may lead to a comprehensive scenario of the biodiversity alterations (due to eutrophication, pollution etc.), the region has witnessed. Such detailed studies can help in the formulation of necessary legal instruments, viable Environmental Management Plans etc. for developing a sustainable urban environment.

b) Storm water management:

The eastern and northern fringes of the Study Area have witnessed large scale LULC modifications – filling the paddy fields, for which soil is hauled by leveling off the intermittent hillocks present there. Such alterations are bound to affect not only the groundwater levels, but also the flooding tendencies in the low-lying city areas. Added to that is the proliferation of built-up areas and paved land coverings. A city already reeling under traffic jams and standstills during intermittent downpours cannot ignore the ramifications of LULC changes of these fringe areas. Detailed studies and planning are required in this topic for future development if not for the bare continuance of the present *status quo*.

c) Zonation Mapping in the context of expected Sea level rise:

Greenhouse warming and resultant sea level rise is no longer a science fable. Developed countries have already done serious studies to visualise the scenarios resulting from various levels of sea level rise. And, they have already marked appropriate zones for future developments. Similar studies for delineating zones suitable for future developmental activities are urgently required for the low-lying Cochin City, to avoid an impending economic collapse and ensuing humanitarian tragedy.

d) Disaster Vulnerability and Management:

All uncontrolled and unplanned growth, whether in the human body or in the urban system will essentially lead to a catastrophe. With the existence of various hazardous and nonhazardous industries and other projects in the anvil as well as several other natural and man-made threats, which can be expected, an in-depth study of disaster identification, social vulnerability and existence of an area-specific disaster management plan is essential for all governments. In this endeavor, the invaluable contribution of Remote Sensing and GIS has to be urgently explored.

e) Open spaces with trees and other foliage are already considered to be the Lungs of an urban system, which help in reducing noise, carbon dioxide content and other pollutants. In the context of increasing global carbon dioxide concentrations and ensuing sea level rise, the potential of trees to sequester carbon dioxide has become a hot topic of scientific investigation throughout the world. Hence, a detailed study of the carbon sequestration potential of the trees, particularly of the mangroves is the call of the day especially for Cochin City.

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Annexure I

LIST OF LOCAL GOVERNING BODIES IN STUDY AREA

1	Cochin Corporation	21	Njarakkal Panchayath
2	Kalamasserry Municipality	22	Choornikara Panchayath
3	Thripunithura Municipality	23	Edathala Panchayath
4	Eloor Municipality	24	Elankunnapuzha Panchayath
5	Maradu Municipality	25	Kottuvally Panchayath
6	Thrikkakara Municipality	26	Kadungalloor Panchayath
7	Aluva Municipality	27	Kedamangalam Panchayath
8	Paravur Municipality	28	Ezhikara Panchayath
9	Thiruvankulam Panchayath	29	Alangad Panchayath
10	Mulavukadu Panchayath	30	Chendamangalam Panchayath
11	Kadamakkudy Panchayath	31	Moothakunnam Panchayath
12	Cheranallur Panchayath	32	Vadakkekara Panchayath
13	Varapuzha Panchayath	33	Puthencruz Panchayath
14	Kumbalam Panchayath	34	Kunnathunad Panchayath
15	Kumbalangi Panchayath	35	Aroor Panchayath
16	Chellanam Panchayath	36	Arookutty Panchayath
17	Kuzhupilly Panchayath	37	Perumbalam Panchayath
18	Pallippuram Panchayath	38	Manakunnam Panchayath
19	Edavanakad Panchayath	39	Karumallor Panchayath
20	Nayarambalam Panchayath		

