Earth Observation for
Sustainable Development

urban development
eo4sd

Urban Development Project

EO4SD-Urban Project: Bhopal City Report

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Summary

This document contains information related to the provision of geo-spatial products from the European Space Agency (ESA) supported project "Earth Observation for Sustainable Development" Urban Applications (EO4SD-Urban) to the World Bank/GEF supported Global Platform for Sustainable Cities (GPSC) programme for the City of Bhopal.

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Executive Summary

The European Space Agency (ESA) has been working closely together with the International Finance Institutes (IFIs) and their client countries to demonstrate the benefits of Earth Observation (EO) in the IFI development programmes. Earth Observation for Sustainable Development (EO4SD) is a new ESA initiative, which aims to achieve an increase in the uptake of satellite based information in the regional and global IFI programmes. The overall aim of the EO4SD Urban project is to integrate the application of satellite data for urban development programmes being implemented by the IFIs or Multi-Lateral Development Banks (MDBs) with the developing countries. The overall goal will be achieved via implementation of the following main objectives:

- To provide a service portfolio of Baseline and Derived urban-related geo-spatial products
- To provide the geo-spatial products and services on a geographical regional basis
- To ensure that the products and services are user-driven

This Report describes the generation and the provision of EO-based information products to the Global Platform for Sustainable cities (GPSC) programme and the counterpart City Bhopal, India.

The Report provides a Service Description by referring to the user driven service requirements and the associated product list with the detailed product specifications. The following products were requested:

- Urban Land Use/ Land Cover and Change
- Settlement Extent and Imperviousness and Change
- Urban Green Areas and Change

The current version of this report contains the description of the generation and delivery of the Land Use/Land Cover (LU/LC) and the LU/LC Change between two time periods of 2005 and 2017 as well as the description of the derived product Urban Green Areas. The updated version further contains advanced spatial analytics, which were produced based on the World Settlement Footprint, the LU/LC classification and the Global Human Settlement Population dataset freely available via this website: https://ghsl.jrc.ec.europa.eu/download.php?ds=pop.

This City Operations Report for Bhopal systematically reviews the main production steps involved and importantly highlights the Quality Control (QC) mechanisms involved; the steps of QC and the assessment of quality is provided in related QC forms in Annexe 2 of this Report. There is also the provision of standard and advanced analytical work undertaken with the products, which can be further included as inputs into further urban development assessments, modelling and reports.

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List of Abbreviations

CDS	City Development Strategy
CS	Client States
DEM	Digital Elevation Model
DLR	German Space Agency
EEA	European Environmental Agency
EGIS	Consulting Company for Environmental Impact Assessment and Urban Planning, France
EO	Earth Observation
ESA	European Space Agency
EU	European Union
GAF	GAF AG, Geospatial Service Provider, Germany
GIS	Geographic Information System
GISAT	Geospatial Service Provider, Czech Republic
GISBOX	Romanian company with activities of Photogrammetry and GIS
GUF	Global Urban Footprint
HR	High Resolution
HRL	High Resolution Layer
IFI	International Financing Institute
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO/TC 211	Standardization of Digital Geographic Information
JR	JOANNEUM Research, Austria
LC / LU	Land Cover / Land Use
LCRPGR	Land Consumption Rate to Population Growth Rate
LULCC	Land Use and Land Cover Change
MMU	Minimum Mapping Unit
NDVI	Normalized Difference Vegetation Index
NEO	Geospatial Service Provider, The Netherlands
PGR	Population Growth Rate
QA	Quality Assurance
QC	Quality Control
QM	Quality Management
SP	Service Provider
VHR	Very High Resolution
WB	World Bank
WBG	World Bank Group

1 General Background of EO4SD-Urban

Since 2008 the European Space Agency (ESA) has worked closely together with the International Finance Institutes (IFIs) and their client countries to harness the benefits of Earth Observation (EO) in their operations and resources management. Earth Observation for Sustainable Development (EO4SD) is a new ESA initiative, which aims to achieve an increase in the uptake of satellite based information in the regional and global IFI programmes. The EO4SD-Urban project initiated in May 2016 (with a duration of 3 years) has the overall aim to integrate the application of satellite data for urban development programmes being implemented by the IFIs with the developing countries. The overall goal will be achieved via implementation of the following main objectives:

- To provide the services on a regional basis (i.e. large geographical areas); in the context of the current proposal with a focus on S. Asia, SE Asia and Africa, for at least 35-40 cities.
- To ensure that the products and services are user-driven; i.e. priority products and services to be agreed on with the MDBs in relation to their regional programs and furthermore to implement the project with a strong stakeholder engagement especially in context with the validation of the products/services on their utility.
- To provide a service portfolio of Baseline and Derived urban-related geo-spatial products that have clear technical specifications, and are produced on an operational manner that are stringently quality controlled and validated by the user community.
- To provide a technology transfer component in the project via capacity building exercises in the different regions in close co-operation with the MDB programmes.

