

Urban Land Growth Mapping of South-East Asia Cities

This document represents additional information accompanying the poster ID 1143 in session "Land Posters"

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Abstract

In the recent years a couple of operational urban mapping activities for international financial institutions have been implemented by Gisat in South-East Asia and Pacific region. Mapping services have been delivered in frame of EOWORLD2 and its precursor EOWORLD, both joint initiatives of ESA and World Bank, and PUMA project, follow-up initiative of World Bank. Service cases have aimed to contribute to understanding the extensive urban growth in various metropolitan areas including e.g. Karachi, Mumbai, Dhaka, Colombo or Surabaya by assessment of urban land use development.

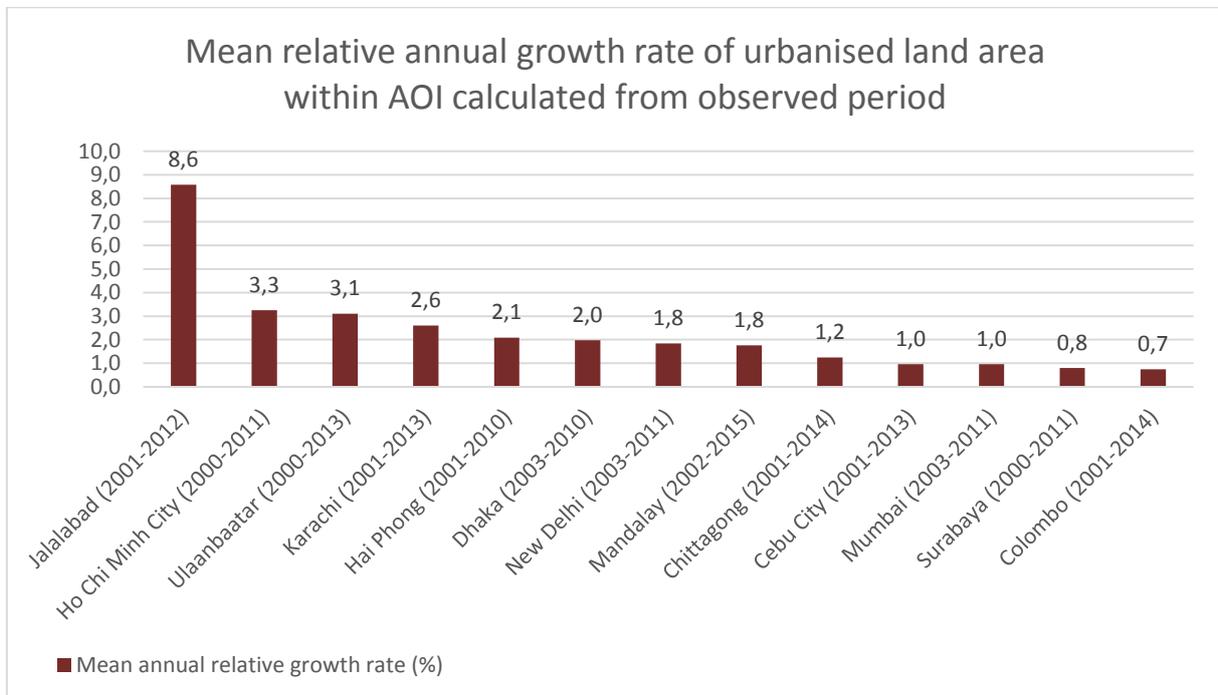
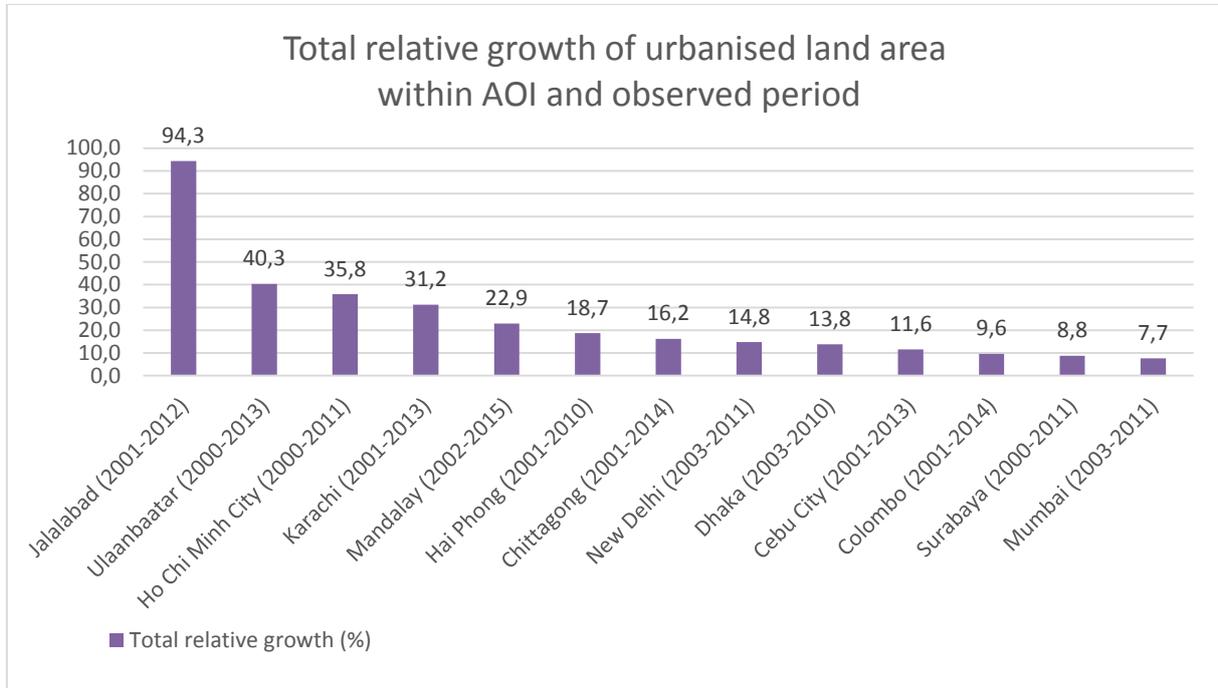
The service is based on two pillars. First, Earth observation data and techniques are utilized for extraction of both retrospective and up-to-date information on urban land use and subsequently, assessment and comparison of extracted information and their links to the statistical figures are provided within dedicated web-based platform.

