MODULE 3

LAND USE EFFICIENCY

UN HABITAT
FOR A BETTER URBAN FUTURE

LAND USE EFFICIENCY

TARGET 11.3: *By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.*

Indicator 11.3.1: *Ratio of land consumption rate to population growth rate*

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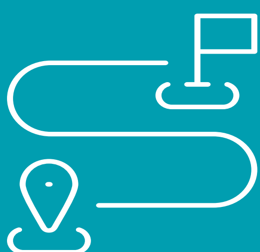
SECTION 1:

INTRODUCTION



1.1 Background

Human settlements, in all their diverse forms, appropriate land in varied ways. *Just like living organisms, urban settlements (cities) evolve, transform, adapt, innovate and change with emerging trends (Hernandez, 2014).* Urban settlements expand, shrink, densify, intensify, age, and sometimes their functions even migrate to areas that are more conducive to their survival. All these trends in urban settlements are closely associated with such factors as changes in population, economic potential and productivity, prevailing physical and social conditions, presence of enabling policies, among other things.

A country that maximizes the many benefits associated with urbanization is one that is able to understand, measure and predict the growth trends of its urban areas; and in turn put in place the necessary actions / interventions to tap on the benefits of such growth, while minimizing the equally diverse challenges associated with unplanned urbanization. Pro-active planning - which is a major pre-requisite for sustainable urbanization - requires that city authorities and other relevant actors predict the direction of growth of a city, and/or shape this growth by providing the required facilities, services and policy and legal frameworks ahead of development. This results in planned and equitable growth in which majority of the city residents have access to the basic services, economic and social opportunities, and where environmental sustainability prevails. At the centre of all these is the need for generation and dissemination of up-to-date and accurate data on growth trends across cities and urban settlements.

Indicator 11.3.1 measures **how efficiently cities utilize land**, which is measured as a ratio of the rate at which cities spatially consume land against the rate at which their populations grow. Empirical evidence has shown that, cities that are compact use land more efficiently and are better placed to provide public goods and basic services at a lower cost. Such cities can consume less energy, manage waste better, and are more likely to maximize the benefits associated with economics of agglomeration (UN-Habitat, 2018). On the other hand, sprawling cities (non-compact cities) experience increased demand for mobility; increased energy consumption; environmental degradation; increased cost of providing basic services per capita (e.g. water, sanitation, drainage); increased cost of infrastructure per capita; reduction in economies of agglomeration; and decreased urban productivity (UN-Habitat, 2018).

By measuring the rate at which cities consume land against their rate of population growth, city authorities and decision makers can project demand for public goods and services, identify new areas of growth, and pro-actively influence sustainable urban development (UN-Habitat, 2018). This is needed to provide adequate infrastructure, services and amenities for the improvement of living conditions to all. Generation and dissemination of data on this indicator is thus not only crucial for understanding urban growth dynamics and formulation of informed policies and guidelines, but is also at the core of promoting sustainable urbanization.

Indicator 11.3.1 is connected to many other SDG indicators such as 11.7.1 (Public space), 11.a.1 (Regional Development Plans), 15.1.2 (Forest area), 8.1.1 (City Product per Capita), 8.2.1 (Growth rate per employment), 8.5.2 (Unemployment Rate) and 11.6.1 (Solid Waste Collection). The indicator ensures that the SDGs integrate the wider dimensions of space, population and land, adequately, providing the framework for the realization of other goals such as those promoting interventions on poverty, health, education, energy, inequalities and climate change. In addition, the indicator has a multipurpose measurement, as it is not only related to the type/form of the urbanization patterns but also to other dimensions of productivity and sustainability such as economic factors (proximity of factors of production), environmental considerations (e.g. lower per capita rates of resource use and GHG emissions), and social factors (reduced travel distance and cost expended).

Rural - urban divide, Shenzen, China © imgur

1.2 Rationale for Monitoring

Understanding how a city/urban area expands spatially against its rate of population change is critical to determining, among other things, the nature of human settlements growth (formal versus informal) and the speed of conversion of outlying land to urbanized functions. These two elements have significant implications on the demand for and cost of providing services, as well as on environmental preservation and conservation.

To attain sustainable development, countries need to understand how fast their urban areas are growing, and in which direction. This will not only help them understand growth trends and effectively address demand for basic services but also help create policies that encourage optimal use of urban land, effectively protecting other land uses (natural environments, farmlands, etc).

In addition, achievement of inclusive and sustainable urbanization requires that the resources be utilized in a manner that can accommodate population growth from migration and natural increase while preserving environmentally sensitive areas from development.

The purpose of monitoring progress against the SDG indicator 11.3.1 is therefore to provide necessary and timely information to decision makers and stakeholders in order to accelerate progress towards enhanced inclusive and sustainable urbanization.

Meeting Target 11.3 by 2030 requires, at the minimum, slowing down urban sprawl and if possible, ensuring that the compactness of cities is maintained or increased over time.

Land-use on a coutryside town © rau.ac.uk

1.3. Monitoring and reporting process

The monitoring and reporting process will require the involvement of many stakeholders at national and local levels. Some of the key stakeholders include city authorities, national statistical agencies, UN agencies, agencies working on earth observation and geographic information, among others.

DATA COLLECTION

National Statistical Agencies are responsible for data collection. However, for this particular indicator, high resolution data on built up areas is required, that can be generated by city authorities, and/or through partnerships with agencies and ministries involved with spatial data extraction and earth observations.

CAPACITY DEVELOPMENT

UN-Habitat and partners working in the geospatial community (GEO, European Commission, NASA, ESA, ESRI, etc) will support both capacity development and data generation activities on this indicator.

DATA RELEASE

To make it possible to detect land cover change from openly available medium resolution satellite imagery with reasonable precision, a 5 year monitoring interval is proposed for this indicator. In addition, to understand how the consumption of land by cities contributes to sustainable urbanization – in line with target 11.3 - historical image analysis is highly encouraged for this indicator, with a proposed baseline year of 2000.

Data at the regional levels will be estimated from national figures derived from the National Sample of Cities generated for each country based on a scientific sampling method developed by UN-Habitat.

UN-Habitat will lead global monitoring efforts, with support from other partners and regional commissions.

1.4 Concepts and Definitions

Population growth

The rate at which population size changes in a country during a period, usually one year, expressed as a percentage of the population at the start of that period. It reflects the number of births and deaths during a period and the number of people migrating to and from a country. For this indicator, the population growth rate is measured at the urban area / city level as opposed to the country level.

Urban area / city

For this indicator, this describes an area that is spatially, functionally, or otherwise urban in nature (See Section 2.1.1 of this document). The urban/ city extent is not limited to existing municipal boundaries.

Land consumption

The uptake of land by urbanized land uses, which often involves conversion of land from other uses to urban functions

Land consumption rate

The rate at which land occupied by a city/urban area changes during a period of time (usually one year), expressed as a percentage of the land occupied by the city/urban area at the start of that time.

Urban Growth illustration © Biologicaldiversity.org.

SECTION 1:

HOW DO WE MEASURE LAND CONSUMPTION TO POPULATION GROWTH RATE?

Indicator 11.3.1 aims to measure the rate at which urban areas transform spatially (capturing both positive and negative growth where such happens), in relation to the rate at which their populations grow over time. The first principle to achieving accurate and representative estimations for this indicator is by viewing urban areas as constantly changing settlements which can expand and/or shrink as a result of various factors, as opposed to viewing them as fixed entities within administratively (or otherwise) defined boundaries.

The indicator is thus reliant on the accurate identification of the functional city area, or actual areas where urban growth happens over a defined period of time, which can be achieved through a diversity of spatial analysis approaches. In their study on 200 cities that constitute the Atlas of Urban Expansion (*www.atlasofurbanexpansion.org*), a team of experts at New York University working in partnership with the Lincoln Institute of Land Policy and UN-Habitat identified four ways through which urban areas/cities grow:

Infill – which consists of all additional developments (built-up areas) to what was previously open spaces within the urban area in an earlier period;

Extension - which consists of all newly developed (built -up) areas that are attached to the urban areas of an earlier period;

Leapfrog development – which consists of all new developments (built-up areas) that meet urban character threshold but are not attached to the urban areas of the earlier period or to new urban extension;

Inclusion – which consists of all existing developments (built-up areas) that were outside the main urban area in an earlier period, but which get engulfed by the outwards growth of settlements in a new period.

An important point to note is that growth of urban areas/ human settlements is not always positive. Sometimes, negative growth can be recorded, such as where disasters (e.gs floods, earthquakes) result in collapse of buildings and/or reduction in the built-up area mass.

Identification of the functional urban area which can be used to measure this indicator requires adoption of globally applicable and comparable metrics and thresholds. These not only make it possible to measure the rate of urban transition between countries, but also create a system through which change can be tracked throughout the human settlements continuum within countries.

Through a global commitment established during the Habitat III conference in Quito in 2016, various organizations have been supporting efforts towards harmonizing the metrics and thresholds for defining human settlement typologies that help make clear distinctions between different types of settlements over time (e.g. distinguishing urban from rural areas). These efforts, which aim to attain a globally harmonized definition of a city by 2020, acknowledge and incorporate the dynamic nature of human settlements – That indicator 11.3.1 aims to measure. So far, experts have identified two candidate approaches for a global city definition, which are discussed in detail in reports by the European Commission and New York University[1]

1 See
a) Dijkstra, L., H. Poelman, 2014. A harmonized definition of cities and rural areas: the new degree of urbanisation. Directorate General for Regional and Urban Policy, Regional working paper 2014;
b) Florczyk, A.J., Melchiorri, M., Corbane, C., Schiavina, M., Maffenini, M., Pesaresi, M., Politis, P., Sabo, S., Freire, S., Ehrlich, D., Kemper, T., Tommasi, P., Airaghi, D. and L. Zanchetta, Description of the GHS Urban Centre Database 2015, Public Release 2019, Version 1.0, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-99753-2, doi:10.2760/037310, JRC115586.;
c) http://atlasofurbanexpansion.org/file-manager/userfiles/data_page/Methodology/Understanding_and_Measuring_Urban_Expansion.pdf?time=1476446554646

In acknowledgment of the ongoing efforts at the global level to achieve a harmonized city definition, the steps presented in this module explain the key underlying concepts for the indicator computation, which can be followed to achieve accurate results regardless of the city definition approach used.

The subsequent sections demonstrate how to measure land consumption and population growth rates, and the computation of the core indicator. Section 2.1 demonstrates the concept of dynamic and functional city boundaries and why understanding this is key to accurately measuring urban growth; and discusses how to compute the land consumption rate component of the indicator. Section 2.2 demonstrates how to match population to the dynamic city boundaries, and how to measure the population growth rate component of the indicator. Section 2.3 discusses how to compute the full indicator, and also identifies some secondary indicators which can be computed to further understand growth trends in the study city.