This Report supports the fulfilment of the third objective, which requires the provision of geo-spatial Baseline and Derived geo-spatial products to various stakeholders in the IFIs and counterpart City authorities. The Report provides a Service Description, and then in Chapter 3 systematically reviews the main production steps involved and importantly highlights whenever there are Quality Control (QC) mechanisms involved with the related QC forms in the Annexe of this Report. The description of the processes is kept intentionally at a top level and avoids technical details as the Report is considered mainly for non-technical IFI staff and experts and City authorities. Finally, Chapter 4 presents the standard analytical work undertaken with the products, which can be inputs into further urban development assessments, modelling and reports.

2 Service Description

The following Section summarises the service as it has been realised for the city of Bhopal, India within the EO4SD-Urban Project and as it had been delivered to the GPSC Implementing Agency UNIDO (United Nations Industrial Development Organisation) which is the Implementing Agency for the Indian cities Bhopal and Vijayawada.

2.1 Stakeholders and Requirements

The EO4SD-Urban products described in this Report were provided to the GPSC programme. GPSC is funded by the Global Environment Facility (GEF) and comprises currently 28 cities in 11 countries. The GPSC initiative is supported by different Multi-Lateral Development Banks (MDBs) and UN organisations. The two Indian Cities of Bhopal and Vijayawada are part of the Sustainable Cities Integrated Approach Pilot Project in India and as part of the GPSC programme were identified for collaboration with the EO4SD-Urban project via interactions with UNIDO the Implementing Agency.
The GPSC has an overarching aim to provide a knowledge platform for partner cities, as well as relevant networks and institutions to support the cities via:

- “Knowledge transfer activities that support urban investments and sustainability initiatives,
- A global network for collaborative engagement, tapping into and complementing existing efforts,
- Long-term, systematic engagement with cities, financial institutions, and organizations for transformational impact” (GPSC Programme Booklet, 2016).

Bhopal is a GPSC Partner City; it is the capital city of the state of Madhya Pradesh in the second largest state of India. In the context of the GPSC programme the city has the objective “to demonstrate an integrated package of technologies and involve interventions to assist in carrying out and facilitating investments which will reduce GHG emissions and enhance the effectiveness, efficiency and safety of the cities technical and industrial systems and processes – with potential scale up to other cities,” (GPSC website, 2018). The local organizations in charge of the GPSC project in Bhopal and Vijayawada are the Schools of Planning and Architecture (SPA).

2.2 Service Area Specification

Due to the fact that there is currently no internationally accepted definition for the term “Urban Area” and the related Core and Peri-Urban areas, there are different initiatives which are trying to address a standardised approach for defining the terms. During discussions with the GPSC Co-ordinator it was considered important to use an uniform definition for the GPSC Cities in order for the Cities to exchange information and share products/experiences and conduct potential comparative studies.

In this context, it was decided to use an international approach for the demarcation of the Areas of Interest (AOI) for mapping for the GPSC Cities of both Bhopal and Vijayawada in terms of a Core Urban Area and Peri-Urban area. Thus the approach is based on the European Union’s Directorate-General for Regional and Urban Policy (DG REGIO) method and the definitions are described in the Regional Working Paper 2014 from the European Commission on “A harmonised definition of cities and rural areas: the new degree of urbanisation” (European Commission, 2014). Following the naming of the DG Regio approach, the Urban Core is named as “High Density Core” and the Peri-Urban area is termed “Urban Cluster.” This nomenclature will be used in this Report when describing these two regions. Within the DG REGIO approach, the High Density Cluster (or Core) is defined as contiguous grid cells of 1 km^2 with a density of at least 1 500 inhabitants per km^2 and a minimum population of 50 000. The Urban Cluster is defined as Clusters of contiguous grid cells of 1 km^2 with a density of at least 300 inhabitants per km^2 and a minimum population of 5 000.