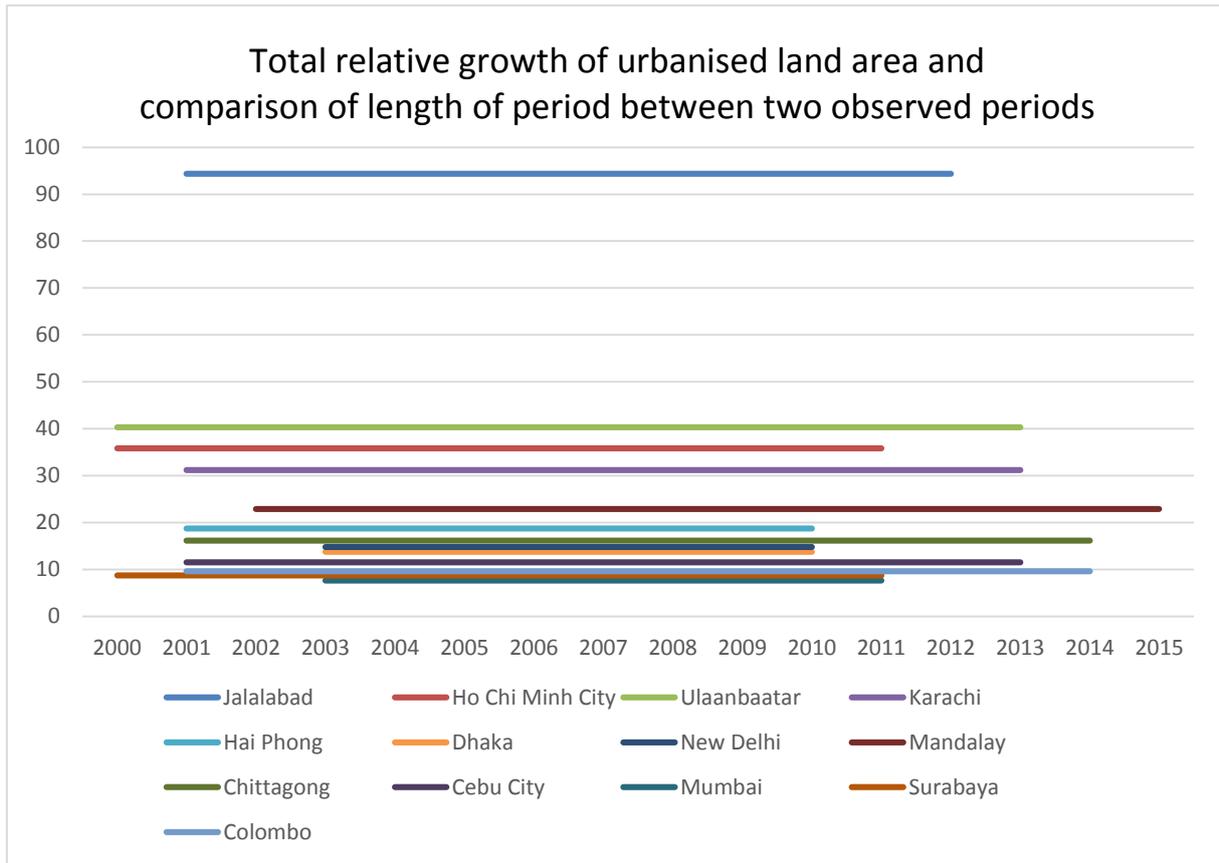
Land use status and changes are extracted by analysis of optical satellite imagery. Based on previous experience and throughout the course of the projects object-based image analysis techniques of detecting complex land use classes have been developed and tuned up using multi-resolution data. Semi-automated workflows preceding manual enhancements support consistent operational implementation of the service for large urban areas. Depending on recency of requested retrospective land use high or very high resolution data are used as baseline for information extraction.

The platform for Urban Management and Analysis (PUMA) represents web-based geospatial software for exploration and analysis of spatial data. PUMA adapts open-source software and allows users with no prior GIS experience to access, explore, visualize, analyse, integrate and share local, regional and global urban spatial data from a variety of sources in an interactive and customizable way. It supports the objectives of Global Urban Growth Data initiative: it helps the World Bank and its clients to develop a shared understanding of the long-term spatial, economic and environmental implications of land use by assessment of harmonized, comparable urban reference datasets. Trends of urban development and its patterns could be analysed both individually and between the cities mapped in South-East Asia.

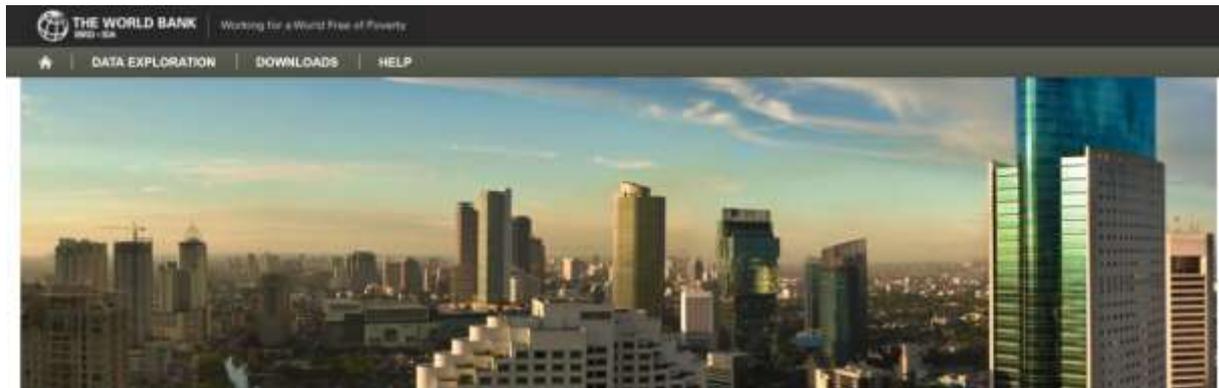
Services have been defined in a way to be operationally extendable in short or long term update time frame in order to serve as a base for further monitoring in future. The service components have also been proven in frame of urban risk assessment domain in Copernicus Emergency Management Service or ESA's initiative EO for a Transforming Asia Pacific (EOTAP) supporting EO inception in Asian Development Bank (ADB).

Comparison of urban land growth in cities observed in frame of the projects (EOWORLD, EOWORLD2, PUMA, EOTAP)





PUMA platform



PUMA – a new platform for urban spatial data for the World Bank

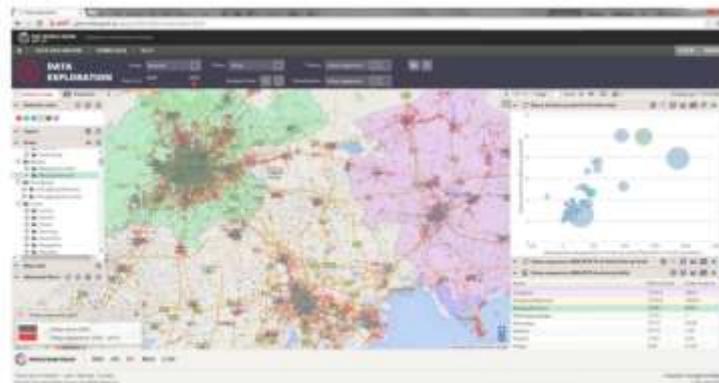
PUMA, or Platform for Urban Management and Analysis, is a geospatial tool that allows users with no prior GIS experience to access, analyze and share urban spatial data in an interactive and customizable way. Developed by the East Asia and Pacific Urban Development and Disaster Risk Management unit of the World Bank's Social, Urban, Rural and Resilience Global Practice (GPSURR), it adapts open-source software to the data needs of the urban development sector. Read a one-page [beginner's guide to using PUMA](#).

Explore PUMA

Note: This tool is optimized for use in Chrome or Firefox browsers.

www.worldbank.org

PUMA was developed as part of the larger Australian Aid-funded analytical activity that studies urban expansion in the region (East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth, 2000–2010). A major output of this activity is the mapping of built-up land, urban expansion, and urban population change across the East Asia Pacific (EAP) region between 2000 and 2010. This data set, produced in collaboration with the University of Wisconsin and the WorldPop project, is unprecedented in its scope. For the first time, it allows us to compare urbanization across countries that otherwise define "urban" in very different ways. This data can be explored in PUMA. The development of a map of urban expansion at a global scale is underway and will be available via PUMA when completed.



