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MAPPING AND CHANGE DETECTION OF BUILT-UP IMPERVIOUS SURFACES IN AND AROUND KOCHI USING GIS

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ABSTRACT

Urbanization fuels the alteration of Land use / Land cover (LULC) pattern of the region including increase in built-up area, leading to imperviousness of the ground surface. Impervious surface mapping is inevitable for studying urban hydrological aspects like water cycling, water quality, soil erosion, flood water drainage, non-point source pollution as well as in urban climatic studies like heat island effect. Among the different methods of impervious surface classifications, Supervised classification is found to be the most suitable method. In this study, temporal variations in impervious surface coverage is studied using Landsat images for the years 1990 and 2014, LISS III images for the years 1998 and 2007 and LISS IV image for the year 2012. Effect of spatial resolution on the mapping of impervious surface is studied using LISS IV images for the year 2012 having 5.6 m resolution and PAN sharpened Landsat 8 image for the year 2014 having 10 m resolution. Comparative analyses of satellite images for the years 2009 and 2014 show that there is a fast expansion of impervious surface of more than 100 km^2 in area.

Keywords: LULC, Impervious Surface, Remote Sensing, GIS, Image Classification,

1. INTRODUCTION

Scientific studies of the relationship between landuse and impervious surfaces began in the field of urban hydrology during the 1970's [1]. In earlier studies, imperviousness was evaluated in four ways: 1) Identifying impervious areas on aerial photography and then measuring them using a planimeter; 2) overlaying a grid on an aerial photograph and counting the number of grids of impervious surfaces among various land uses; 3) supervised classification of remotely sensed images and 4) an empirical method of equating the percentage of urbanization with the percentage of imperviousness. Later on, numerous research efforts have been devoted to quantify the urban impervious surfaces more precisely using ground-measured and remotely sensed data [2,3]. The methodologies range from multiple regression [4-6], spectral mixture analysis ,artificial neural network [7], classification trees [8], integration of remote sensing data with geographic information systems [9] and digital image classification. Among these, Digital Image Classification is used in the present study, which shows considerable accuracy for the studies of large areas.

Many factors must be taken into account in selecting an image processing method. A review of the literature on remote sensing of impervious surfaces during the past decade reveals that spatial resolution of remotely sensed data is an important aspect in the selection of image processing methods. Also, factors to be considered are the user's need, research objectives, availability of remotely sensed data, image processing algorithms and computer software, compatibility with previous work and time constraints [10]. Among these, the selection of suitable remote sensing data is the major factor for a successful application [11]. Since remotely sensed data vary in spatial, geometric, radiometric, spectral, and temporal resolutions, complete understanding of the strengths and weaknesses of various types of data is key to a proper data selection.

1.1. Digital Image Classification

Image classification is one of the widely used methods in the extraction of impervious surfaces [12-14] but results are often unsatisfactory while dealing with low/medium resolution imagery, due to mixed pixel problems arising out of spectral similarity of various features in an image and the heterogeneity of urban landscapes. Such problems arise due to several reasons and makes it difficult to process the data using conventional classification techniques. Use of high resolution images in mapping impervious surfaces enables the separation of dark impervious surface areas from surfaces shadowed by buildings and areas shaded by tree crowns and water bodies [15]. In cases of mixed pixel problem, sub-pixel classification can be used. Traditional image classification methods using high resolution imageries have been employed in a good number of studies [10,15]. Some researchers have applied image classifications to aerial photographs and LiDAR data too. A few works compared the performance of per-pixel maximum likelihood classifier, ISODATA, and a rule-based classification algorithm applied to digitized aerial photos and LiDAR data in Richland County, South Carolina, and found the maximum likelihood classifier yielded the highest accuracy while the ISODATA the lowest accuracy [13].

In the present study, we have used high resolution data for the years 2012 and 2014. However, for understanding the temporal variations in impervious surface coverage, medium resolution data, which only is available, is used for other years (Table. 1).

2. MATERIALS USED

2.1. Data used for the study

IRS LISS images for the years 2007, 2009 and 2011 were procured with minimum cloud cover with the help of NRSC image browsing facility. The images for 1990, 1998 and 2014 were downloaded from GLCF and 1973 image was downloaded from USGS. The details of the data used are given in the table 1.