The DG REGIO methodology used in the EO4SD-Urban project was slightly adjusted to Non-European countries. The classification into High Density Core and Urban Cluster is based on the Global Human Settlement Population Grid which has a spatial resolution of 1 km. The raster dataset is available for the years 1975, 1990, 2000, 2015. This dataset depicts the distribution and density of population, expressed as the number of people per cell. The data can be downloaded under following link http://data.jrc.ec.europa.eu/dataset/jrc-ghsl-ghs_pop_gpw4_globe_r2015a.

The High Density Core AOI for a city is created by merging the contiguous grid cells of 1 km^2 with a density of at least 1500 inhabitants per km^2 and a minimum population of 50 000. In the definition of the High Density Core the contiguity is only allowed via a vertical or horizontal connection. In a last step gaps are filled.

The Urban Cluster is created very similar to the High Density Core. Here continuous grid cells of 1 km^2 with a density of at least 300 inhabitants per km^2 and a minimum population of 500 are merged together to form the Urban Cluster. The contiguity within the Urban Cluster can be also diagonal. Again, gaps are filled within the last step.

To smoothen the border of the AOIs, a buffer of 1km is calculated around the High Density Core AOI and around the Urban Cluster AOI.

In all remaining GPSC cities, the border was not smoothed, but when the population grid was under or over estimating the real settlement extent, grid cells were added or removed.

In some cases, the city counterparts requested that the AOIs for the High Density Core and the Urban Cluster follow the municipal or administrative boundary of the city. In this case, the municipal/administrative boundary was used, but enlarged in areas where the AOI created according to the adjusted DG Regio approach was bigger. This adjustment of the DG Regio AOI was done for Abidjan, Dakar and Campeche. These further adjusted DG Regio AOIs are in the following report named as Core City Area and Larger Urban Area.

A more detailed description on how the AOIs are calculated is provided in Annex 1.

The AOIs were presented in a power point, and sent to the Users for verification. Figure 1 shows the created AOIs.

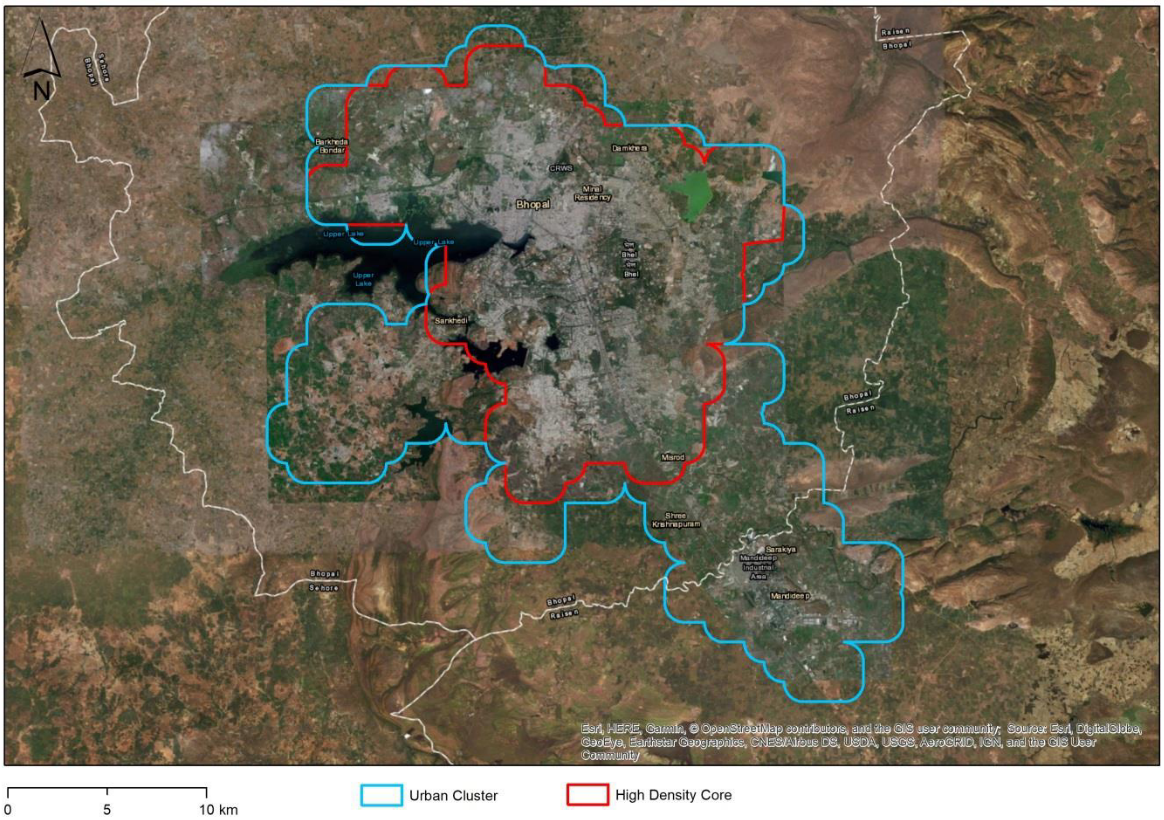


Figure 1: Illustration of High Density Core and Urban Cluster of mapping for Bhopal.