Results from PUMA and EOWORLD2 projects are available in the PUMA platform developed for World Bank by GISAT: <https://puma.worldbank.org>

EOWORLD2



Interactive summary of the project's results is available on: <http://project.gisat.cz/eow2>

EOTAP



Interactive summary of the project's results is available on: <http://project.gisat.cz/eotapk>

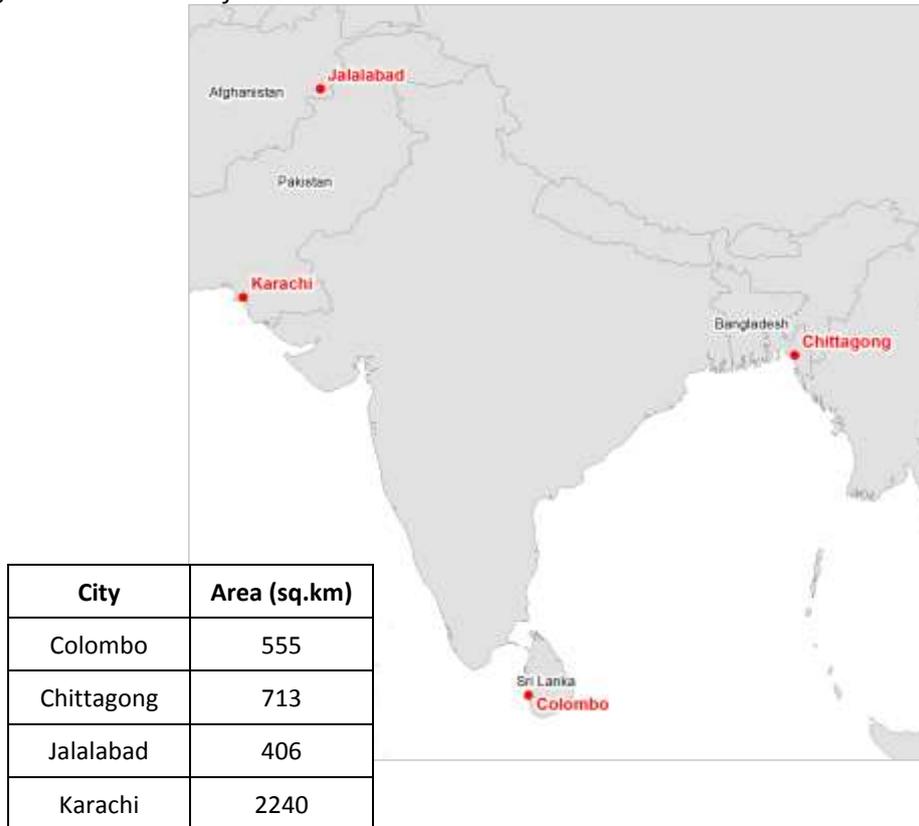
Example of detailed land use / land cover change analysis conducted for 4 cities in frame of EOWORLD2 project

This chapter provides brief highlights of statistics and indicators that have been derived from the EOWORLD2 service final products. Examples indicate achievable mode of interpretation of the LULC and LUCC results, though they are not exhaustive and may be further extended.

City facts	
City Country	Description
Jalalabad, Afghanistan	With population of more than 200,000, Jalalabad is the second-largest city in eastern Afghanistan as well as the center of its social and business activity. Located at the junction of the Kabul River and Kunar River near the Laghman valley, Jalalabad is the capital of Nangarhar province.
Chittagong, Bangladesh	Chittagong is the main seaport and second largest city of Bangladesh. It is located at the estuary of the Karnaphuli River in south-eastern Bangladesh. The city proper has an estimated population of over 4 million people, while the Greater Chittagong metropolitan area has a population of 6.5 million. It is one of the fastest growing cities in the world.
Karachi, Pakistan	Karachi is the largest and most populous metropolitan city of Pakistan and its main seaport and financial centre, as well as the capital of Sindh province. The city has an estimated population of 23.5 million people as of 2011, and a density of nearly 6,000 people per square kilometre.
Colombo Sri Lanka	Colombo is the largest city and the commercial, industrial and cultural capital of Sri Lanka. It is located on the west coast of the island and adjacent to Sri Jayawardenepura Kotte suburb or the parliament capital of Sri Lanka. Colombo is a busy and vibrant place with a population of about 750,000 in the city limits.

Table 1 Service Summary Sheet

Figure 1 Overview of AOI – 4 cities



Total area of 2914 sq.km divided into four AOIs has been mapped in framework of the service delivered. The largest AOI was established for Karachi while the rest of the AOIs were more or less comparable in size. All AOIs included core city, suburban area and agriculture surroundings, which are usually subject to land cover changes of variable intensity. For each city the **land cover and its changes** are provided for **two temporal horizons: former (T1)** from interval 1999-2001(-2004) and **later (T2)** from interval 2012-2014, depending on satellite data availability (see Appendix 1). Narrow definition of intervals ensures mutual comparability of results in temporal point of view. For simplicity and better readability, *in the figures headings below, the 2001 refers in fact to T1 and 2013 refers to T2.*

The Table 2 provides overview of land cover class nomenclature including codes and abbreviations utilized in the further text. For detailed specification of land cover classes see the Appendix 2. For simplicity of graphs in the document, Roads, Airports and Harbours (121, 122, 123) were aggregated into class 120, however, they could be distinguished by the unique codes in the vector data.

Class name	Code	Abbreviation
Formal high density residential (Continuous urban fabric)	111	CUF
Formal low density residential (Discontinuous urban fabric)	112	DUF
Commercial, Industrial and Transport Units & Non-residential urban fabric	120	CIT

Construction sites	130	CON
Urban Greenery	140	UGR
Agricultural Land	200	AGR
Trees	310	TRS
Other Natural and Semi-natural Areas including Wetlands	320	NAT
Vacant land not obviously being prepared for construction	330	VAC
Water Bodies	510	WAT

Table 2 Land cover (/ land use) classes nomenclature

The text below is broke down into sub-sections in order to indicate various means of analysis and accounting of EO-based land cover statistics combining spatial and thematic information.

Land cover structure

As documented in the Fig. 2, results prove that different proportions of land cover classes between the cities, both for urbanised areas and for non-urban surroundings, are being formed either by agricultural or by (semi-)natural landscape.