The examples used in this module are for demonstration purposes only and do not in any way represent the position or endorsement of the United Nations regarding designations of boundaries for any country and/or at any level.

2.1 Computing land consumption rate

2.1.1 The concept of dynamic and functional city boundaries

In this example, we use a small section of the city X to demonstrate why adopting a functional city boundary is important to the indicator measurement. Hypothetical boundaries are created to explain the concept, which do not in any way represent any official boundaries in city X.

Figures 1 and 2 represent two hypothetical city boundary situations and the growth of city X in two time periods (***t1***, ***t2***). In both scenarios, the adopted assumption is that the presence of buildings is a good indicator of urbanness of an area – i.e., an area that is densely built up is likely to be urban, while a sparsely built up area is likely to represent rural settlements.

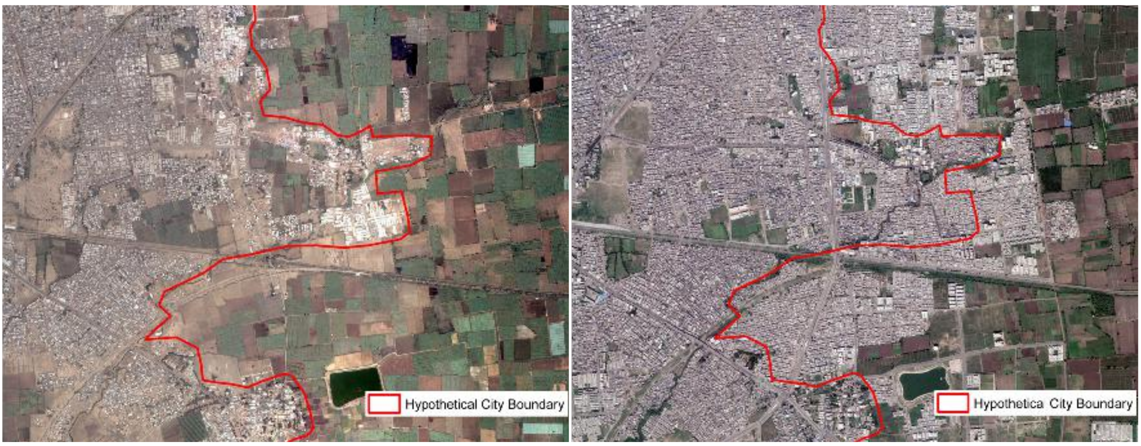


Figure 1: Boundary scenario 1

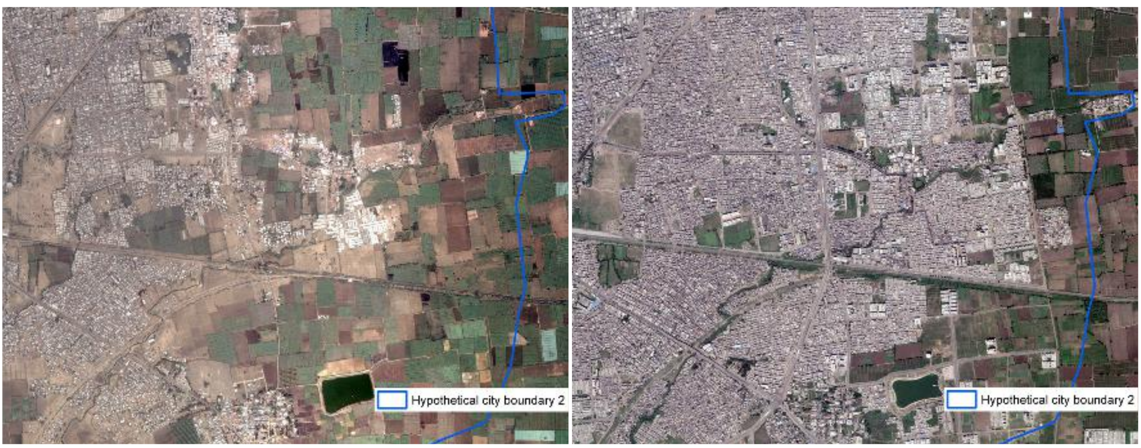


Figure 2: Boundary scenario 2

In scenario 1, the hypothetical boundary in ***t1*** captures most areas with an urban character (as defined by presence of buildings), while it leaves out a significant part of the urban area in ***t2***. In scenario 2, the hypothetical boundary in ***t1*** captures a large area whose character is rural in nature (as defined by presence of buildings based on the adopted assumption), which significantly reduces in ***t2***. Based on this, if we were to compute indicator 11.3.1 for city X using the hypothetical boundaries presented in scenarios 1 and 2, there will be some level of misrepresentation of the actual urban change trends in both cases.

To achieve accurate results thus, countries are highly advised to adopt the use of dynamic and functional city boundaries as proposed in the prevailing approaches to global city definition. By using these approaches, only areas which meet the urban thresholds for ***t1***, ***t2*** will be included in the indicator computation. This will produce results which represent the actual prevailing growth trends in the city, that can in turn produce accurate sub-national and national level aggregates, and inform better decision making and policies on sustainable urbanization at the local and national level in countries.

BOX 1

Based on surveys undertaken by UN-Habitat in 2018, it was observed that in many countries, there exists major variations between what is statistically identified as urban (the separation of enumeration areas into urban and rural as implemented by national statistical offices for census purposes), and what is officially defined as urban (as per existing municipal or city boundaries in the country). In almost all the surveyed countries, the classification of enumeration areas as either urban or rural changes over time, with rural units which meet certain population or density thresholds getting reclassified as urban units from one census cycle to the other.

In most countries however, these revisions barely inform the revision of municipal or city boundaries. In many cases, what is statistically delineated urban is much larger than what is officially (administratively) defined as urban. Matching the dynamic statistical classifications at the country level to the proposed global city definition approaches can offer good insights into the identification of functional city boundaries. This can in turn enhance the quality of data on indicator 11.3.1.

2.1.2 Measuring land consumption rate.

Using the example of city X, we will compute the rate of land consumption between ***t1*** (2000) and ***t2*** (2010). In this demonstration, we integrate the concept of dynamic and functional city boundaries as presented in section 2.1.1, in which the city size changes based on the character of each segment of the analysis area, in line with the adopted urban area definition thresholds. This way, the computation of urban change captures only areas which are actually urbanized in each measurement year.

For demonstration purposes, in this example we use visual interpretation of satellite imagery to illustrate how to measure urban change in city X. We retain the assumption made earlier that areas that are densely built up are urbanized, while sparsely built up areas are rural in nature. This assumption can be easily switched to reflect other approaches to city definition, such as use of enumeration areas or population grids that meet a certain population size or density threshold.

Below are the generic steps to follow in the computation of the land consumption for a given urban area consumes land

1. Identify the total urbanized area in ***t1*** for the analysis city. Total urbanized area in this case includes the entire spatial extent that meets the defined threshold of "urban" (as distinguished from "rural"). Annex 1 describes the GIS steps that can be followed to achieve this using both the urban extent and degree of urbanization approaches to city definition[1].
2. Identify the total urban area in ***t2*** for the area of interest (similar approach as in 1).
3. Compute the land consumption rate (LCR) using the formula

$$LCR = \frac{(LN(Urb_{(t2)}/Urb_{t1}))}{(y)}$$

Where:

Urb_{t1} is the total area covered by the urban area in the initial year ***t1***;

Urb_{t2} is the total area covered by the urban area in the final year ***t2***; and

y is the number of years between the two measurement periods (***t1*** and ***t2***)

The detailed steps to computing the land consumption rate are presented below. Hypothetical scenarios for city X are used to demonstrate the method.

1 This approach uses density of built up pixels to delineate urban from non-urban areas

Step 1: Define functional urban areas for each analysis year

By adopting the concept of dynamic city boundaries presented in part 2.1.1, define the urbanized areas for each analysis year. This should be implemented by analyzing the character of an area against the set urban thresholds. The two broad approaches that can be used include analysis of the built-up density of an area, or classification of small administrative or statistical units based on their character. In the first approach (fig 3), we use simple visual interpretation of satellite imagery to demonstrate the concept.

In the second approach (fig 4), we achieve the same

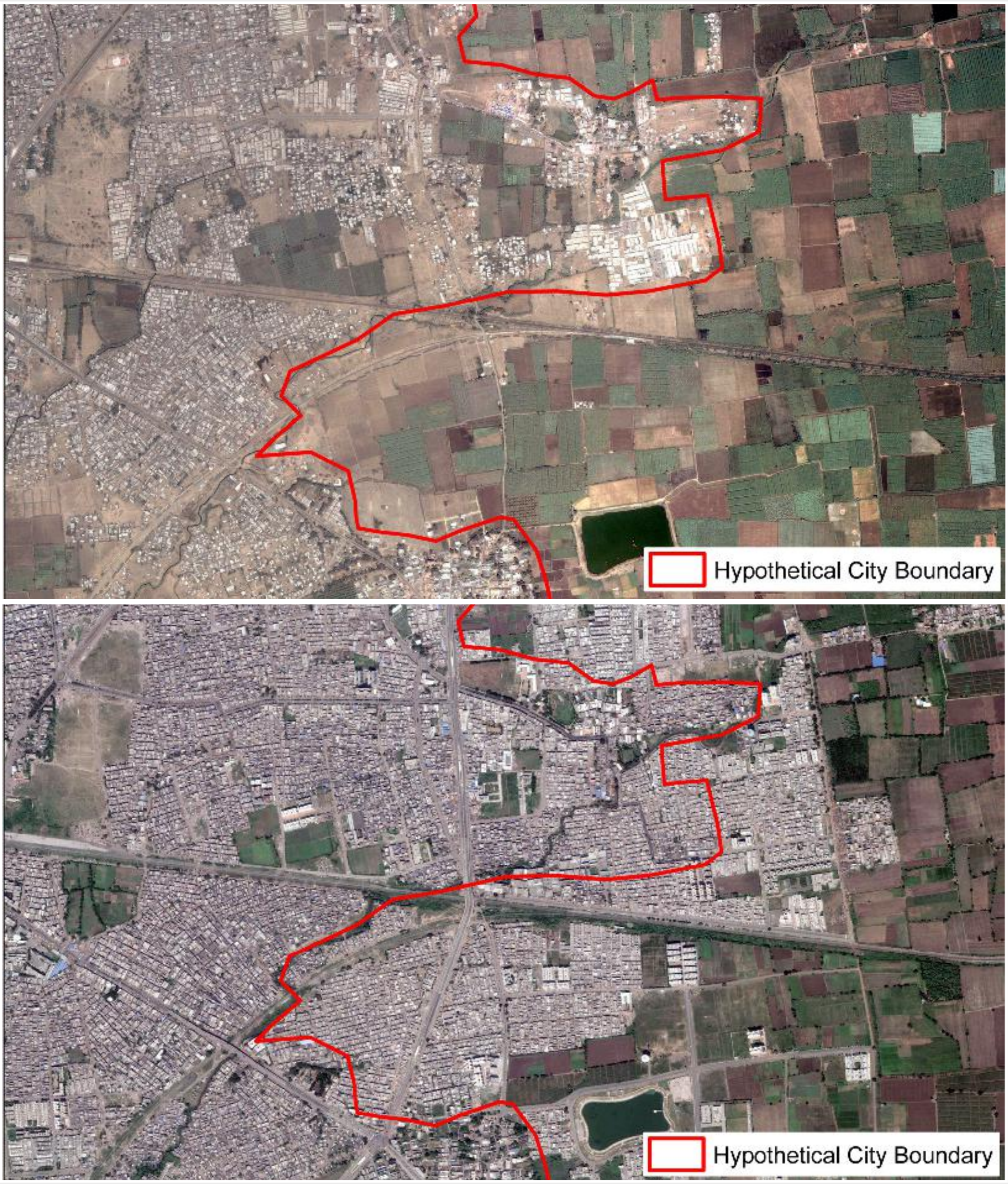


Figure 3: Hypothetical dynamic and functional city boundaries in city X – t1 and t2 based on built-up area density