Table 1: List of Satellite Images used in this study

Space-craft	Acquisition Dates	Sensor	Bands	Spatial Resolution (Meter)	Radiometric Resolution (Bits)	Source	Image Details	Level of Processing
Landsat-8	11-02-2014	TM	2,3,4, PAN	10	16	GLCF	Path-143, row-53	Geo rectified, radiometric corrected.
IRS-P6	08-02-2012	LISS-IV	2,3,4	5.6	16	NRSC	Path-99, Row-67	Geo-rectified, radiometric corrected.
IRS-P6	01-02-2011	LISS-III	2,3,4	24	7	NRSC	Path-99, Row-66 (70% Shifted to Row 67)	Radiometric corrected
IRS-P6	20-12-2009	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70% Shifted to Row 67)	Geo-Rectified
IRS-P6	07-12-2007	LISS-III	2,3,4	24	7	NRSC	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
IRS-IC	04-01-1998	LISS-III	2,3,4	24	7	GLCF	Path-99,Row-66 (70%Shifted to Row 67)	Radiometric corrected
Landsat 5	24-01-1990	TM	2,3,4	30	8	GLCF	Path-144,Row-53	Geo-Rectified
Landsat 1	10-02-1973	MSS	2,3,4	60	6	USGS	Path-155 Row-53	Radiometric corrected

2.2. Study Area

The Kochi city lies near the western coast of Kerala, the south-western state of India. The city and the surrounding rapidly urbanizing area comprises about 330 km^2 extending from 9º 49' to 10º14'N latitudes and 76º 10' E to 76º 31'E longitudes. Kochi is geographically linked with the wetlands of Vembanad estuary. Kochi has a tropical climate with intense solar radiation and abundant precipitation. Like the rest of coastal Kerala, Kochi experiences warm climate and the annual temperature ranges between 20°C and 35°C. Being a coastal metropolis, majority of the Kochi region lies within the low land regions of the state. The average altitude of the land is less than 1 m. above MSL and hence requires proper urban planning and is also most susceptible to the impacts of climate change. The whole of the land slopes gradually from east to west. The flat terrain of the central city interspersed with a network of canals provide the link to the backwaters (Figure 1). The secondary canals serve as natural conduits to the city for the drainage of flood waters.

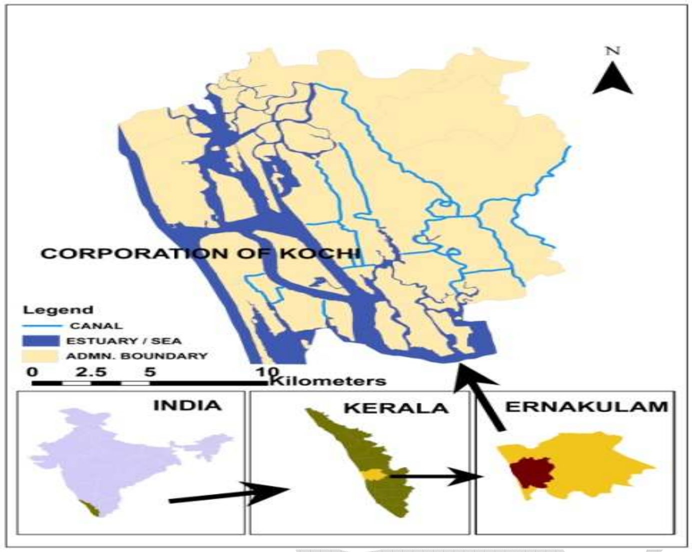

Fig 1: Study Area

3. METHODOLOGY

3.1 Pre-processing of Satellite Images

All the LISS III, LISS IV, Landsat MSS and Landsat TM images were co-registered or geometrically corrected using image to image registration with reference to geometrically corrected 2014 Landsat 8 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 to < 0.5 pixel accuracy. All the image processing were done in ArcGIS 9.3 and Erdas Imagine 9.1. Atmospheric correction was done using minimum pixel subtraction method [16-18]. All the images were georectified and subsetted using the subset tool in data preparation menu in the ERDAS imagine software.