Figure 2 Structure of land cover in years 2001 and 2013 (100% = Total AOI area for given year)

- **Significant differences in structure of all LC classes as compared between AOIs and reference years.**

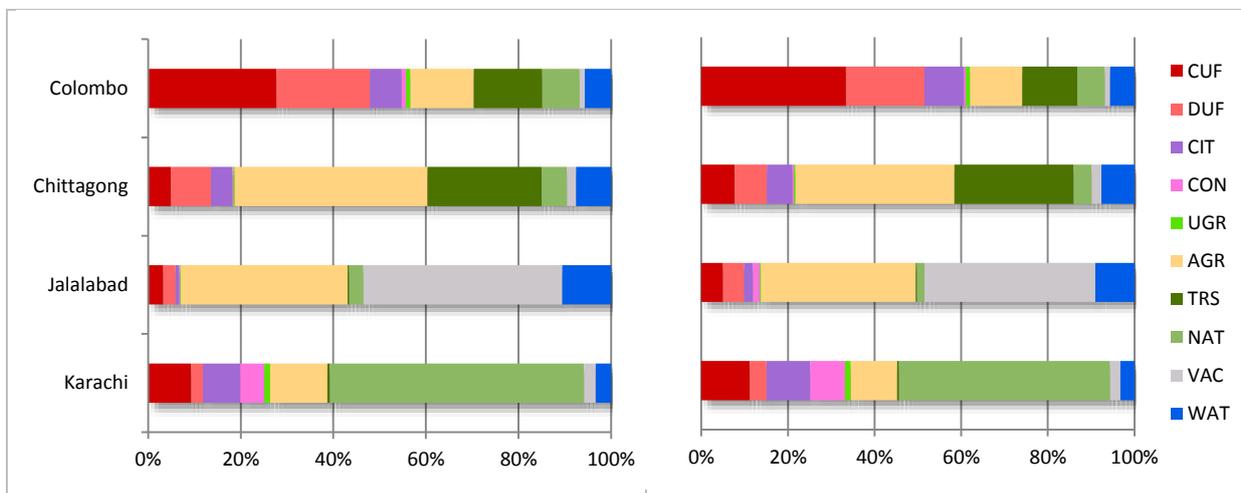
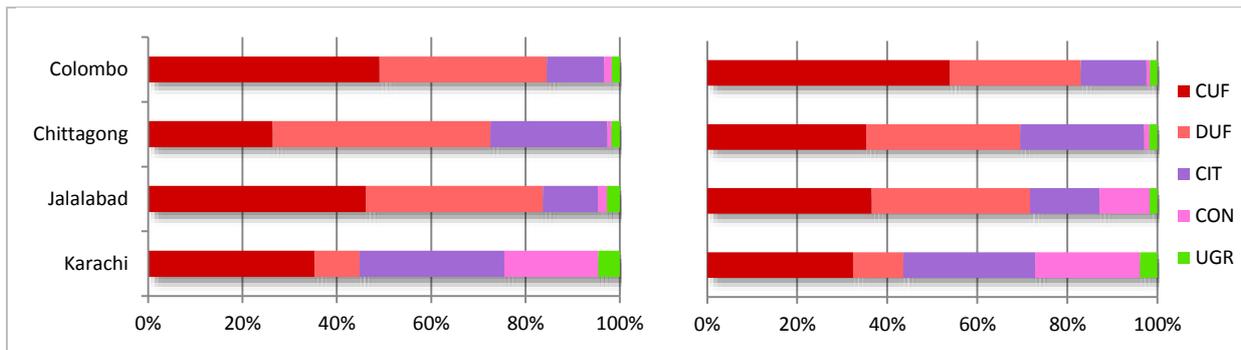


Fig. 3 gives more insight into urban land cover structure within areas of interest. Significantly different proportions of continuous (CUF) and discontinuous (DUF) urban fabric between 2001 and 2013 were detected in Chittagong. In Jalalabad increase of share of construction sites (CON) is apparent. Extraordinarily large proportion of construction sites compared to other cities is present in Karachi in both horizons.

Figure 3 Structure of urban classes in years 2001 and 2013 (100% = Total urban area ¹for given yr.)

- **Significant differences in structure of urban LC classes as compared between AOIs and reference years.**



Land cover distribution

Comparison of land cover status maps extents of urban footprint in reference horizons could indicate axes of development zones. Figures below exemplify spatial extent comparison (Please note, figures are not fit to comparable map scale).

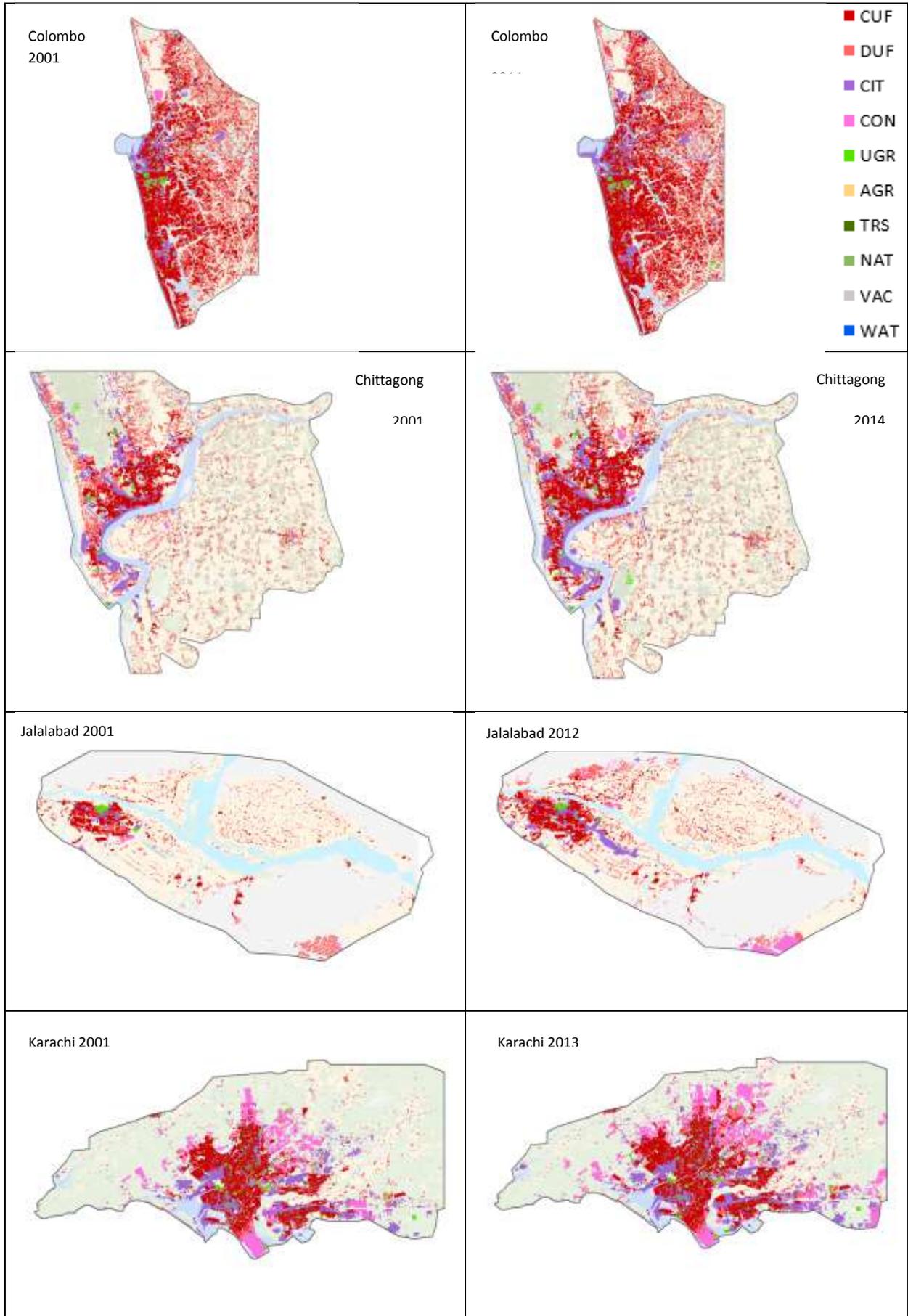
If detailed administrative district are available and viable for mutual comparison the class proportions (or any optional statistical variables) could be aggregated per districts and visualised in the thematic (choropleth²) maps.