ERROR MATRIX SUPERVISED MLC

	Paddy Fields	Sea	Estuary	River	Pokkali Fields	Mangrove	weeds	Sandy area	Built-up	Rubber	Mixed Land use	Raw Total	Producers Accuracy	Users Accuracy	Conti Kappa
Paddy Fields	48	0	0	2	0	3	0	1	21	4	17	96	65.75%	50.00%	0.4307
Sea	0	55	1	0	0	0	0	0	0	0	0	56	93.22%	98.21%	0.9802
Estuary	0	2	47	0	3	0	0	0	0	0	0	52	55.29%	90.38%	0.888
River	0	0	13	19	0	0	0	0	0	0	0	32	76.00%	59.38%	0.5761
Pokkali Fields	0	0	21	0	35	0	0	0	0	0	0	56	71.43%	62.50%	0.5917
Mangrove	2	0	0	0	0	12	2	0	0	0	0	16	75.00%	75.00%	0.7432
Weeds	10	0	0	0	0	0	16	0	4	0	1	31	88.89%	51.61%	0.5012
Sandy area	0	1	0	0	0	0	0	13	0	0	0	14	81.25%	92.86%	0.9266
Built-up	3	1	3	3	9	0	0	2	82	0	5	108	69.49%	75.93%	0.7003
Rubber	3	0	0	0	0	0	0	0	3	25	3	34	80.65%	73.53%	0.7209
Mixed Land use	7	0	0	1	2	1	0	0	8	2	84	105	76.36%	80.00%	0.7551
Column Total	73	59	85	25	49	16	18	16	118	31	110	600			

Annexure III

ERROR MATRIX OF PCA WITH SUPERVISED MLC

	Paddy Fields	Sea	Estuary	River	Pokkali Fields	Mangrove	weeds	Sandy area	Built-up	Rubber	Mixed Land use	Raw Total	Producers Accuracy	Users Accuracy	Conti Kappa
Paddy Fields	23	0	0	0	0	2	13	1	12	1	1	53	31.50%	43.40%	0.356
Sea	0	45	5	0	0	0	0	0	0	0	0	50	76.27%	90.00%	0.889
Estuary	0	12	52	0	11	0	0	5	1	0	0	81	61.18%	64.20%	0.583
River	0	0	8	20	0	0	0	0	0	0	1	29	80.00%	68.97%	0.676
Pokkali Fields	1	0	19	1	28	1	0	0	1	0	2	53	57.14%	52.83%	0.486
Mangrove	3	0	0	0	0	9	2	0	0	0	0	14	56.25%	64.29%	0.633
weeds	4	0	0	1	0	0	3	0	0	0	2	10	15.79%	30.00%	0.277
Sandy area	0	2	1	1	2	0	0	8	1	0	0	15	50.00%	53.33%	0.521
Built-up	13	0	0	0	5	2	0	2	74	2	14	112	62.18%	66.07%	0.577
Rubber	3	0	0	0	0	0	0	0	3	22	2	30	75.86%	73.33%	0.720
Mixed Land use	26		0	2	3	2	1	0	27	4	88	153	80.00%	57.52%	0.480
Column Total	73	59	85	25	49	16	19	16	119	29	110	600			

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ERROR MATRIX OF PCA WITH UNSUPERVISED CLASSIFICATION

	Mangroves	Sea	Paddy Fields	River/Lake	Mixed Land Use	Built-up	Weeds	Rubber	Estuary	Pokkali Fields	Sandy Area	Raw Total	Producers Accuracy	Users Accuracy	Conti. Kappa
Mangroves	7	0	6	0	1	2	12	0	0	0	0	28	50.00%	25.00%	0.2321
Sea	0	43	1	0	1	0	0	0	1	0	0	46	72.88%	93.48%	0.9277
Paddy Fields	0	0	23	0	3	7	0	1	0	0	0	34	31.51%	67.65%	0.6317
River/Lake	0	0	0	19	1	0	0	0	8	0	0	28	76.00%	67.86%	0.6646
Mixed Land Use	4	1	25	2	100	27	1	2	3	14	0	179	86.21%	55.87%	0.4529
Built-up	0	0	4	2	4	72	0	0	3	5	6	96	59.02%	75.00%	0.6862
Weeds	3	0	11	2	2	0	5	1	0	0	0	24	27.78%	20.83%	0.1838
Rubber	0	0	3	0	2	1	0	21	0	0	0	27	84.00%	77.78%	0.7681
Estuary	0	15	0	0	0	0	0	0	47	5	1	68	57.32%	69.12%	0.6423
Pokkali Fields	0	0	0	0	0	0	0	0	20	25	0	45	51.02%	55.56%	0.516
Sandy Area	0	0	0	0	1	13	0	0	0	0	10	24	58.82%	41.67%	0.3997
Column Total	14	59	73	25	116	122	18	25	82	49	17	600			