outcome by classifying each small administrative as urban or rural based on high resolution census data or through creation of population grids which integrate population and built up area data. Both scenarios presented in figures 3 and 4 are meant to illustrate the underlying concept for the indicator computation, as opposed to different approaches to its computation. Annexes 1 present detailed steps on how to implement the first approach in GIS software. Methodological steps for implementation of the second approach will be presented as global guidelines become available from the European Commission / Joint research centres.

In both scenarios, there is a notable increase in the urbanized areas between ***t1*** and ***t2***.

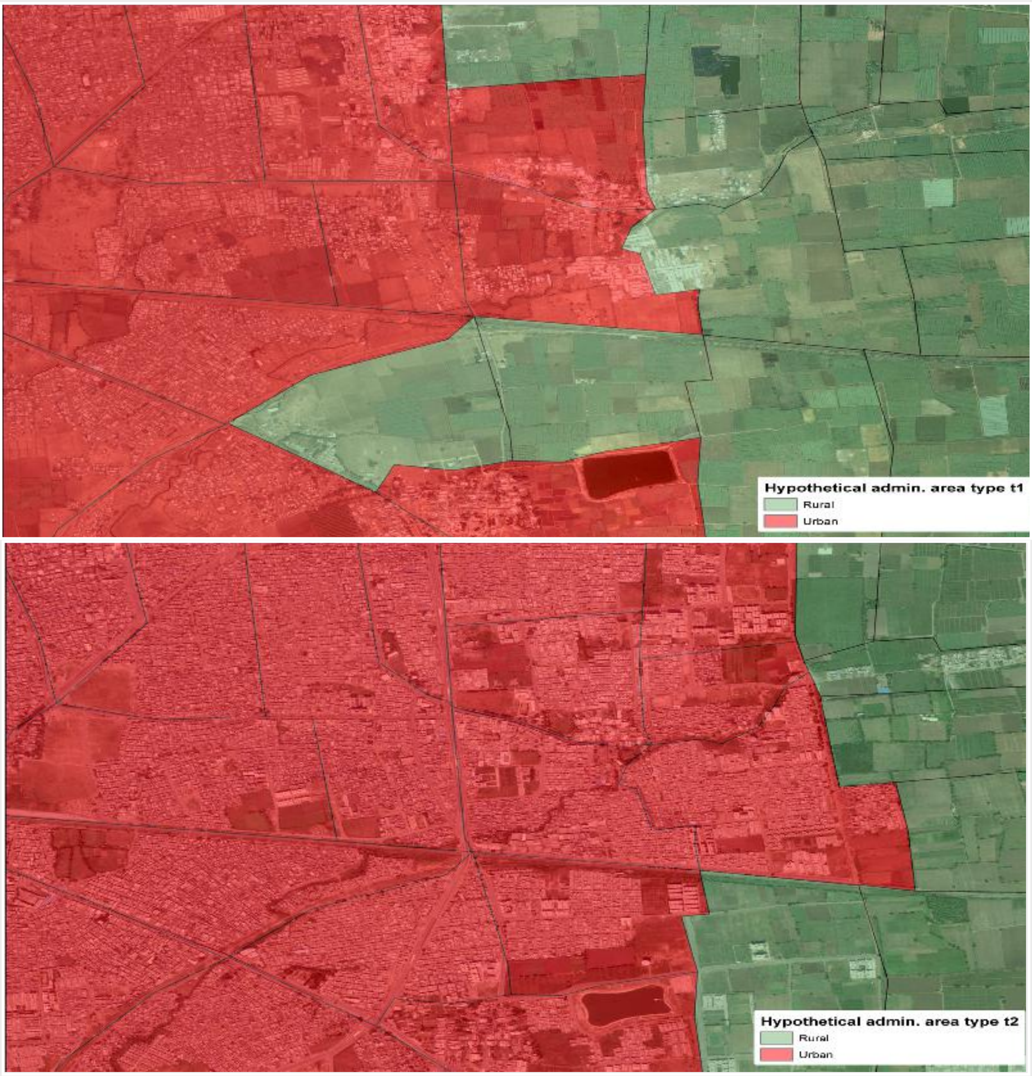


Figure 4: Hypothetical dynamic and functional city boundaries in city X – t1 and t2 based on classification of lowest level administrative units

Step 2: Calculate the size of the urbanized area in each analysis year.

After defining the urbanized area in each analysis year as per step 1, the area of the urban/city area can be calculated in GIS software (ArcMap, QGIS, etc). For city X, the urban areas in ***t1*** and ***t2*** can be explained as $\mathbf{Urb_{t1}}$ and $\mathbf{Urb_{t2}}$.

Step 3: Compute the land consumption rate

In our hypothetical example of city X, our computed urban extent area using the urban extent approach to city definition (fig 3) was 145km^2 in ***t1*** (2000), which increased to 180km^2 in ***t2*** (2010). The land consumption rate is thus computed from these values using the formula below.

$$LCR = \frac{(LN(Urb_{(t2)}/Urb_{t1})}{(y)}$$

$\mathbf{Urb_{t1} = 145\ Km^2}$

$\mathbf{Urb_{t2} = 180\ Km^2}$

$\mathbf{y = 10}$

$$\textbf{Thus;} \quad LRC = \frac{LN\ (180\ /\ 145)}{10}$$

$$= 0.02162$$

NB; This can easily be calculated in Ms Excel using the formula

From the computation above, between 2000 and 2010, city X appropriated land from other uses to urban use at an annual rate of 2.16%.

For this indicator, it is recommended to consider analysis periods with intervals of 5 or more years. Based on pilots undertaken by UN-Habitat, shorter time intervals do not produce significantly different results, unless such analysis is undertaken using high resolution (and often costly) satellite imagery. Due to the richness of open source imagery from the Landsat missions (1975 to date), historical analysis of changing urban growth trends and how these affect sustainable development can be achieved for most countries.

Year 2000

Year 2010

The red circle shows how the urban settlement has changed within years 2000 and 2010 as depicted by the two images above .

2.2 Computing population growth rate

Once the urbanized areas have been defined, the next step is to establish how many people live within those areas for each analysis year. This information is then used to compute the annualized population growth rate.

The estimation of the number of people living within each service area can be achieved through two broad approaches;

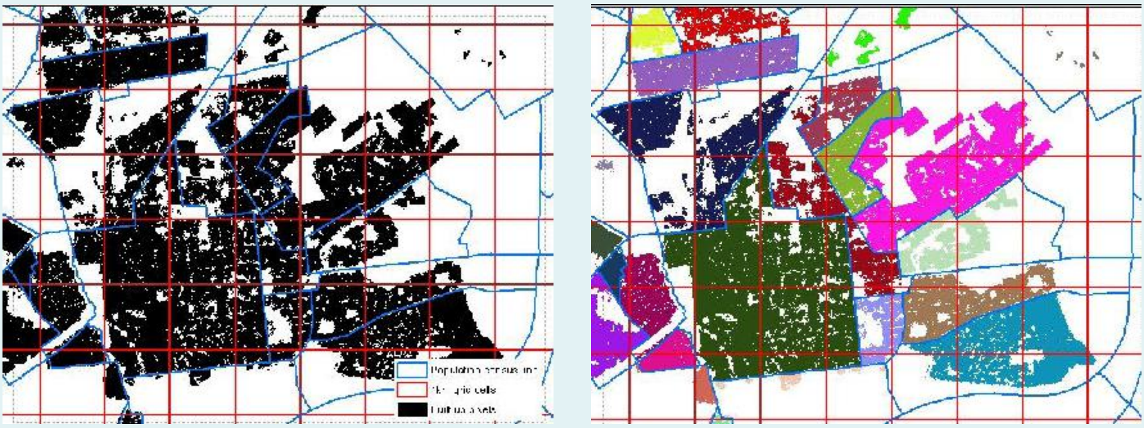
1. Use of high-resolution data from national statistical offices (NSOs) In this option, census data is used to aggregate the number of people living in all households within the urban boundaries. Projections and extrapolations can also be easily undertaken based on the household characteristics to particular reporting years. The process is much easier where dynamic census units are used to identify the urbanized area, particularly because these are well aligned with the official population data architecture. This option provides the most accurate and authoritative population data for the indicator computation and is highly encouraged.

2. Use of gridded population In this option, a population grid is made by distributing population to the entire administrative or census area unit. Attributes such as presence of habitable areas (land use classes) can be used to distribute the population, such that grid cells in tracks of undeveloped land or in industrial areas will have less population than high density residential areas. In the resulting grid, each grid cell will have a unique value, which is dependent on factors such as the total population within the enclosing administrative/census unit, and the number and/or quantity of the habitable land use classes. Figure 5 illustrates the general logic of population grids using only one land use class – the built-up areas. The population grid should always cover an area larger than the defined urban boundaries. Once the population grids are created, estimation of the population living within the urban boundaries can then be achieved by aggregating populations of the enclosed grid cells. In the absence of high-resolution data from NSOs, this option produces better estimates for population, although high quality input data and multi-level analysis are essential for enhanced data accuracy. Global datasets representing populations at 1km and 250m grids are available (e.gs GPWv4, GHS-POP, WorldPop); most of which assume equal distribution of population to the habitable classes (e.g built up areas). This approach is proposed for the indicator computation where high resolution data from national statistical offices is not available or readily accessible.