Figure 4 Land cover maps of 4 AOIs and 2 horizons

- **Comparison of land cover maps between reference years shows clearly development of each city.**

¹ Urban area in this context shall be understood as aggregation (sum) of classes 111, 112, 120, 130 and 140, within the AOI extent.

² Choropleth map uses graded differences in shading or colour for defined areas (e.g. administrative boundaries) in order to indicate average quantities (of arbitrary property or quantity) within those areas.



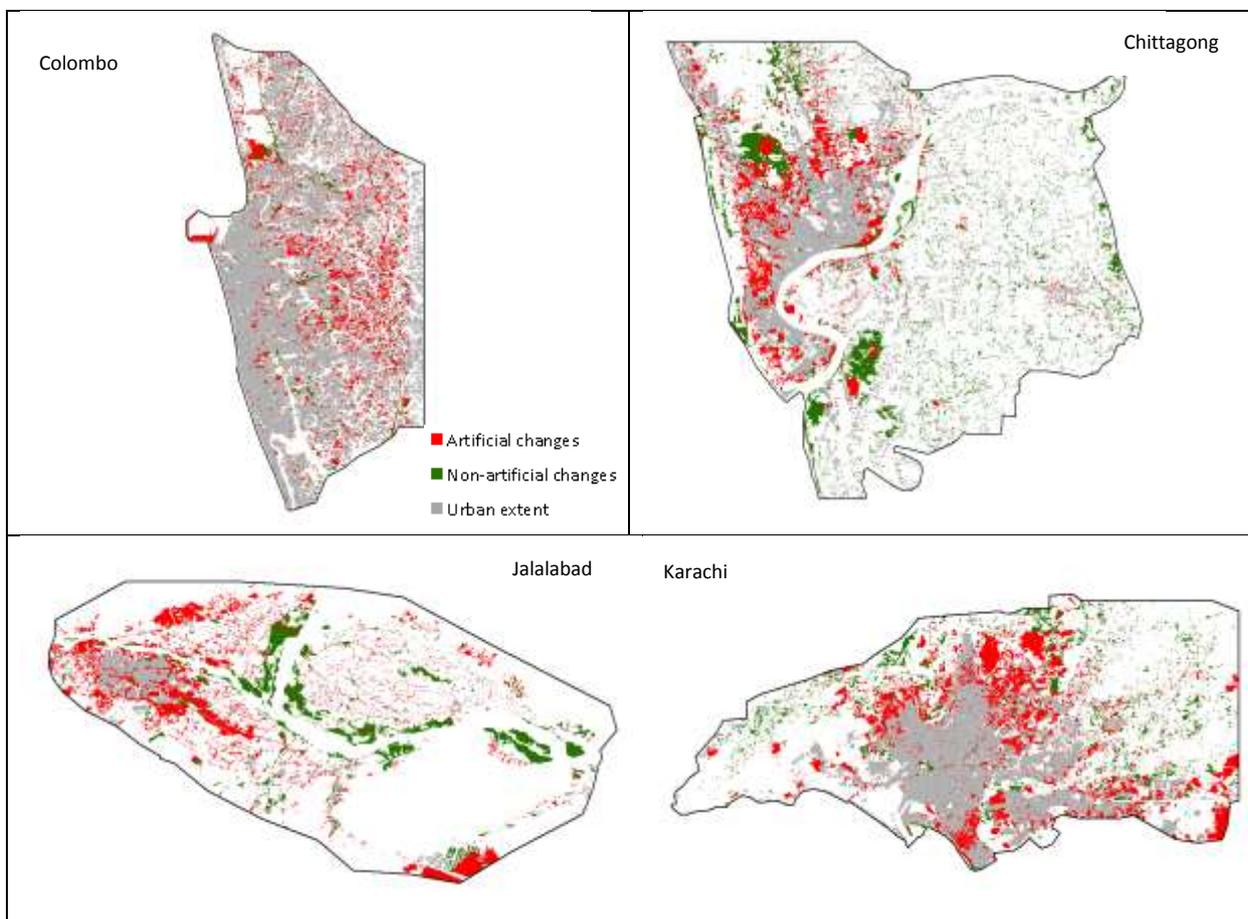
Distribution of land cover changes

Main benefit of EO-based land accounting is linked to its capacity to describe and quantify development of land cover classes in time. Distribution of land cover changes supports understanding patterns of urban growth in spatial context.

Changes could be arbitrarily categorized; either at basic level (see Fig. 5) or further in-depth according to land cover (change) flows (refer to further sections).

Figure 5 Distribution of land cover changes – categorized to land cover changes of urban areas (artificial) (sum of Urban extension and Urban internal changes) and other land cover changes of non-urban (non-artificial) classes between 2001 and 2013 for 4 AOIs

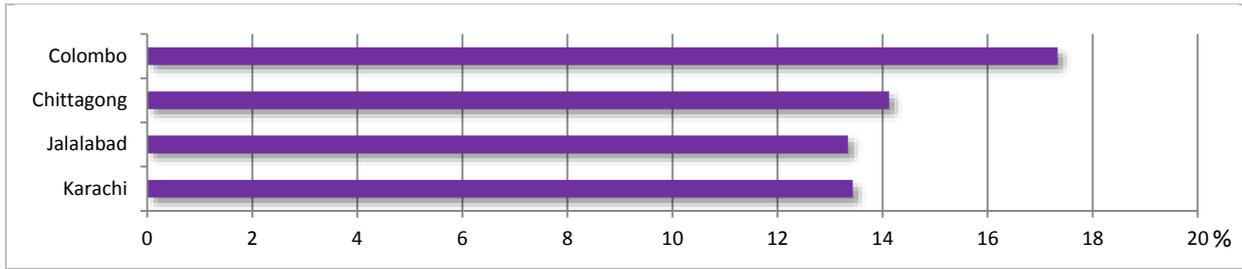
- **Figures show clearly for each city distribution and density of “artificial changes” (= extension and internal urban changes) and “non-artificial changes” (= conversions between natural classes or agriculture).**



Relative comparison of change share on total AOI areas is given in the Fig. 6.

Figure 6 Share of sum of changes between 2001 and 2013 (100% = Total AOI area)

- **Figure shows share of AOI's area affected by (sum of) changes which is comparable for 3 AOIs except Colombo**