SPATIO-TEMPORAL CHANGES OF WETLANDS

YEAR	Total Wetlands km²	Estuary km²	Pokkali km²	Paddy km²	Total Mangrove km²	Dense Mangrove km²	Sparse Mangrove km²
1944		116.599	68.214				
1973	268.88	107.931	79.438	55.019	1.91	1.592	0.318
1990	253.235	104.208	75.382	46.45	2.939	2.114	0.825
1998	247.987	103.21	71.59	44.031	4.862	3.552	1.31
2007	239.794	101.814	69.145	41.081	4.878	3.339	1.539
2009	237.443	101.506	68.541	40.119	4.534	2.96	1.574
2011	237.238	101.486	68.538	40.019	4.349	2.792	1.557

Year	River/Lake km²	Aquaculture with Coconut km²	Sandy /Beach km²	Clay Mines km²	Marshy km²	Canal km²
1973	12.991	2.471	3.708	0.382	1.82	3.211
1990	12.569	3.341	2.504	0.873	1.602	3.329
1998	12.349	3.558	2.608	1.154	1.316	3.329
2007	12.222	3.715	1.638	1.357	0.619	3.324
2009	12.222	3.733	1.34	1.364	0.753	3.324

SPATIO-TEMPORAL CHANGES OF MANGROVES IN DIFFERENT LOCATIONS

Spatio-Temporal Changes of Mangroves in Vypin and Vallarpadam Area

	Total Mangrove ,km^2	Dense Mangrove, km^2	Sparse Mangrove, km^2
1973	0.108	0.098	0.01
1990	0.188	0.178	0.01
1998	0.413	0.212	0.201
2007	0.457	0.255	0.203
2009	0.47	0.243	0.226
2011	0.47	0.227	0.244

Spatio - Temporal Changes of Mangroves in Nettoor ,Maradu and Valanthakad Area

	Total Mangrove ,km^2	Dense Mangrove, km^2	Sparse Mangrove, km^2
1973	0.163	0.152	0.011
1990	0.196	0.185	0.011
1998	0.421	0.365	0.056
2007	0.687	0.603	0.085
2009	0.615	0.52	0.095
2011	0.599	0.523	0.076

Spatio-Temporal Changes of Mangroves in Edakochi and Chellanam Area

	Total Mangrove ,km^2	Dense Mangrove, km^2	Sparse Mangrove, km^2
1973	0.108	0.098	0.01
1990	0.188	0.178	0.01
1998	0.413	0.212	0.201
2007	0.457	0.255	0.203
2009	0.47	0.243	0.226
2011	0.47	0.227	0.244

Spatio-Temporal Changes of Mangroves in Mangalavanam

	Total Mangrove ,km^2	**Dense Mangrove, km^2**	**Sparse Mangrove, km^2**
1973	0.119	0.11	0.009
1990	0.087	0.068	0.019
1998	0.084	0.061	0.023
2007	0.061	0.033	0.028
2009	0.061	0.031	0.03
2011	0.061	0.031	0.03

Annexure VII

SPATIO-TEMPORAL CHANGES OF BUILT UP AREA

Year	Total Built up km^2	Built up km^2	Built up-Industrial km^2
1944	5.7252	5.7252	
1973	83.739	69.4032	14.336
1990	125.19	109.2554	15.9351
1998	139.228	121.2143	18.0141
2007	166.3995	146.0864	20.3132
2009	172.8641	152.5415	20.3227
2011	176.891	154.028	22.8639