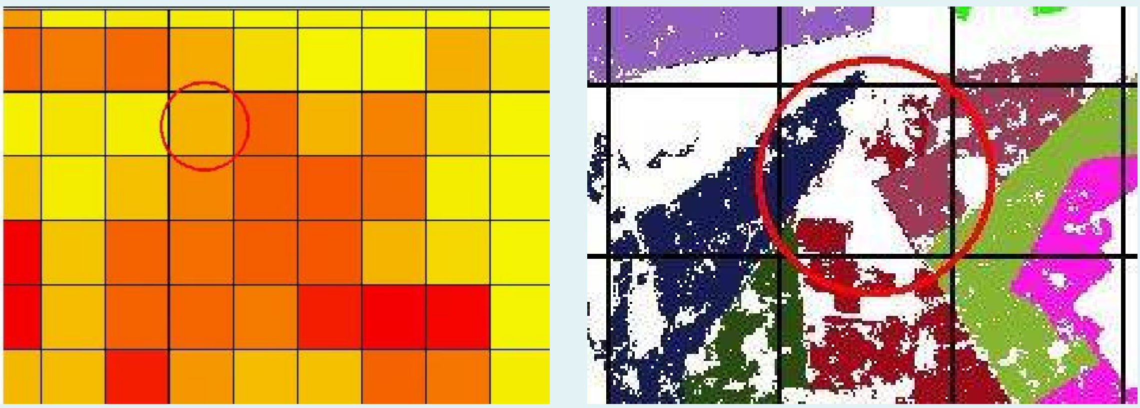
A third approach that can be used to estimate population within the urban boundaries is one that adopts population density variables. In this option, density measures, which mimic conventional population density measurement (population devided by area) are used to estimate the number of people within the delineated urban boundaries. This approach results in huge generalizations about the population distribution, often assuming that large tracks of undeveloped land are habited. It is thus not recommended for the indicator computation.

Once the number of people living within the urban

Figure 5: Generic approach to creation of population grids



Left: Land use class data is overlaid with population data at the lowest unit; **Right** Dasymetric mapping techniques are used to re-allocate population to every habitable land use class cell (in this case built up pixels within the same population enumeration area share a single value based on the assumption that population is equally distributed)



Cell population is aggregated to a reasonable grid cell (1km² in this case). Each grid cell has habited and non-habited pixels and a single value that represents either the total population or the population density.

boundaries has been established using one of the two recommended methods above, the next step is to compute the population growth rate (PGR) component of indicator 11.3.1. This is implemented through the formula below:

$$PGR = \frac{(LN(Pop_{(t2)}/Pop_{(t1)}))}{(y)}$$

Where

Pop_{t1} is the total population within the urban area in ***t1*** (initial year)

Pop_{t2} is the total population within the urban area in ***t2*** (final year)

y is the number of years between the two measurement periods.

In our example of city X, let us assume that there was a total of 800,000 people living in the urban area in ***t1***, which increased to 1,000,000 people in ***t2***. The annual population growth rate for the city between the two years - 2000 to 2010 will be thus computed as follows:

Pop_{t2} = 1,000,000

Pop_{t1} = 800,000

y = 10

Thus;

$$LRC = \frac{LN\ (1{,}000{,}000\ /\ 800{,}000)}{10}$$

= 0.02231

NB; This can easily be calculated in Ms Excel using the formula ==LN(1000000/800000)/10)

In our hypothetical city X case, the population increased at an annual rate of 2.23% between 2000 and 2010.

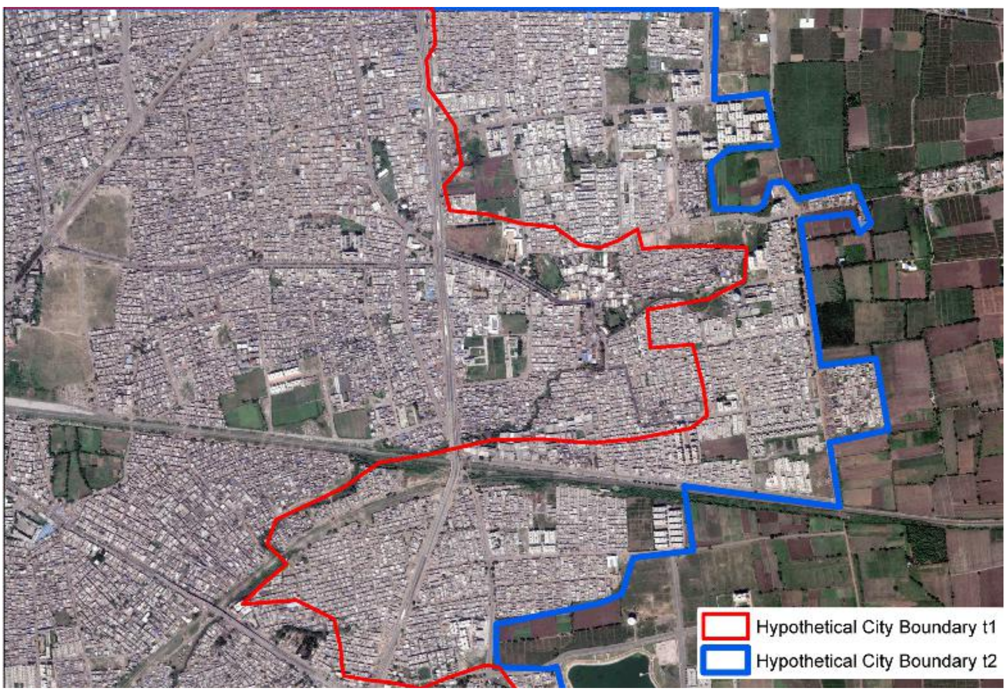


Illustration showing a comparison between the hypothetical boundaries during *t1* and *t2*

2.3 Final Indicator computation, interpretation and recommended secondary indicators

2.3.1. Computation and interpretation of Indicator 11.3.1

The final indicator, land consumption rate to population growth rate (LCRPGR), is computed by dividing the calculated land consumption and population growth rates;

$$LCRPGR = \frac{(\text{Annual Land Consumption rate})}{(\text{Annual Population growth rate})}$$

When all factors are held constant, a city that is compact in nature is likely to be more functional, because activities and services are close to the people, making such a city both walkable and one where the cost of infrastructure development and provision of basic services is lower. This city equally preserves and/or conserves outlying land for other purposes, with overall positive impacts to the environment. For such a city, the value of LCRPGR should be less than one.

On the other hand, a city that appropriates land outwards every time the population increases faces the challenges related to sprawl, such as high costs of infrastructure development, reliance of motorized transport (translating to traffic congestion), and environmental degradation.

In our hypothetical case of city X, the LCRPGR is computed as follows;

LCR = 0.02162

PGR = 0.02231

Therefore;

$$\text{LCRPGR for City X} = \frac{0.02162}{0.02231}$$

$$= 0.96899$$

Following the above generic interpretation, between 2000 and 2010, the LCRPGR for city X was almost equal to 1, suggesting that the rate at which the city appropriated land from other uses to urbanized functions was almost equal to the rate at which its population grew. In other words, as population grew in city X over the analysis period, there was an almost equivalent increase in new developments around the city.

Table 1 summarizes the inputs used in the computation of LCRPGR for city x.

Table 1: Required inputs for computation of LCRPGR

	t1 (2000)	t2 (2010)	Annualized change t1 - t2 (2000 - 2010)
Urban area (km^2)	120	180	0.02162 (LCR)
Population	800,000	1,000,000	0.02231 (PGR)
		LCRPGR	0.96899

2.3.2. Computation of secondary indicators

In real life human settlement structures, there are many factors at play, that make it more difficult to generalize the implication of a single LCRPGR value to sustainable urbanization. For example, while a value less than 1 could be a good indicator of urban compactness and its associated benefits, intra-city analysis may reveal high levels of congestion and poor living environments, which is against the principles of sustainable development. This thus calls for integration of secondary indicators to help explain the actual growth patterns.

Such has been a subject of discussion among urban experts, who collectively agree that incorporation of secondary measurements to indicators 11.3.1 will be most valuable to cities. For example, Corbane et al (2017) have identified that a single value for LCRPGR is likely to miss areas where a city's built up mass gets reduced when a disaster occurs. Equally, as highlighted earlier, urban areas grow in different ways – through infill, extension, leapfrogging and inclusion. Each of these patterns is unique, and appreciating the variation can result in more informed decision making. As a result, UN-Habitat recommends that countries should collect data on 2 secondary indicators to help them get a complete picture of urban expansion patterns: land consumption per capita and total change in urban infill (Urban densification).

a) Land consumption per capita

Land consumption per capita represents the average amount of land each person in a city consumes/occupies during each analysis year.

The computation of this secondary indicator uses two inputs – the *built up area mass*, and the *urban population* – both of which are generated during the core indicator computation (See section 2.1.2 and Annex 1). In practice, the land consumption per capita (LCPC) is computed by dividing the total built up area within the urban boundaries by the total urban population within the same boundaries as defined in section 2.2 using the formula below:

$$LCPC_{t1} = \frac{UrBu_{t1}}{Pop_{t1}}$$

Where

$UrBu_{t1}$ is the total built up area within the defined ***t1*** urban boundaries

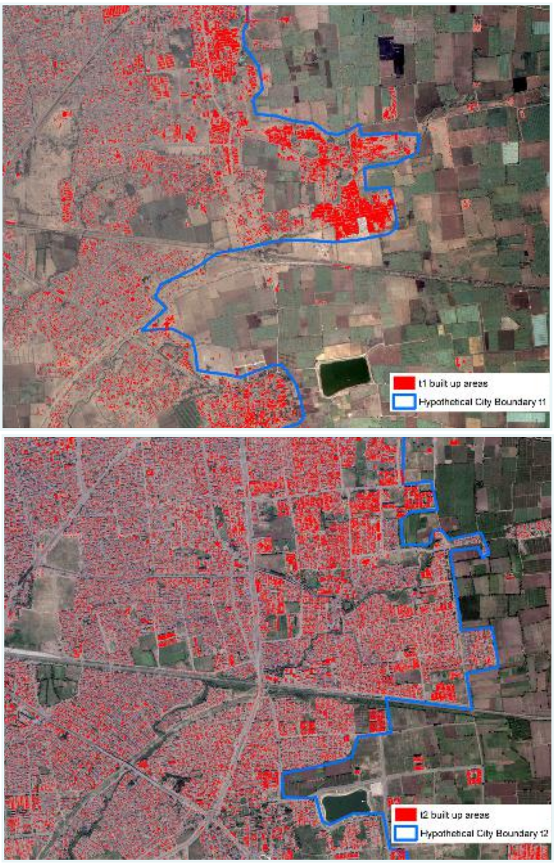
Pop_{t1} is the total population within the ***t1*** urban boundaries

Using results from this analysis, the percentage change in land consumption per capita between analysis years can be measured using the formula below;

$$\%\ \text{Change in } LCPC_{(t1-t2)} = \frac{LCPC_{t2} - LCPC_{t1}}{LCPC_{t1}} \times 100$$

In our example of city X, using the dynamic boundaries we created in section 2.1.2 (figures 3 and 4), we can extract the built up areas for both ***t1*** and ***t2*** through different image classification methods in GIS and/or remote sensing software. Figure 6 illustrates an extraction of the built up areas for city X.