3.2 Selection of a Suitable Method for the Preparation of Impervious Surface Map

Land cover maps having four classes - Water bodies, Vegetation, Open/Exposed and Built-up areas are prepared using IRS LISS IV image for the year 2012 having 5.6 m. spatial resolution using three different digital image classification techniques and three supervised classification algorithms. The different techniques tried are supervised and unsupervised classifications, as well as NDVI. There are mainly three classification algorithms for supervised classification. Mean distance to minimum, Mehalanobis distance and Maximum likelihood classifier (MLC). Unsupervised classification is done with Iterative Self-organizing Data (ISODATA) Algorithm. In this study, the image is subjected to unsupervised classification with a cluster size of 30 clusters. After classification, each of these 30 clusters is assigned with one of the four land use classes by correlating the classified image with ground reference. After the classification, accuracy assessment to each classified image is done using the accuracy assessment tool in Erdas Imagine. Sampling points (300) were selected at random and the accuracy assessment is done for all the classified images, supported by ground information collected using a Garmin-60 hand held GPS system. Google Earth is also used to obtain the current spatial scenario.

Among all these classification techniques and algorithms 'Supervised Maximum Likelihood Classification (MLC) yielded the highest classification accuracy and was selected for further estimates. The classification accuracy is in the following order; Supervised MLC > Unsupervised classification > NDVI > Mean distance to minimum > Mehalanobis Distance.

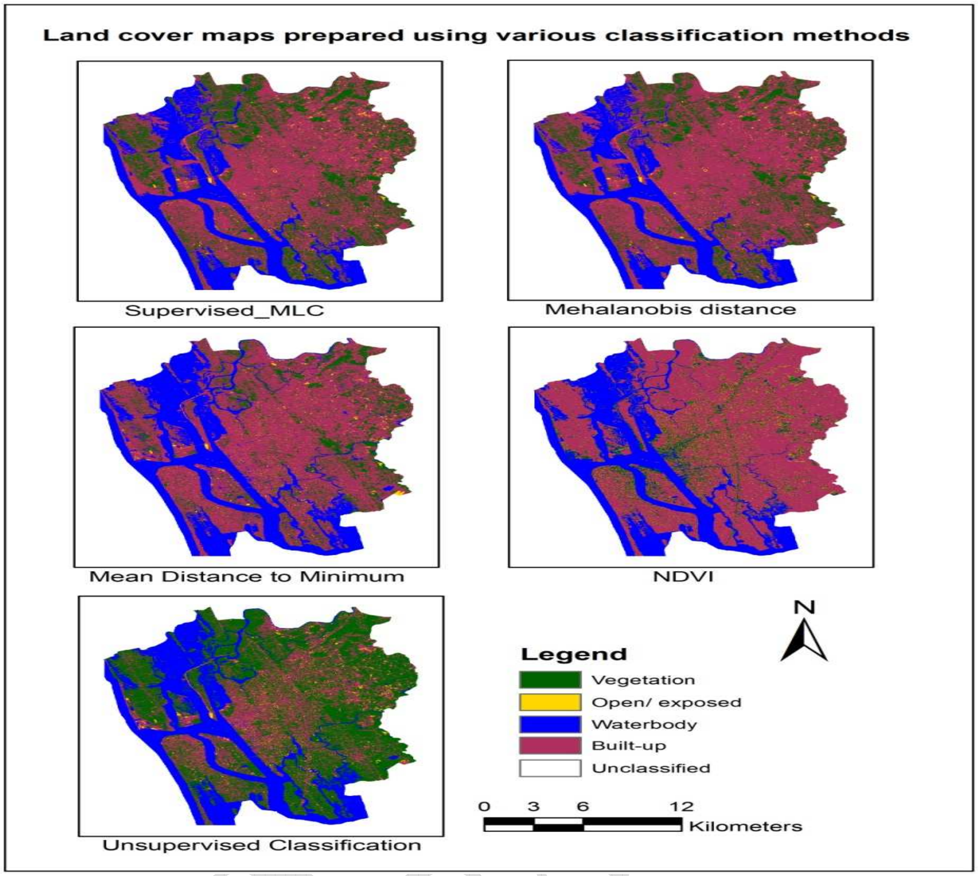

Fig 2: Landcover Maps prepared using various Classification Methods

3.3 Preparation of 'Total Impervious Surface (TIA)' Maps

Land cover classified layers for the years 1973, 1990, 1998, 2007, 2009, 2012 and 2014 having the four classes were prepared using supervised MLC classification. Vegetation and Open / Exposed land is considered as pervious and Built-up areas alone is taken as impervious. Confined water bodies, which adds to the perviousness, are absent in the study area. There are only flowing water bodies, which do not add to the infiltration (perviousness) but only increase the run-off. Hence, they are considered neither as pervious nor impervious and hence are left alone as water bodies in the Figure 5. Total Impervious Area (TIA) maps for the city were composed from these layers.