Land cover flows

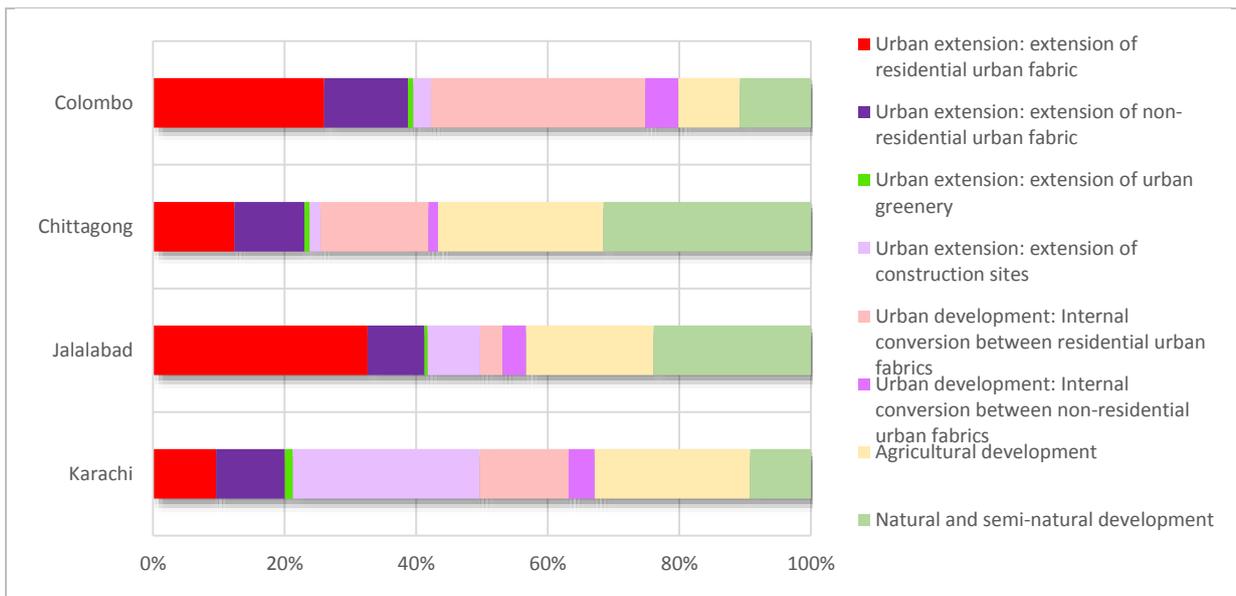
For evaluation of land cover changes (in frame of so called *land accounting*) concept of *land cover flows* is being widely utilized. Single land cover flow consists of specific change or combination of similar related changes, e.g. “Urban internal (functional) change” (sometimes called “Urban (internal) development, which may consist of several conversion classes both at consumption and formation level. For further details see the Appendix 3.

Fig. 7 indicates relative structural comparison of all land cover flows at city levels. Apparently, proportions of urban-related flows (residential and industrial extension, internal changes) differ significantly among the cities investigated.

From comparison it is evident that (except Chittagong) proportion of urban-related changes represented by flows Urban residential extension, Urban internal development and Extension of non-residential, industrial and commercial sites dominate over non-urban changes/flows. Going deeper into detail, in Karachi and Jalalabad the residential extension significantly predominates over the rest of urban-related changes while in Chittagong and Colombo it is predominated by internal functional change (though not significantly).

Figure 7 Relative structure of Land cover flows (100% = total area of changes in AOI)

- **Figure shows relative proportions of land cover changes categorized into so called “land cover flows”. Different cities have different structure of changes.**

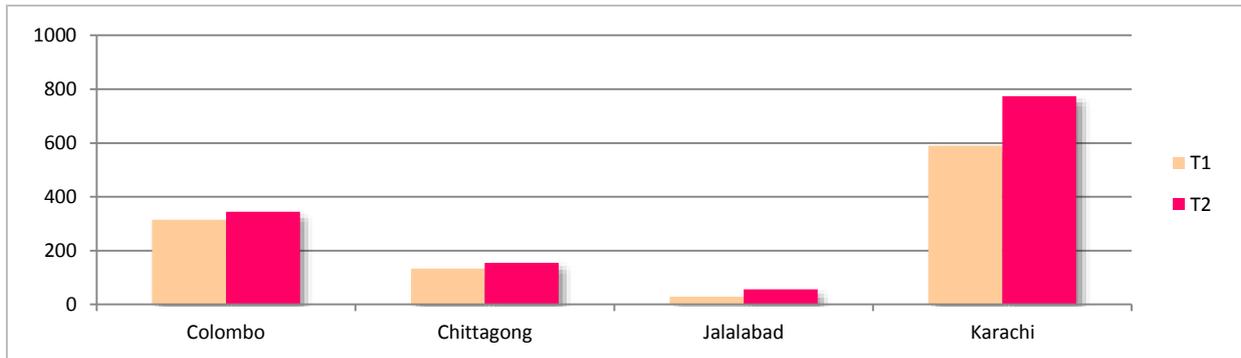


Extension of urban land area

Graphs in Fig. 8 provide absolute comparison of urban area classes' extent between both reference horizons. Absolute amount of urban area increase (aggregate land cover flow that is referred to as *Urban extension*) could be read from the graphs.

Figure 8 Absolute areas of urban area extent for 2001 and 2013 (sq.km)

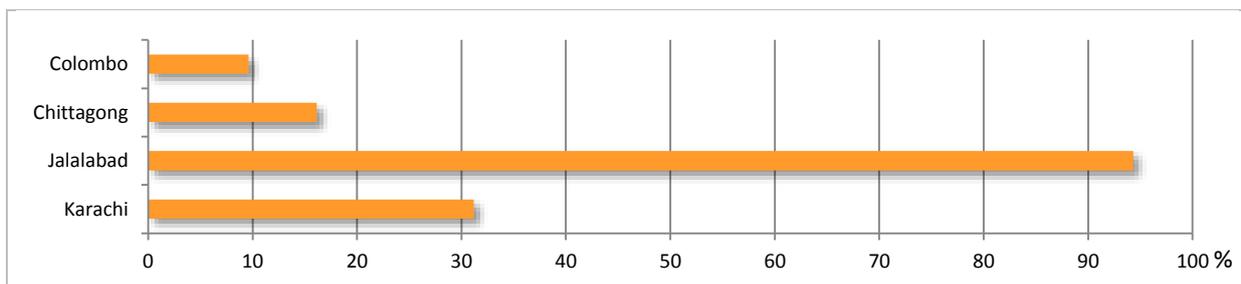
- **Absolute urban area and absolute urban increase indicate global importance. Though the urban extent of Jalalabad almost double increased (see the Fig. 9) between reference years, in absolute figures it is negligible compared to Karachi, which is one of the world's megacities.**



Relative increase rate could be estimated for individual class or flow. Fig. 9 provides estimate exclusively for increase of urban areas between two horizons. Rate of Urban extension should not be confused with annual rate of Urban extension, which could be averaged by dividing the overall rate by number of years, but whose real estimate could vary significantly between individual years. It is apparent that Jalalabad area has undergone substantial extension of urban area classes – the extent of built-up has almost doubled during the last decade.

Figure 9 Relative urban increase for 2001 – 2013 = overall rate of Urban extension (100% = Total Urban area in 2001)