Figure 6: Built up areas in t1 and t2



NOTE: The built-up area is always smaller than the total urban area because it excludes other urbanized land uses e.g. open spaces, areas covered by water etc.

Assuming that that a total of 100sq km (100,000,000m^2) of land was built up in ***t1***, which increased to 150sq km (150,000,000m^2) in ***t2***, the land consumption per capita for city X at periods ***t1*** and ***t2*** will be:

*Land consumption per capita **t1** (2000)*
= 100Km² / 800,000 = 125 m²/person

*Land consumption per capita **t2** (2010)*
= 150Km² / 100,000 = 150 m²/person

Table 2: Summary of the inputs for computation of land consumption per capita

Table 2: LC per capita for city X between 2000 and 2010.

	2000	2010	Percentage change LCPC between 2000 and 2010
Built up area (km^2)	100	150	
Population	800,000	100000	
LC per capita (m^2/ person)	125	150	20%

This implies that in city X, there was a 20% average increase in the amount of space occupied by each person between 2000 and 2010. For a city that is moving towards compactness, the land consumption per capita value will be on a declining trend, while it will be on an increase for a sprawling city. To illustrate this, let us take the example of an island city like Singapore, where the population is consistently growing, yet very little land is available for expansion. Since we are measuring the built-up areas footprints (as opposed to vertical expansion of buildings), Singapore will record a declining land consumption per capita between ***t1*** and ***t2***. On the other hand, if we take the example of a city like Nairobi, Kenya, whose outwards expansion is not restricted by lack of developable land or policy restrictions, and where land is cheaper in outlying suburbs, the value of land consumption per capita will increase as more developments come up beyond the core city area – which is a good indicator of a sprawling city.

b) Total change in urban infill (Urban Densification)

Another secondary indicator that can help explain urban growth patterns is the percentage change in urban infill, which measures how much a city is densifying over time (how many new developments emerge between ***t1*** and ***t2*** within the ***t1*** urban boundaries). Figure 7 illustrates the change in built up area between 2000 and 2010 for city X. The yellow features show the areas that were built up in 2000 (***t1***), and the red features show the new areas that were newly built between 2000 and 2010 (***t2***). A combination of the yellow and red features constitutes the total built up areas in city X in 2010 (***t2***)

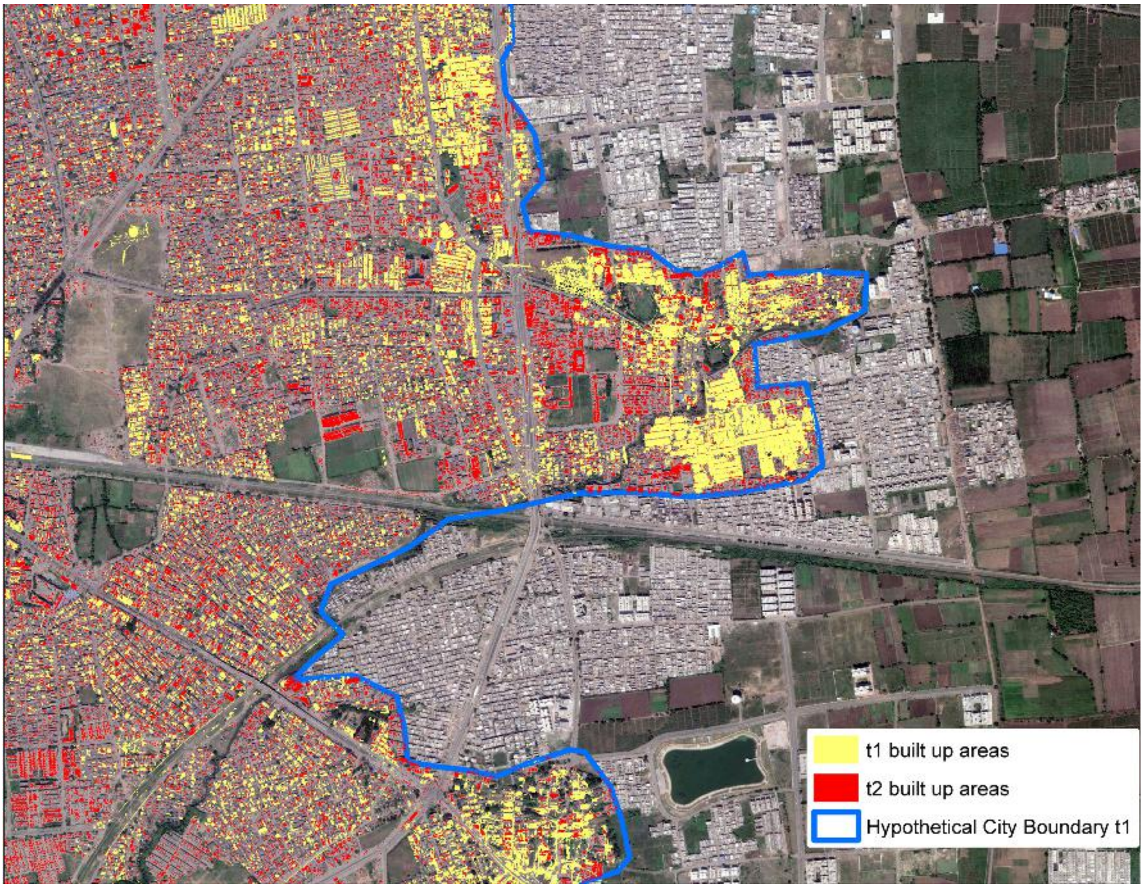


Figure 7: Infill developments for city X between 2000 and 2010

The percentage change in urban infill (densification) is computed as;

$$\frac{\text{Total built up area in } \boldsymbol{t2} \text{ within t1 urban boundaries - Total built up areas in } \boldsymbol{t1}}{\text{Total built up areas in } \boldsymbol{t1} \text{ within the boundaries}} \times 100$$

(Only built up areas within t1 boundaries are measured in both cases)

In addition to showing the percentage urban infill, this secondary indicator can help countries understand when a city losses part of its built up land (negative values from the above computation), as well as identify where dense and informal settlements are developing.

In our City X example, lets assume that 100km^2 of land was occupied by built up areas in 2000, and that the total built up area in 2010 within the 2000 urban boundaries increased to 120km^2. The percentage urban infill for city x will be 20%.

Table 3 below summarizes the inputs required for computation of the percentage change of urban infill.

Table 3: Percentage change in urban infill

	2000	2010	% Change in urban infill 2000 - 2010
Built up area (km^2)	100	120	20%

Interpretation of these two secondary indicators against the LCRPGR value provides a wholistic picture of the urban growth trends in the city, and in turn supports more informed decision making towards sustainable urbanization. Since the two secondary indicators rely on the same input data used for computation of the core indicator, their computation will not add much workload to the national statistical offices and other agencies involved in the indicator computation; yet the value of the resulting data will be very significant for enhanced understanding of urban trends.

BOX 2

Conservation International in collaboration with NASA, with inputs from UN-Habitat have developed a tool that helps compute indicator 11.3.1 using open source Q-GIS platform. The tool is available at *http://trends.earth/docs/en/training/tutorial_compute_urban_indicator.html* and is currently being piloted and refined for global applicability

BOX 3 Monitoring SDG 11.3.1 with the Global Human Settlement Layer

The Global Human Settlement Layer[1] (GHSL) project produces reliable, open and free information on the presence of buildings and population. Resident population and built-up areas maps as well as a settlement typology maps according to the *Degree of Urbanisation*[2] definition are available for 1975-1990-2000-2015. They are produced in a geographical and thematically consistent way to allow change analysis. The *Degree of Urbanisation* is the basis for a global definition of cities and rural areas[3]. Applied to the GHSL data, this definition identifies about 10,000 urban centres across the globe for the year 2015.

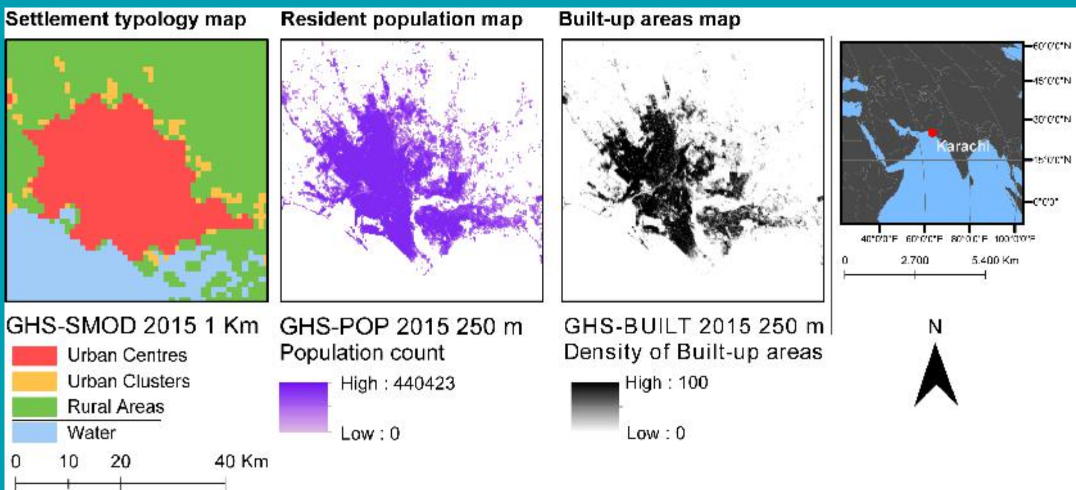


Figure 1. Example of GHSL data, three geospatial layers that map settlement typologies (GHS-SMOD), resident population (GHS-POP), and built-up areas (GHS-BUILT) displayed in the area of Karachi, Pakistan.