3.4 Spatio- Temporal Analysis of Impervious Surfaces

Spatio temporal analysis of TIA is performed by considering the image differences of 2014 and 1990 TIA layers. Even though data for the year 1974 was available, a comparison between 1974 image with 72 m. resolution and 2014 image with 15 m. resolution can result in serious error. Hence only the 1990 image having 30 m. resolution is used for the comparison with 2014 data.

4. RESULTS AND DISCUSSION

Spatio temporal Changes of Impervious Surfaces

Spatio temporal analysis of impervious cover over Kochi shows that along with the increase in urbanization, there is a corresponding decrease in water bodies and vegetation. Analysis of satellite data shows that the impervious coverage of 53.74 km^2 in 1990 increased to 154.63 km^2 by 2014, while there was a corresponding decrease of pervious areas from 183.70 km^2 to 87.25 km^2 during the same period. Also, it can be seen that this change is not only contributed by conversion of pervious lands into built up area, but also by land reclamations of the backwaters (Fig 3). This trend was visible from 1944 to 2009 [19]. Only, this trend seems to accelerate in the present decade.

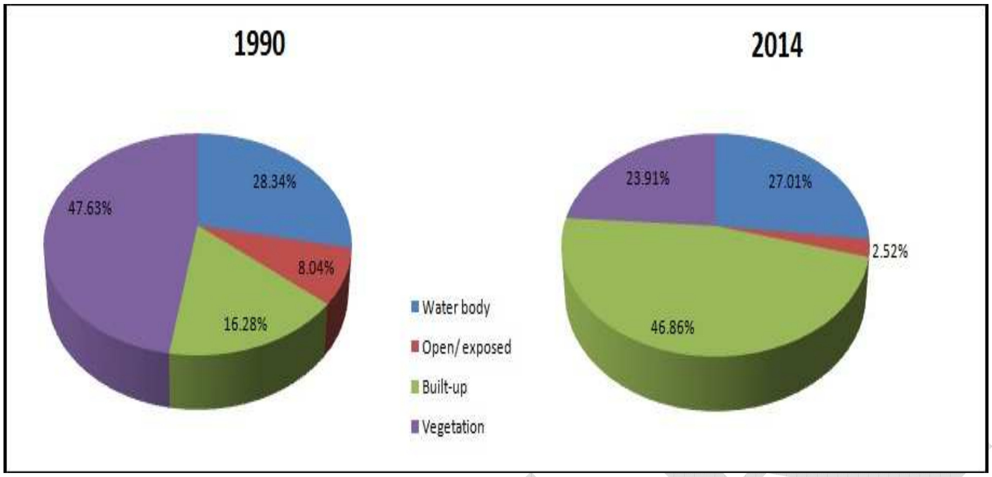

Fig 3: Landcover Pattern for 1990-2014

The impervious surface expansion mainly takes place along the periphery of new roads as can be seen in Fig. 4 & 5. Also, impervious cover of the city increased considerably with the onset of major developmental activities such as International container transshipment terminal (ICTT), Metro Rail, Liquefied Natural Gas (LNG) Terminal, Kochi International Airport, Smart City, Info Park etc. Construction of ICTT was started in 2005 and it became fully operational in 2011. Metro rail project started in 2013 also added its own share of impervious surface increase for its allied infrastructure developments. Change detection studies shows that impervious cover over the city is increasing at a very rapid pace. Land cover maps for the years 1974, 1990, 1998 and 2007 are given in figure 4 and that for the years 2009, 2011, 2012 and 2014 are given in the figure 5. Spatio temporal changes of impervious surface from 1990 to 2014 is given in figure 6.