CHANGE MATRIX OF 1973-1990 (VALUES IN km^2)

1990 ↓ / 1973 →	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	0.381																
Pokkali Fields		74.024	0.858	2.038		0.169				0.129		1.975					0.162
Aquaculture with coconut			2.455														0.015
Built-up				69.352													
Built-up Industrial including Port Area					14.336												
Reclaimed Land						0.427											
Canal							3.2										
Estuary		1.233		0.547	0.141	0.805		104.208		0.032	0.462	0.509					0.046
Paddy Fields	0.49			2.296	0.399				46.371			5.277		0.104			
Dense Mangrove			0.029	0.093						0.402	0.009	0.846					0.067
Marshy				0.038			0.071			0.602	0.684	0.193					0.202
Mixed Land use		0.112		34.645	1.458	0.025				0.045		277.23		3.242	0.119		0.143
River/Lake				0.06					0.026			0.305	12.599				
Rubber														13.808			
Sandy Area				0.229						0.013	0.032	1.251			1.617	0.547	0.015
Sea											0.32	0.119			0.802	25.396	0.104
Sparse Mangrove										0.184	0.053	0.028					0.083

CHANGE MATRIX OF 1990-1998 (VALUES IN km²)

1998 ↓ / 1990 →	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	0.873																
Pokkali Fields		71.53	0.238	1.193		0.719				0.479		0.75					0.465
Aquaculture with coconut			3.31	0.011													0.012
Built-up				108.9	0.34												
Built-up Industrial including Port Area					15.93												
Reclaimed Land						1.71				0.041							0.08
Canal							3.34										
Estuary		0.044		0.224	0.36	0.15		103.21		0.028	0.015	0.17			0.0141		
Paddy Fields	0.216			0.865	0.204	0.356			43.906			0.895					
Dense Mangrove			0.0103							1.908	0.051						0.074
Marshy				0.012		0.031				0.655	0.435	0.24					0.227
Mixed Land use	0.065			9.889	0.842					0.171	0.117	274.16		2.55	0.042		0.031
River/Lake				0.035	0.012				0.055			0.114	12.38				
Rubber				0.082	0.367							0.59		16.195			
Sandy Area										0.046	0.276	0.322			1.636	0.254	
Sea			0.016							0.09	0.356	0.039			0.897	24.54	
Sparse Mangrove										0.122	0.082	0.217					0.42

CHANGE MATRIX OF 1998-2007 (VALUES IN km^2)

2007 ↓ / 1998→	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	1.153																
Pokkali Fields		68.88	0.198	0.57		0.362				0.336		0.78					0.445
Aquaculture with coconut			3.494	0.016	0.021					0.021							
Built-up				119.95	1.132												
Built-up Industrial including Port Area					18.014												
Reclaimed Land				0.983		1.92						0.584					
Canal							3.306										
Estuary				0.553		0.625		101.814		0.019		0.141					0.045
Paddy Fields	0.1			0.834		0.732			41.07			0.797					0.457
Dense Mangrove		0.079		0.434		0.159				2.595	0.057						0.137
Marshy				0.552		0.022				0.042	0.487				0.093		0.056
Mixed Land use	0.102			20.143	0.643						0.023	256.432					0.025
River/Lake												0.148	12.222				
Rubber				1.389	0.026	0.069						0.145		17.11			
Sandy Area			0.011	0.555								0.247			1.24		0.63
Sea				0.124						0.027	0.019					24.28	0.048
Sparse Mangrove		0.132	0.012	0.11		0.091				0.208							0.705

CHANGE MATRIX OF 2007-2009 (VALUES IN km²)