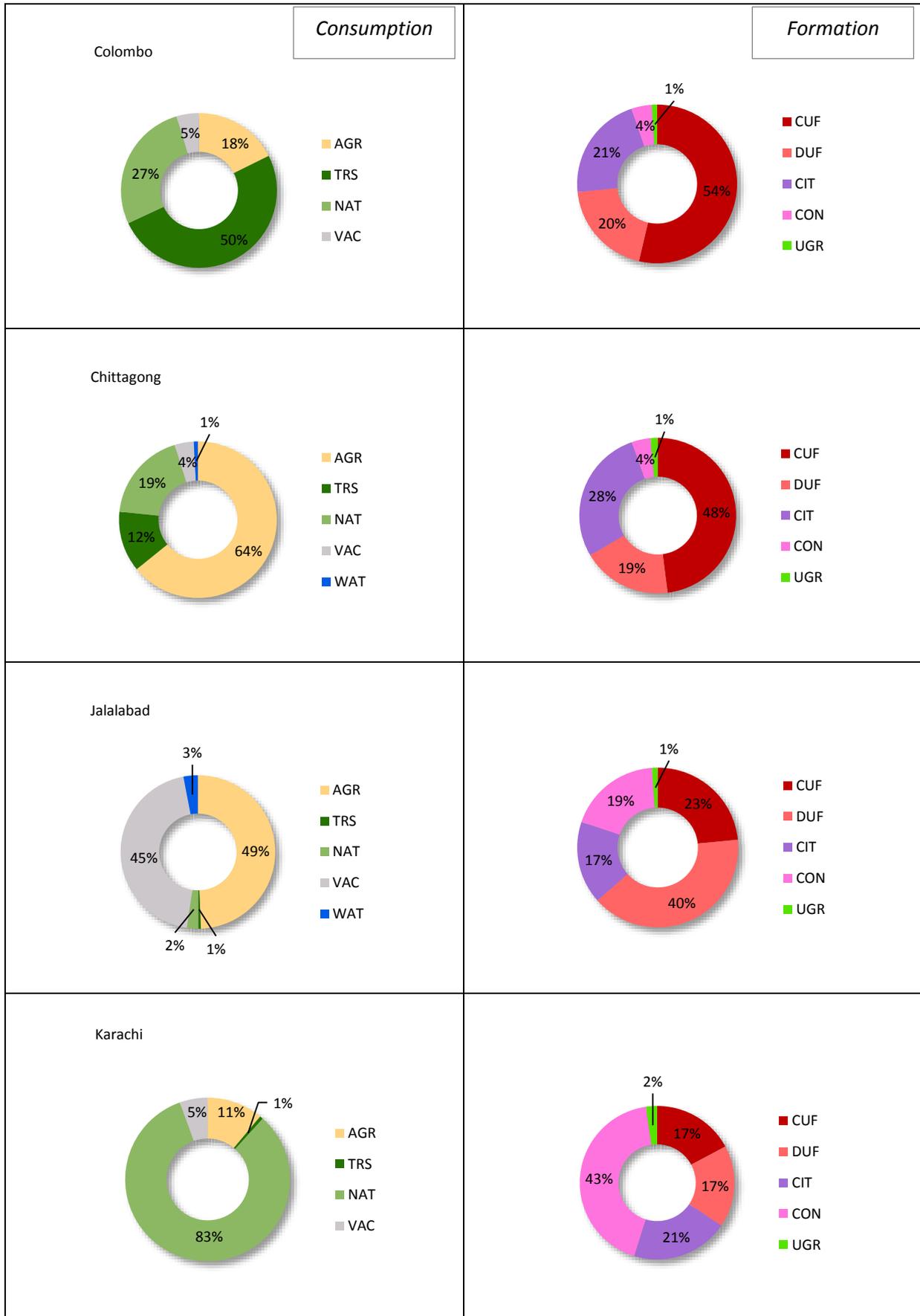
- **Figure compares significant differences in relative increase of urban area between AOIs. Karachi has had double increased compared to Colombo and Chittagong, but Jalalabad underwent the most dynamic extension.**



Structure of urban changes – extension and internal development

As opposed to conventional statistical records, which usually provide only net estimates (*saldo*), Land accounting based on EO-derived land cover statistics enables in-depth analysis of real increase and decrease of class area and internal structure of changes at flow level. Individual land cover flows could be hence structuralized according to shares of classes being consumed (in favour of target flow components) or shares of classes being formed in process of flow formation. Graphs in Fig. 10 provide examples of relative structural quantification for land cover flow of interest - Urban extension.

Figure 10 Consumption (left) and Formation (right) of Urban extension (100% = Total area of Urban extension in AOI)