The statistics derived from the settlement classification are summarised in *Country Fact Sheets*[4] for about 220 countries and territories. The fact sheets propose national statistics on built-up areas and population for the 4 epochs, maps displaying the delineation of the capital city or a first tier settlement, and a list of cities with related statistics. Information for the year 2015 directly forms a baseline data for the year 0 of the SDG monitoring framework.

In addition to the fact sheets, the GHSL Urban Centre Database (GHS-UCDB)[5] published in 2019 provides new open data supporting the monitoring of Sustainable Development Goals, the New Urban Agenda and the Sendai Framework for Disaster Risk Reduction at city level. The database contains a specific variable for all the 10,000 plus cities to estimate the SDG 11.3.1 (Ratio of Land Consumption Rate to Population Growth Rate). The indicator is currently calculated for the period 1990 – 2015 following the UN-Habitat metadata[6] with a replicable methodology[7]. The GHSL baseline data support the SDG 11.3.1 calculation at a city level with the following information:

- The area in which the indicator is estimated is the extent of the urban centre in 2015 (GHS-SMOD);
- The *Land Consumption Rate* is calculated from the built-up areas detected in the epoch 1990 and 2015 in the GHS-BUILT 1990 and GHS-BUILT 2015;
- The *Population Growth Rate* is calculated from the population estimated in the epoch 1990 and 2015 in the GHS-POP 1990 and GHS-POP 2015.

The above data sets are available in tabular form in the GHS-UCDB baseline statistics (using the statistical tabular dataset prepared at JRC), or can be used in a Geographic Information System (GIS) using the corresponding 1 km GHSL geospatial layers[8]. The GHSL suite also includes five tools[9] to provide new spatial data mining technologies for the automatic processing, analytics and knowledge extraction. With a compatible population grid and built-up layer, the user can deploy the DUG Tool to apply the *Degree of Urbanisation* to its layers to map urban centres, urban clusters and rural areas (urban areas as the union of clusters and centres). Further, with the built-up layers, the population layers and the delineation of urban areas the user can run the LUE Tool that outputs the land use efficiency value per grid cell.

In the case of Karachi below, the substantial population growth over time and the moderate change in built-up areas result in a Land Use Efficiency value of 0.4, whereas the rate of population growth has been higher than that of built-up areas.

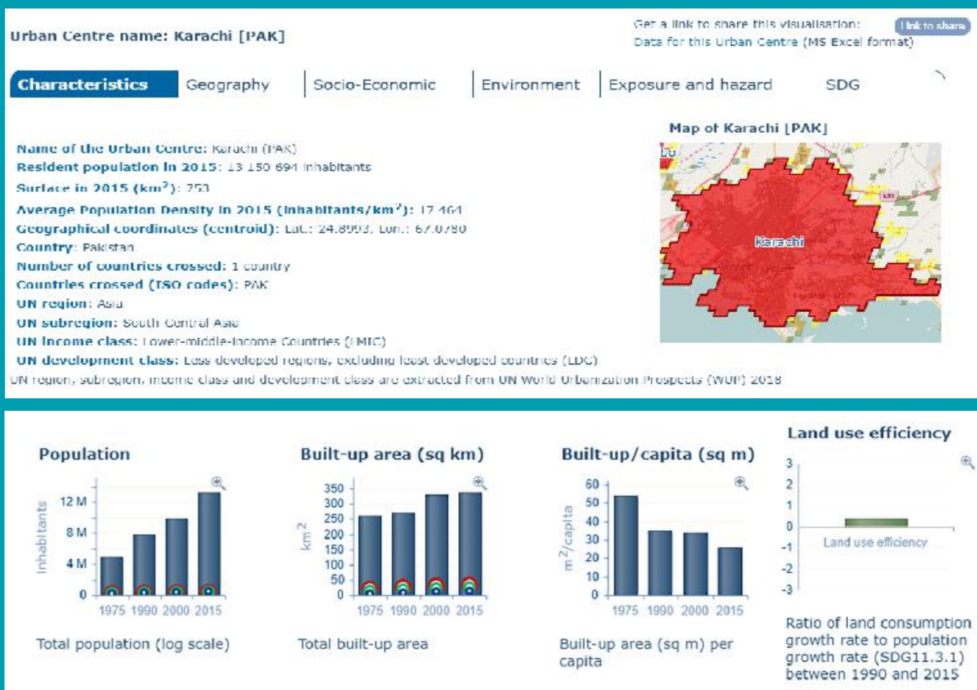


Figure 2. Extract of the GHS-UCDB web version showing the characteristics of the urban centre (and its extent), socio-economic variables (population, built-up area and built-up area per capita) and SDG (Land Use Efficiency) in Karachi urban centre. The full city profile is at: https://ghsl.jrc.ec.europa.eu/ucdb2018visual.php#HDC=6169
Source: Florczyk, A.J., Corbane, C., Schiavina, M., Pesaresi, M., Maffenini, L., Melchiorri, M., Politis, P., Sabo, F., Freire, S., Ehrlich, D., Kemper, T., Tommasi, P., Airaghi, D. and L. Zanchetta. 2019. GHS Urban Centre Database 2015, multitemporal and multidimensional attributes, R2019A. European Commission, Joint Research Centre (JRC) [Data-set] PID: https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e © European Commission 2019

Endnotes
1 *https://ghsl.jrc.ec.europa.eu/*
2 *https://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf*
3 *The global definition of cities and rural areas is currently discussed at the UN Statistical Commission and is supported by the EU, UN-HABITAT, FAO, OECD, World Bank and ILO.*
4 *https://ghsl.jrc.ec.europa.eu/CFS.php*
5 *https://ghsl.jrc.ec.europa.eu/ucdb2018Overview.php*
6 *https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf*
7 *https://www.mdpi.com/2220-9964/8/2/96*
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3. ANNEX 1

DEFINING URBAN EXTENT BOUNDARIES USING BUILT-UP AREA CHARACTER

Version 1: Workflow implementation in ArcMap

Disclaimer:

- This manual assumes that users have limited knowledge in ArcMap workflows – advanced and more automated processes can be adopted at each step
- For ease of implementation, single land use attributes are used in this manual. Method can be implemented at various stages incorporating various land use classes.
- Some processes are repetitive and can be resolved through a batch processing syntax that is available for advanced users. A basic ArcMap model depicting the presented process is annexed to this document.

Part 1: Data Preparation

1. Access image availability & quality and download (safe to use census years where possible) – The coverage of image should be larger than core city area for each analysis year
2. Undertake supervised image classification – include classes on built-up, open spaces (forests, green areas, bare land, etc), water, etc
3. Check classification accuracy and clean accordingly

Part 2: Built Up Area Analysis

4. Reclassify supervised classification file to extract only built up pixels – *ArcToolbox> Spatial Analyst Tools > Reclass > Reclassify.* The next steps are based on the output file from this process
5. Compute focal statistics (SUM) to determine density of built up area per square kilometer

a). *ArcToolbox> Spatial Analyst Tools > Neighbourhood > Focal statistics.* To compute how many built up cells are within one square kilometer circle of a determinant cell, we will use the following as input (see fig 1)

i). Input raster – the built up areas raster layer

ii). Output raster – determine location and name

iii). Neighbourhood – Circle

iv). Neighbourhood settings – select map and input radius of 564 (if cell is the preferred option, divide 564 by cell size to know how many cells fit within this radius)

v). Statistics Type – select SUM

vi). On ignore NoData in calculations – determine based on your preference. Default is box ticked

vii). You can define processing environments if necessary

viii). Click ok

ix). Your output should resemble what is presented in figure 2

Figure 1: Focal statistics analysis inputs

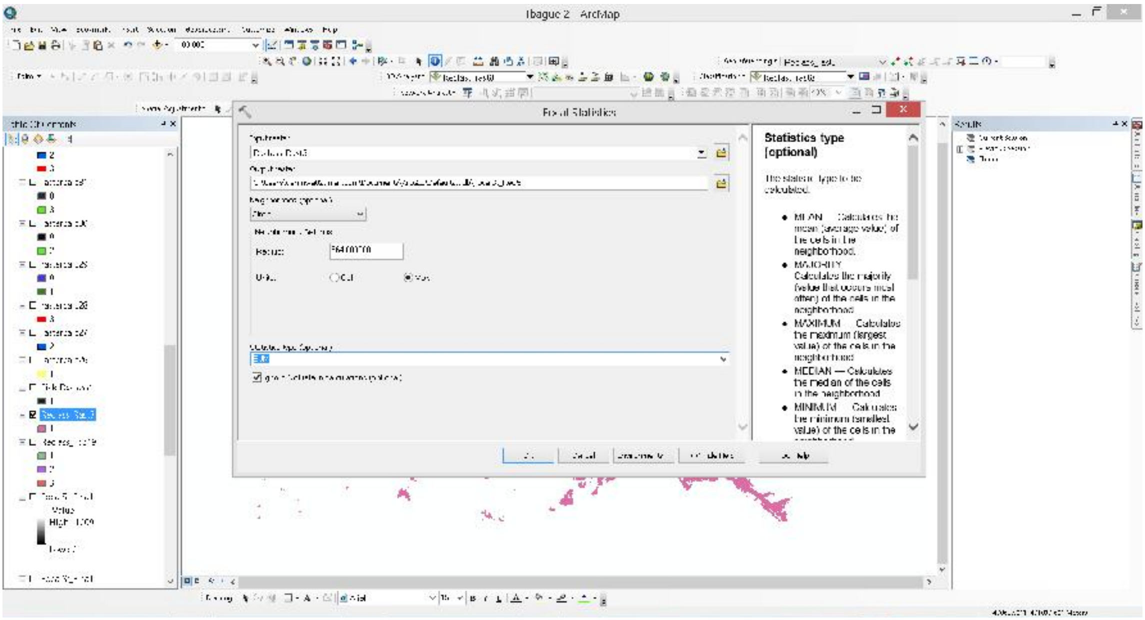
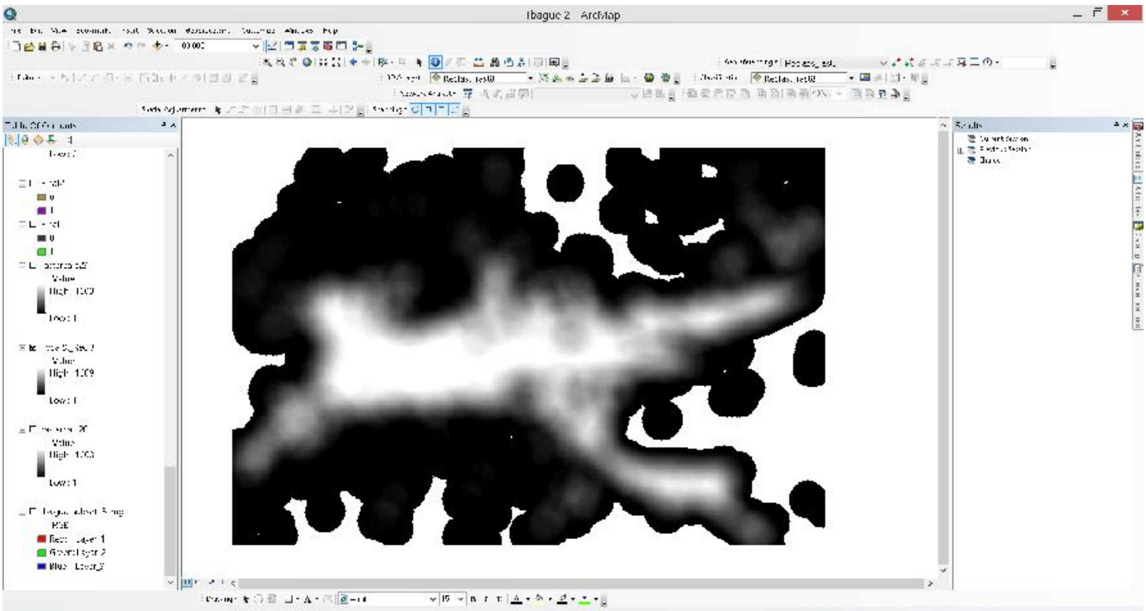