2009↓ / 2007→	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	1.351																
Pokkali Fields		68.423	0.027	0.317		0.145				0.061		0.096					0.076
Aquaculture with coconut			3.685	0.015													0.011
Built-up		0.012		146.005		0.034											
Built-up Industrial including Port Area					20.23												
Reclaimed Land				0.112		3.86						0.187					
Canal							3.324										
Estuary				0.182		0.21		101.506									
Paddy Fields	0.023			0.073		0.792			40.058			0.134					
Dense Mangrove		0.136		0.048		0.078				2.706	0.186	0.05					0.13
Marshy				0.017						0.01	0.542					0.013	0.034
Mixed Land use		0.023		5.189	0.024				0.049	0.016		253.58					0.029
River/Lake													12.22				
Rubber				0.413								0.084		16.68			
Sandy Area				0.015											1.25	0.314	0.045
Sea				0.03											0.067	24.641	
Sparse Mangrove		0.029		0.052						0.119	0.022	0.014			0.013	0.035	1.24

CHANGE MATRIX OF 2009-2011 (VALUES IN km²)

2011→ / 2009→	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	1.364																
Pokkali Fields		68.41				0.0939				0.007		0.012					0.018
Aquaculture with coconut			3.733														
Built-up				151.29	1.19												
Built-up Industrial including Port Area					20.322												
Reclaimed Land						5.156											
Canal							3.324										
Estuary						0.024		101.488									
Paddy Fields				0.014		0.086			39.996								
Dense Mangrove		0.021								2.761	0.134						0.049
Marshy						0.0201				0.016	0.664						0.054
Mixed Land use				4.058								250.132					
River/Lake													12.223				
Rubber														16.695			
Sandy Area															1.34		
Sea																25.004	
Sparse Mangrove		0.019								0.009	0.109						1.436

CHANGE MATRIX OF 1944-1973 (VALUES IN km²)

1973→ / 1944→	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	0.381																
Pokkali Fields		67.43						0.68				0.1					
Aquaculture with coconut			1.738														
Built-up				12.58		2.68						0.035					
Built-up Industrial including Port Area					1.15												
Reclaimed Land						0.433											
Canal							2.91										
Estuary		8.28		0.897	0.098		0.028	104.85			0.0345	2.384					
Paddy Fields									55.019								
Dense Mangrove										0.409							
Marshy											0.034						
Mixed Land use		0.097		55.867				0.243				311.896					
River/Lake													1.29				
Rubber														13.8			
Sandy Area												0.0272			1.67	0.125	
Sea		3.618		0.054			0.264	2.145			1.64	2.66			2.06		0.277
Sparse Mangrove																	0.404

CHANGE MATRIX OF 1973-2011 (VALUES IN km²)

2011 ↓ / 1973→	Quarry	Pokkali Fields	Aquaculture with coconut	Built-up	Built-up Industrial including Port Area	Reclaimed Land	Canal	Estuary	Paddy Fields	Dense Mangrove	Marshy	Mixed Land use	River/Lake	Rubber	Sandy Area	Sea	Sparse Mangrove
Quarry	0.381																
Pokkali Fields		67.303	1.307	5.008		1.054			0.0103	0.995		2.879					0.854
Aquaculture with coconut			2.369	0.011		0.03											0.038
Built-up				69.162	0.233												
Built-up Industrial including Port Area					14.32												
Reclaimed Land						0.275						0.157					
Canal				0.025			3.185										
Estuary		1.031		1.874	1.573	1.212	0.047	101.486		0.138		0.67					
Paddy Fields	0.819			4.387	1.191	2.404			39.83			6.207		0.172			
Dense Mangrove		0.074		0.097		0.017	0.01			0.34	0.079	0.829					0.114
Marshy		0.206				0.108	0.076			0.572	0.255	0.386					0.184
Mixed Land use	0.167			71.611	3.925				0.095	0.141		235.897		5.015			
River/Lake				0.1	0.03				0.08			0.548	1.222				
Rubber				1.325	0.331							0.612		11.505			
Sandy Area			0.011	0.416	0.067	0.12				0.01	0.029	1.574			686	0.897	
Sea				0.0413		0.055				0.474	0.5	0.225			0.546	24.053	0.239
Sparse Mangrove				0.021		0.013				0.097	0.0416	0.065					0.063