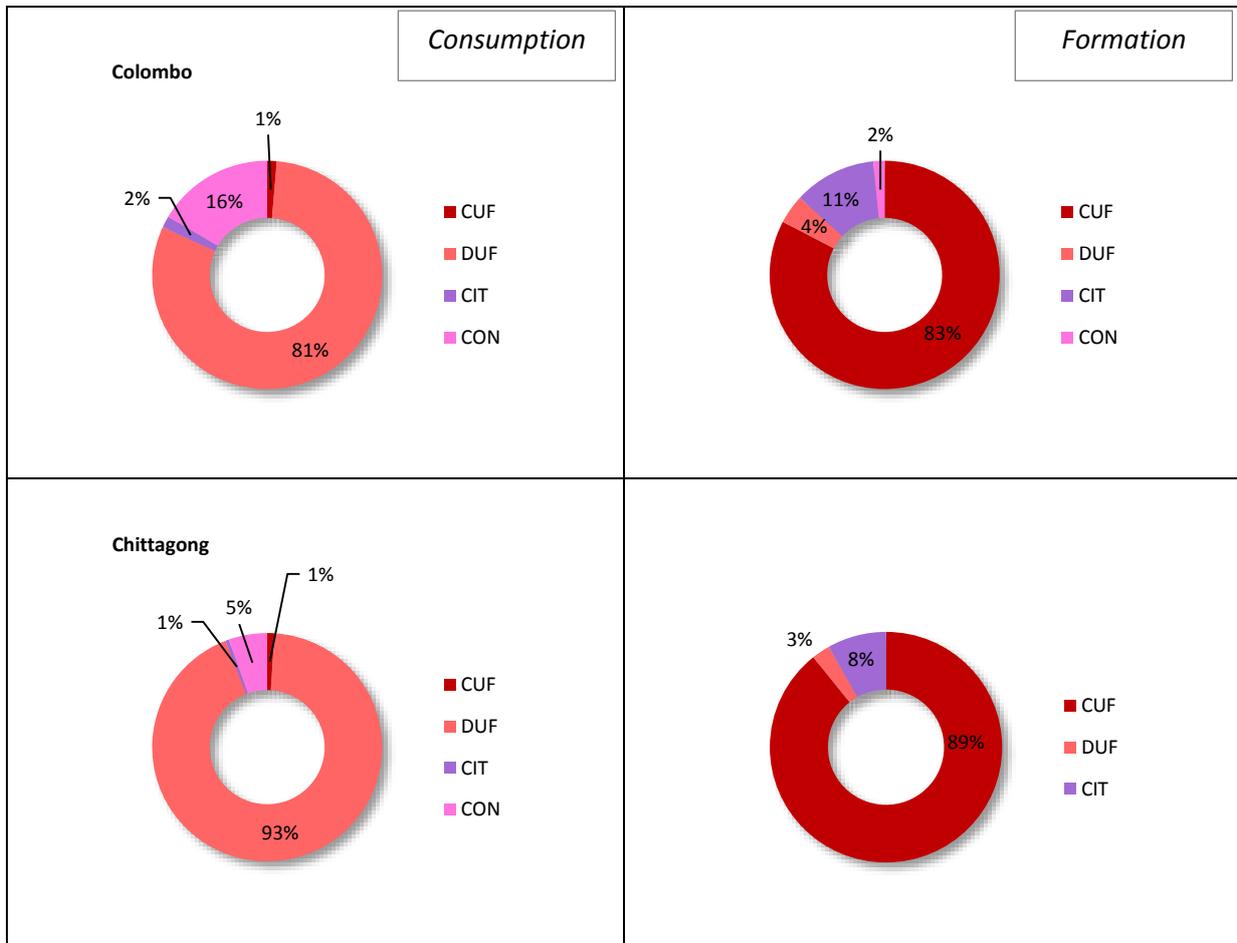


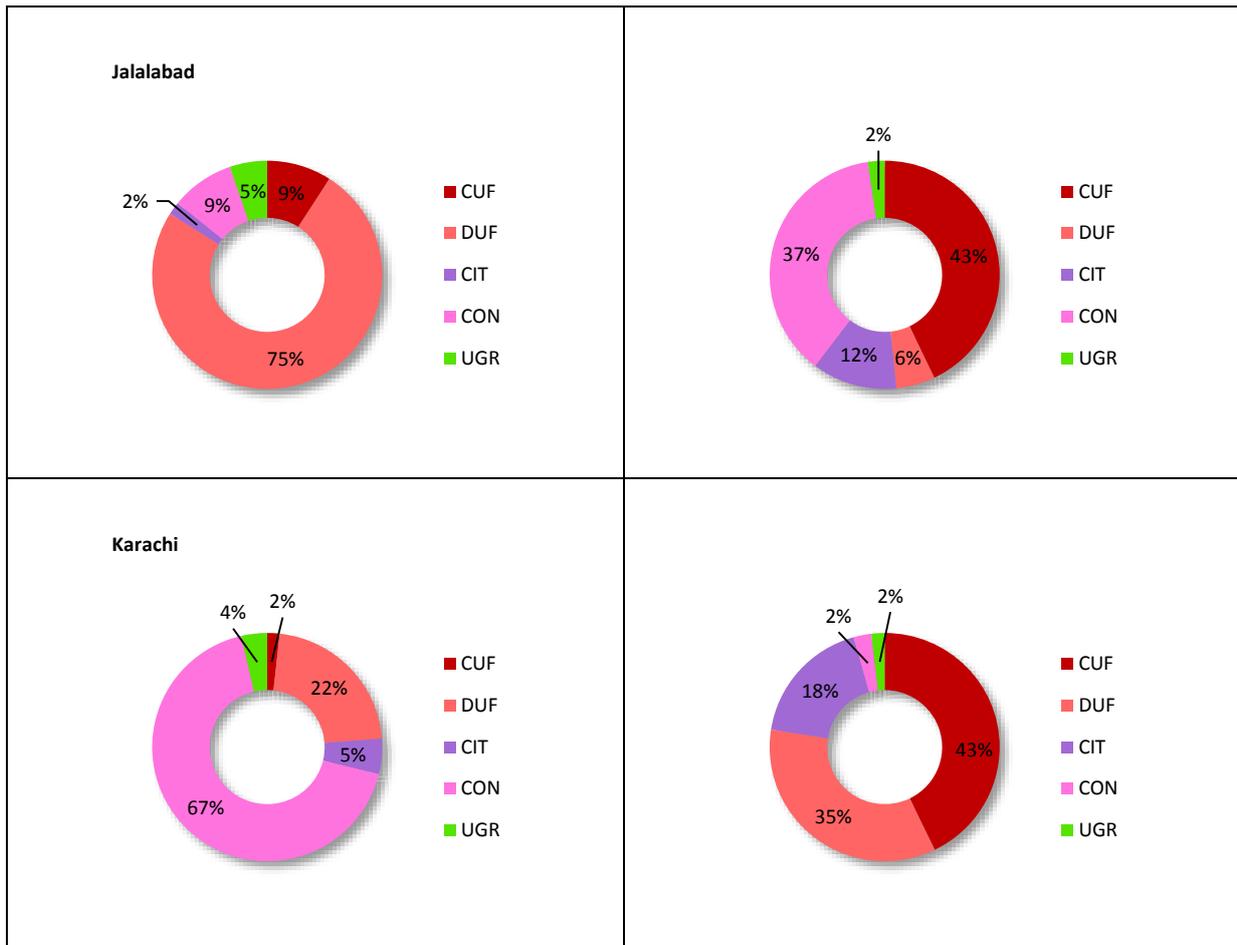
- **Figures compare structure of Urban extension providing answers to questions:**
 - **What is share of non-urban classes which were consumed by urban extension in each AOI?**
 - **Which classes were formed at expense of non-urban classes and what is their share?**

Generally, different structures of consumption are related to different characters of the city surroundings. Different structures at formation level could be related to different character of (sub-)urbanisation processes in each cities.

Graphs in Fig. 11 show structure of internal functional changes within the cities. Mostly, changes represent densification of current urban fabric, built-up at construction sites. In Jalalabad and Karachi, part of internal changes occurred at expense of urban green.

Figure 11 Consumption (left) and formation (right) of Internal urban changes (100% = Total area of Urban extension in AOI)





- **Figures compare structure of Internal development supporting answering to questions:**
 - **Which urban classes have changed their use (or density)?**
 - **What is predominant internal change within city – densification, change of use?**
 - **Are there any impacts on environment (e.g. reduction of urban green areas)?**
 - **What is the extent of revitalisation (represented e.g. by formation of urban green areas)?**

Development of informal settlements

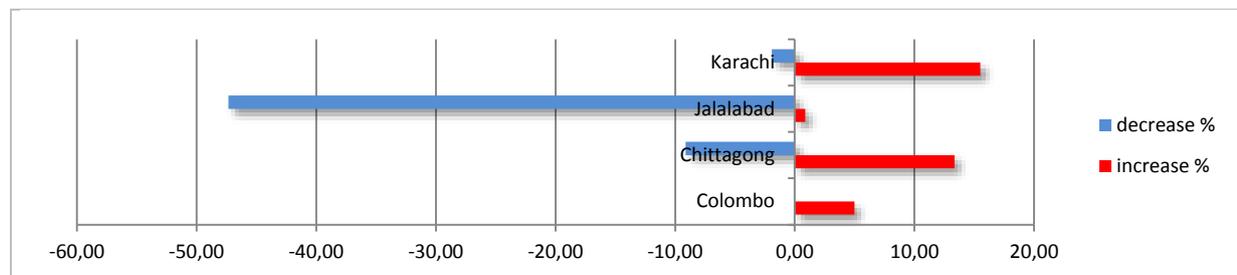
Fig 12 provides descriptive example for real increase (proportion being formed) and decrease (proportion being consumed) for class *potential slums*³. Slums represent very dynamic class. They can sprawl rapidly following influx of rural inhabitants into the city. At the same time, they are subject to reconstruction and revitalisation, when former slum areas are rebuilt into industrial or formal residential areas. Due to this reason, it worth monitoring both increase and decrease of overall slum areas.

³ The term *Potential slum areas* means that these areas selection is based purely on their **physical appearance** and the **other key characteristic** of urban slums like **poverty level** or **informality of land tenure** are not taken into account as their can't be detected by EO means. For further reference please see the note in the chapter 2.4.

It is apparent, that in Chittagong the net change amounts not higher than to 5% increase if scaled according to area of original potential slum in 2001. Reality is that almost 10% of original potential slums were rebuilt and apart from it 13% increase (scaled to original extent in 2001) was identified.

Figure 12 Development of informal settlement – potential slums (100% = potential slum area in 2001)

- **Figure provides detail insight into development of potential slums comparing the AOIs: both increase and decrease could be quantified (relatively, absolutely) from EO data given the methodological and definition constraints.**



	Increase (sq.km)	Decrease(sq.km)	Net change (sq.km)
Colombo	0,18	0	0,18
Chittagong	0,08	0,06	0,02
Jalalabad	0	0,26	-0,26
Karachi	11,42	1,42	10

Table 3 Development of potential slum areas

Totals of potential slum area changes are listed in the table below. In absolute numbers, Karachi has witnessed the most significant extension of potential slum areas, which differs from other cities on order of magnitude.