Figure 2: Sample focal statistics analysis output



The default color ramp uses black and white classes – for which bright white represents the highest density of built up areas and black the least dense areas

6. Reclassify the focal statistics output to determine the urbaneness of each zone based on the built-up area density per square kilometer. This is based on the value assigned to each focal statistics class and determined by pixel size of the original image. For example

   a). Assuming your image has a resolution of 30x30 m, a circle of 1km^2 will contain about 1,111 pixels (1,000,000 / 900)

   b). The adopted classifications are: urban area > 50% of pixels around each cell are built up; sub-urban area – 25-50% of pixels are built up ; rural area - < 25% of surrounding pixels are built up. Based on this, the pixel thresholds for each built-up class are as follows

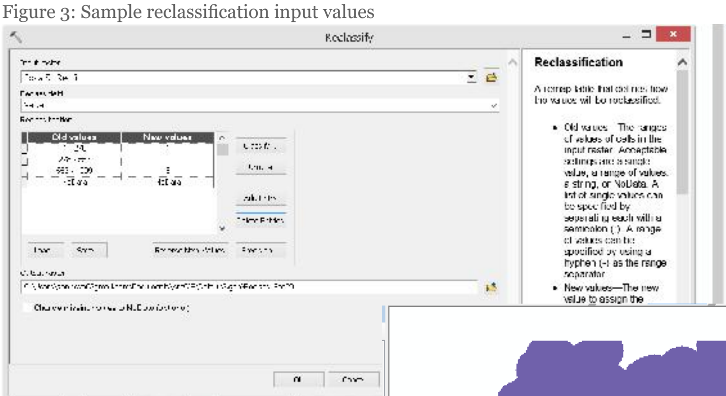
      i). Urban built up areas – 0.5 * 1,111 = > 556 pixels

      ii). Sub-urban built up areas = 0.25 * 1,111 = 278 to 556 pixels

      iii). Rural built up areas = < 278 pixels

   c). Figure 3 presents a sample reclassification under this step. Figure 4 represents the output from this process (you can define the 3 classes by clicking on the “classify” tab in the reclassify window.

Figure 3: Sample reclassification input values



Notice the three tier banding based on urban, sub-urban and rural values computed during the focal statistics step (Orange = urban, green = sub-urban, blue = rural)

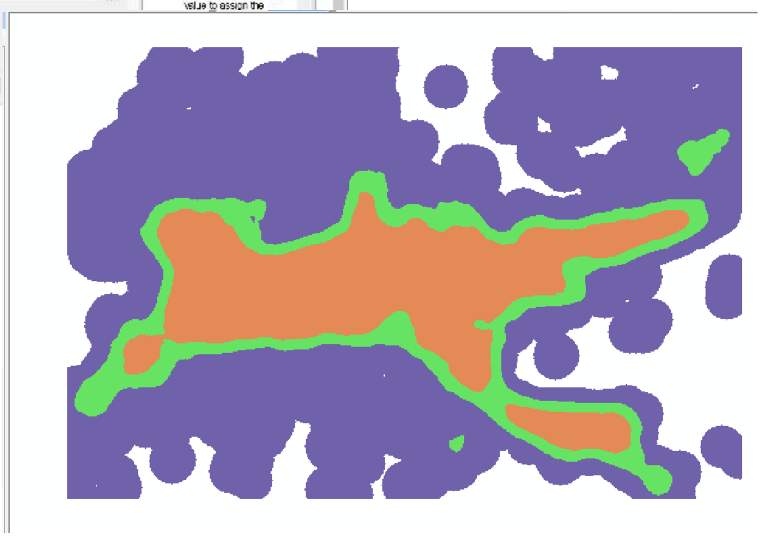


Figure 4: Sample reclassification output (in default colors)

Part 3: Ingesting urban-ness values to built-up pixels

In this part, we transfer the settlement character values (urban, peri-urban, rural area values computed from part 2) to the original built up area layer generated in step 4. Here, we use logical expression "Combinational And"

7. Open ArcToolbox > Spatial Analyst Tools > Math > Logical> Combinatorial And

8. Select reclassified focal statistics output under step 6 as "Input 1" and original built up layer from step 4 as "Input 2"

9. Click Ok to run. The output will contain three layers indicating the urbaneness of each pixel - See figure 5

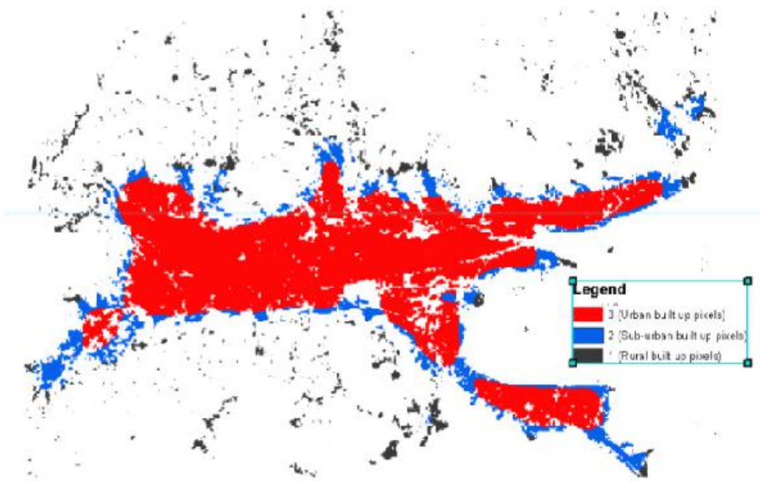


Figure 5: Sample output showing urbaneness of individual pixels

Part 4: Defining Fringe Open Spaces

The method described in this document uses urban and sub-urban built up pixels to determine city/urban boundaries (see detailed explanations at the atlas of urban expansion initiative). In this part, we will use only the urban and sub-urban built up pixels to determine the fringe open spaces – which are defined as the areas within 100 meters of urban and sub-urban pixels. Follow the following steps to define the fringe open spaces

10. Reclassify final output from part 3 to remove rural pixels through ArcToolbox> Spatial Analyst Tools > Reclass > Reclassify. Define the new value associated with the rural class (e.g 1) as NoData

11. Buffer the resulting urban and sub-urban pixels to 100 m to define the fringe open spaces. This is implemented using Euclidean distance tool - ArcToolbox > Spatial Analyst Tools > Distance > Euclidean distance. Use the following inputs

a). Input raster = output raster from step 10 above

b). Define output distance name and location to save

c). Maximum distance = 100 (represents the 100 m area of influence for fringe spaces) d). Output Cell Size = same as the original image used for the analysis area (e.g 30m, 15m, etc)

e). Leave output direction raster unless you want to orient buffer to a certain direction

f). Click ok. Output will look like the illustration in figure 6

12. Reclassify the result to attain a single value for all Euclidean distance buffers –see figure 7

13. Merge urban and sub-urban pixels layer from step 10 with merged Euclidean distance buffer file from step 12. Here you will need to define the null values for both files to make it possible to perform raster addition

a). To define null values for two raster outputs, open ArcToolbox > Spatial Analyst Tools >

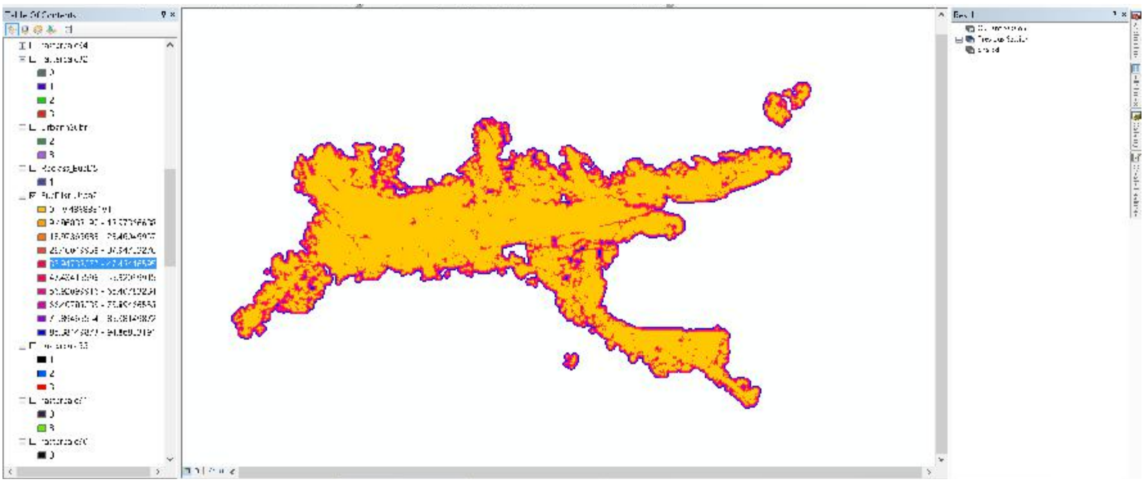


Figure 6: Sample output from Euclidean distance buffering

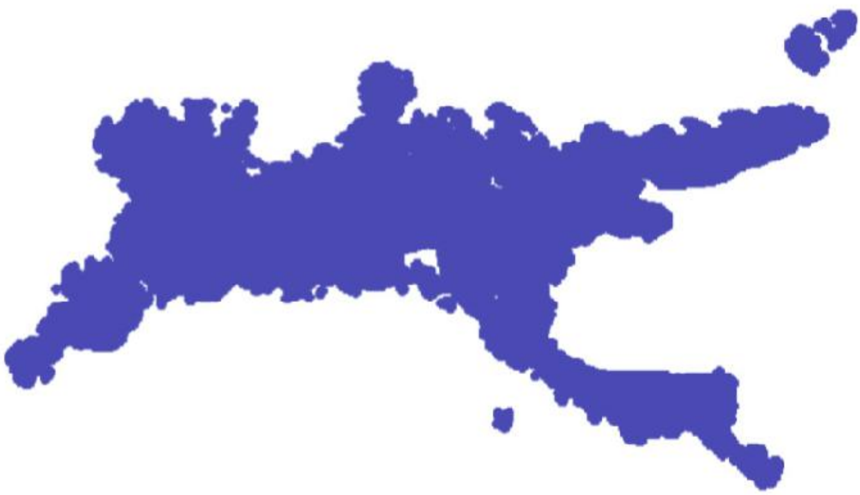


Figure 7: Reclassified Euclidean distance output file

Map Algebra > Raster Calculator > enter the syntax below and click OK

Con(IsNull("name of built up pixels file from step 10"),0,"name of built up pixels file from step 10")

b). Repeat the process and input the output raster from step 12 in the space for "name of raster file"