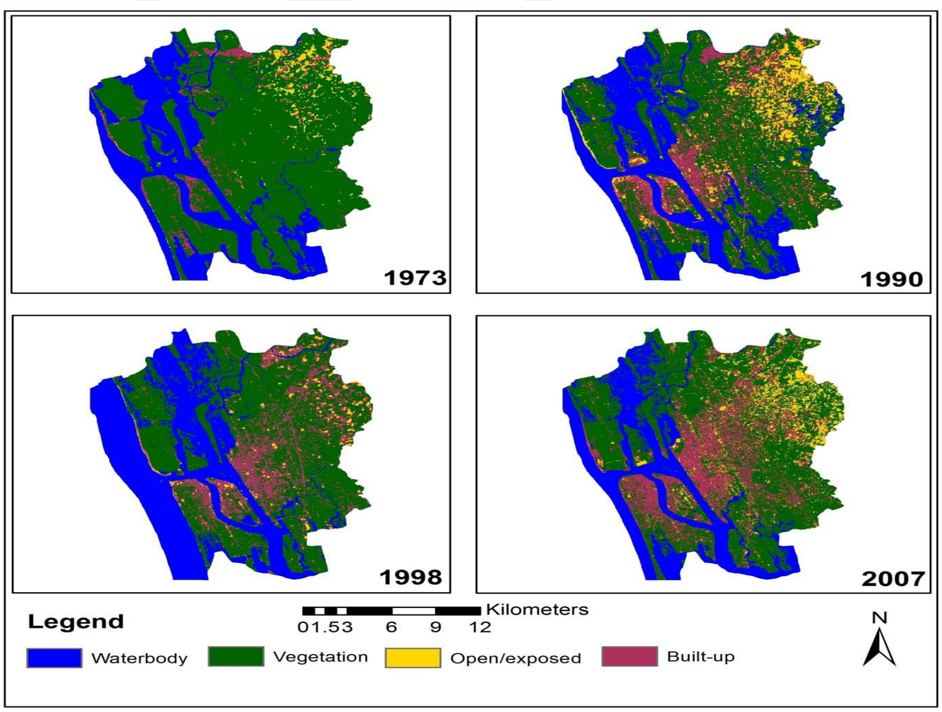

Fig 4: Map showing Temporal Changes in Land Cover from 1973-2007

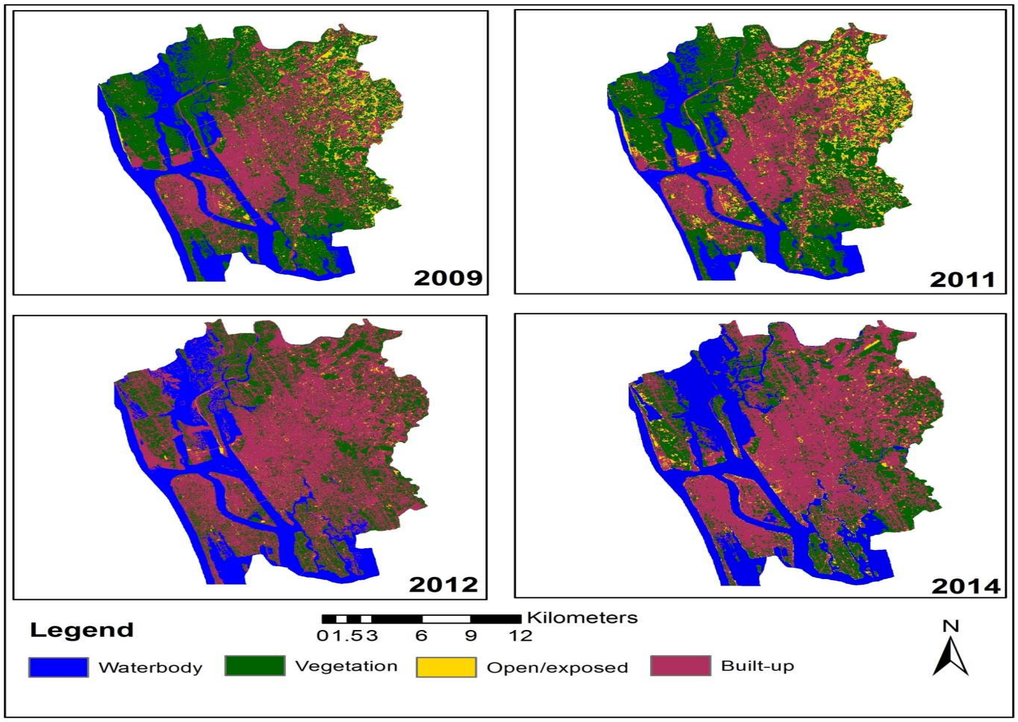

Fig 5: Map showing Temporal Changes in Land Cover from 2009-2014

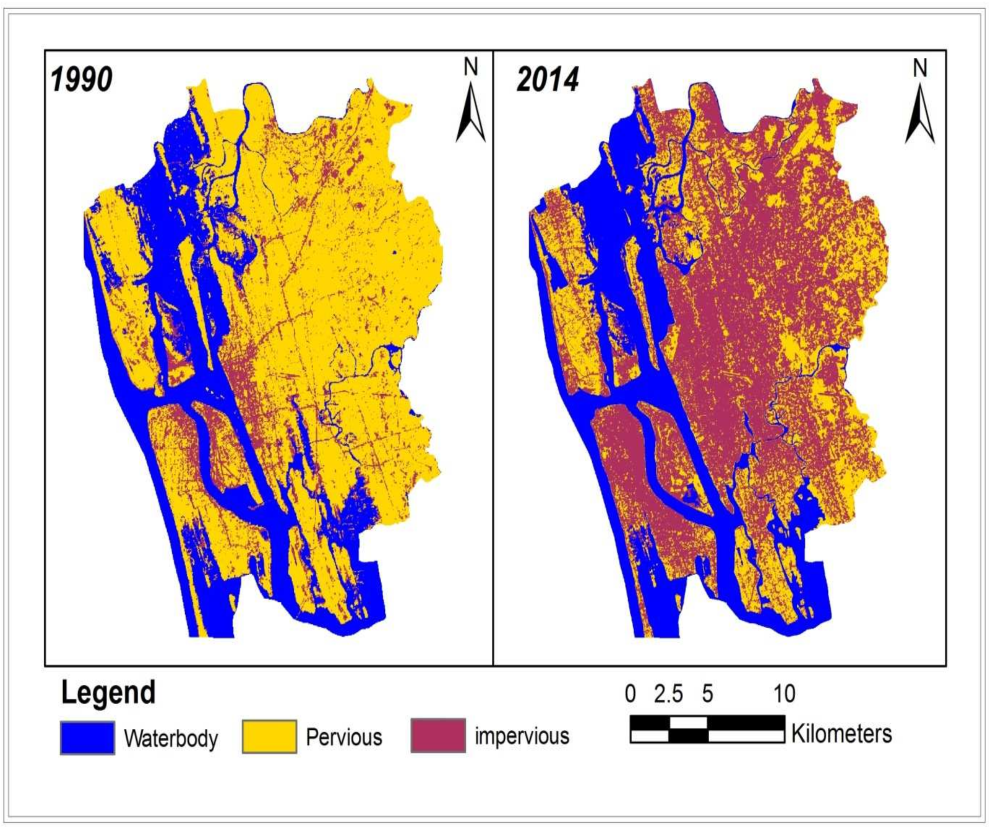

Fig 6: Total Impervious Area Map

5. CONCLUSION

There are many potential applications for the impervious surface maps prepared from this study. Spatially explicit imperviousness estimates and their trends provide urban planners useful data to assist in their decision making and implementation of management strategies. Applications in this field include urban ecological modelling and urban climatological studies. Above all, expansion in impervious surface serves as an indicator of increasing Urban Heat Island (UHI) effect. Geospatial data of impervious surfaces and its change can be used not only as a critical input for urban hydrological modeling but also as an indicator for water quality assessment. Increasing imperviousness plays a big role in degrading water quality and quantity [20].

This study reveals the rapid increase in impervious coverage concurrent with the development of the Kochi metropolis. This calls forth, the urgent implementation of Best Management Practices for the smooth functioning of the city infrastructure. The frequent disruptions of traffic and other public services after heavy rainfalls have become a part of the city life not only in Kochi, but also in most of the cities in the tropical developing countries. This emphasizes the need to develop planned cities at least in emerging metropolises.

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