14. Merge the two outputs from step 13 by adding the files in raster calculator using the (+) function

a). The output has 4 data layers – a) urban built up pixels, b) sub-urban pixels, c) Euclidean distance values, and d) null values. The Euclidean distance values surround both urban and sub-urban pixels and constitute fringe open spaces

15. Set Null value to zero so you are left with only the urban, sub-urban and the fringe open space pixels using the syntax below

SetNull("output file from step 14" ==0, "output file from step 14")

(The output from this step is one of the required outputs for the computation of indicator 11.3.1)

Part 5: Defining Urban Extent Boundaries

16. The input in this step is the final output from step 15

17. Merge the three classes from step 15 into one using reclassify tool

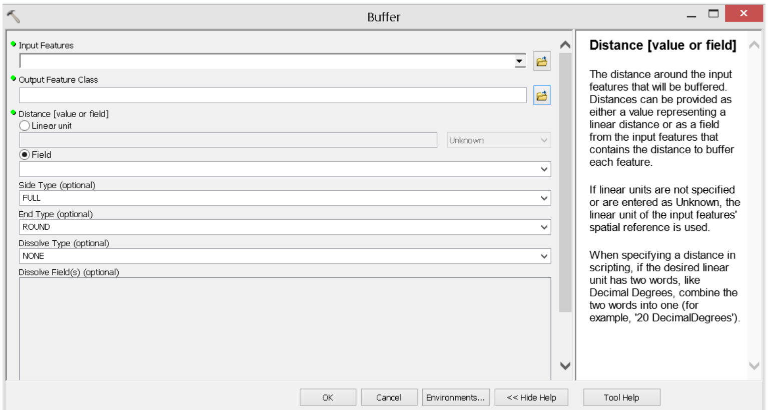
18. Convert the output file from step 17 from raster to polygon (allow for multi-polygons)

19. Calculate the area of each of the resultant polygons using the geometry tool available from the file attribute table

20. Buffer each polygon feature to 25% of its area

a). Create a field in which to calculate area equivalent to 1.25 of the area computed in 19 above (you can achieve this in raster calculator)

b). Buffer each polygon BY FIELD – using the new area as the input buffer feature – *ArcToolbox > Analysis Tools > Proximity > Buffer*



21. Any polygons that intersect from the output file are included as part of the urban extent, otherwise they are excluded – see figure 10. A model for the entire process is presented as annex 2
22. Use this extent to compute indicators as required

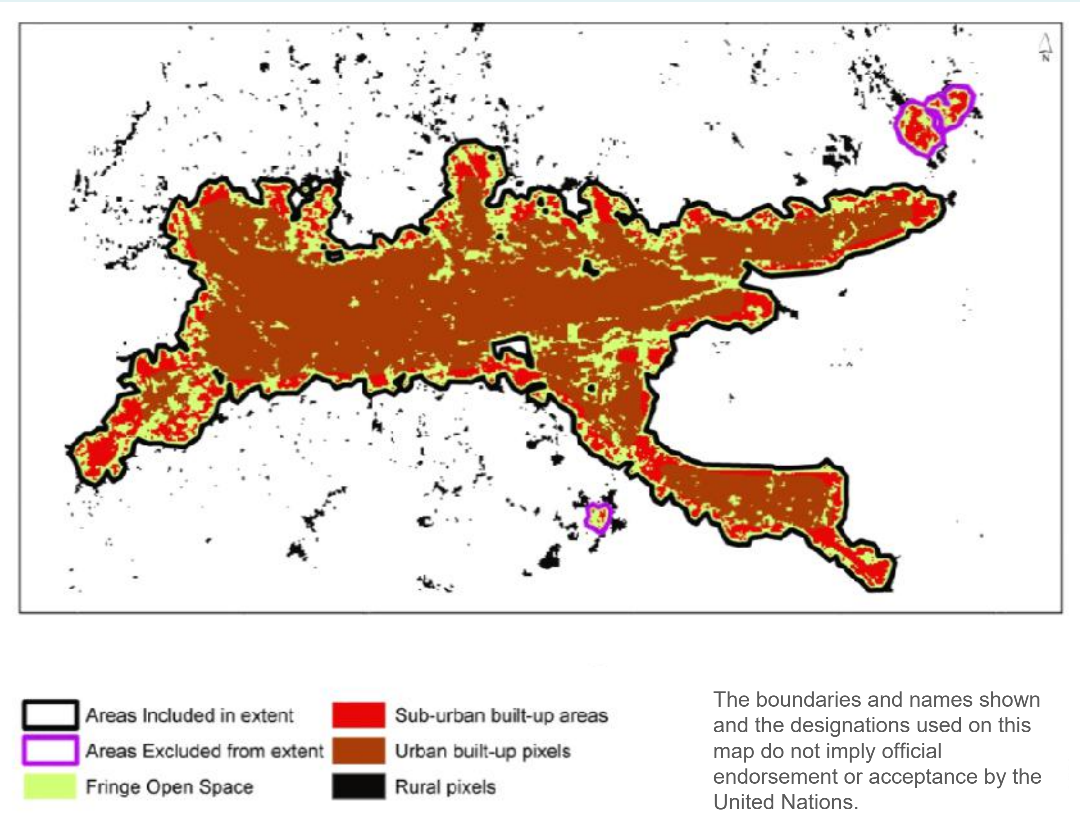
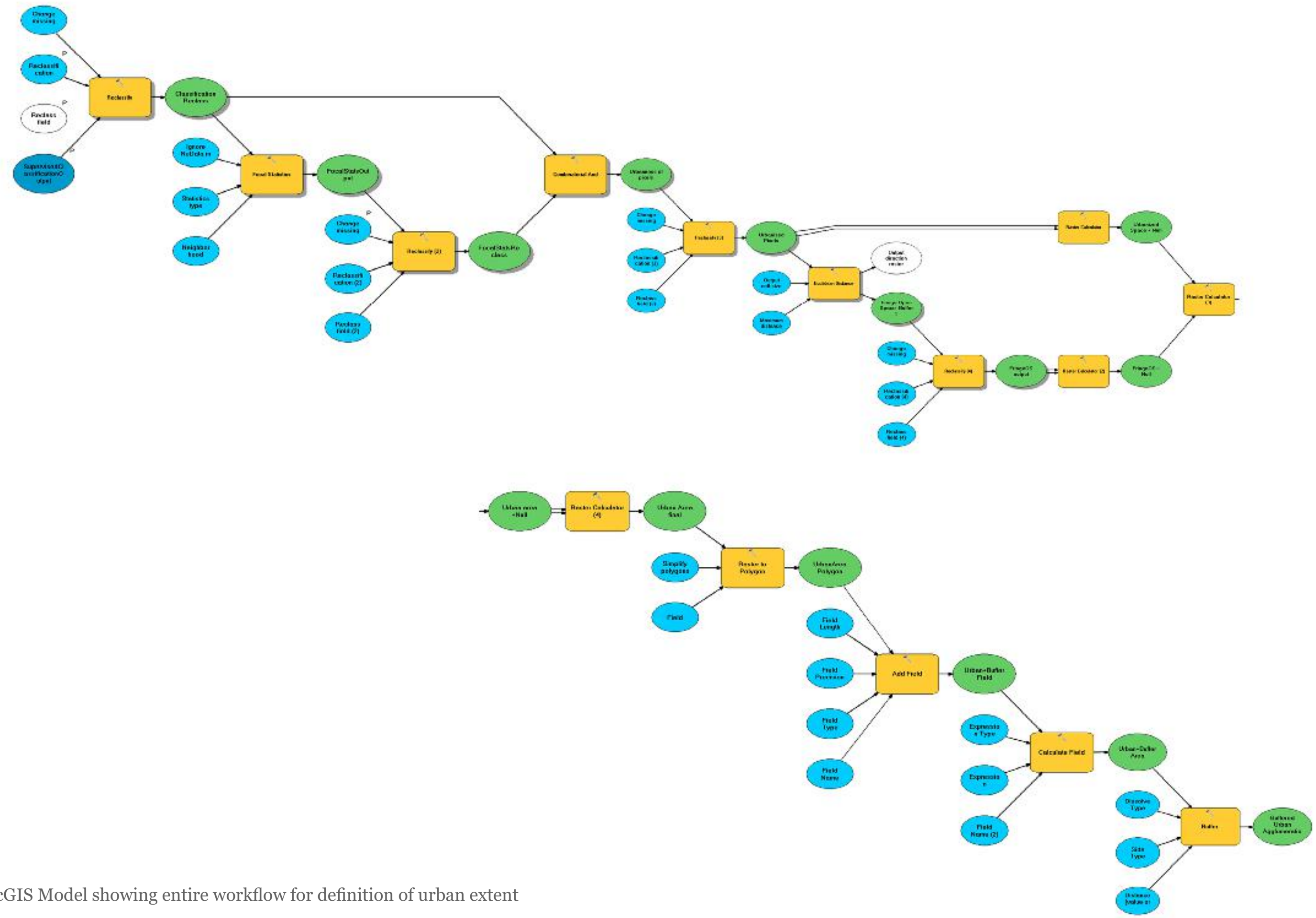


Figure 10: Resultant urban extent for the sample city

4. ANNEX 2

WORK FLOW FOR URBAN EXTENT DEFINITION



Annex 2: ArcGIS Model showing entire workflow for definition of urban extent

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