The High Density Core has an area of 316 km^2 and the Urban Cluster has an area of 256 km^2, for a total service or mapping area of 572 km^2.

2.3 Product List and Product Specifications

During the discussions related to the AOIs the potential geo-spatial products that could be provided for the Cities were also reviewed with UNIDO and the Users. It was noted that the Baseline Land Use/Land Cover (LU/LC) products (for the High Density Core and Urban Cluster) were a standard product that would be provided for all Cities as it is required for the derived products. In the case of Bhopal, the full list of products for both the High Density Core and Urban Cluster areas are as follows:

- Urban Land Use/Land Cover & Change
- Settlement Extent & Change
- Percentage Impervious Surface & Change
- Urban Green Areas & Change

For each of these products two time slots were used to provide historic and recent information; thus for Bhopal it was 2005 and 2017. The current Report will focus on the provision of the Baseline LU/LC products, the Settlement Extent product and the Urban Green Area product for Bhopal. The report further focuses on advanced spatial analytics like urban form analytics (e.g. Fragmentation or Discontiguity Index) and the Sustainable Development Goal 11 Indicators.

2.4 Land Use/Land Cover Nomenclature

A pre-cursor to starting production was the establishment with the stakeholders on the relevant Land Use/Land Cover (LU/LC) nomenclature as well as class definitions. The approach taken was to use a standard remote sensing based LU/LC nomenclature i.e. the European Urban Atlas Nomenclature (European Union, 2011) and adapt it to the User's LU/LC requirements. This nomenclature is applied to all GPSC cities within the EO4SD-Urban project.

Thus, the remote-sensing based LU/LC classes in the urban context can be grouped into five Level 1 classes, which are Artificial Areas, Natural/Semi Natural, Agricultural, Wetland, and Water Bodies. These classes can then be sub-divided into several different more detailed classes, such that the dis-aggregation can be down to Level 2-4. This hierarchical classification system is often used in operational Urban mapping programmes and is the basis for example of the European Commission's Urban Atlas programme which provides pan-European comparable LU/LC data with regular updates. A depiction of the way the levels and classes are structured is presented as follows:

<u>Level I Artificial surfaces</u>

- Level II: Residential

Level III

- Continuous Dense Urban Fabric (Sealing Layer-S.L. > 80%)
- Discontinuous Dense Urban Fabric (S.L. 50% - 80%)
- Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)
- Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)
- Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
- Isolated Structures

- Level II: Industrial, commercial, public, military, private and transport units

Level III

- Industrial, commercial, public, military and private units zoning data
- Road and rail network and associated land (Open Street Map or In-country data needed)

Level IV

    - Fast transit roads and associated land
    - Other roads and associated land
    - Railway and associated land

- Port area and associated land
- Airport and associated land

- Level II: Mine, Dump and Construction Sites

- Mineral Extraction and Dump Sites
- Construction Sites
- Land Without Current Use

- Level II: Artificial Non-Agricultural Vegetated Areas

- Green Urban Areas
- Sports and Leisure Facilities

(Reference: European Union, 2011)

It should be noted that in the current project, the Level 1 classes were used as the basis for classification of the Urban Cluster areas using the High Resolution (HR) data such as Landsat or Sentinel. However, for the High Density Core areas using the Very High Resolution (VHR) data it was possible to go down to Level III and IV. The different levels, classes and sub-classes from the remote sensing based urban classification, were harmonised within the GPSC cities. The following tables give the nomenclature for the High Density Core and the Urban Cluster region.

Table 1: LU/LC Nomenclature for GPSC Cities (High Density Core AOI).

Actual and Historic Nomenclature			
Level I	Level II	Level III	Level IV
1000 Artificial Surfaces	1100 Residential	1100 Residential	1110 Continuous dense urban fabric
			1121 Discontinuous dense urban fabric
			1122 Discontinuous medium density urban fabric
			1123 Discontinuous low density urban fabric
			1124 Discontinuous very low density urban fabric
			1130 Isolated Structures
	1200 Industrial, Commercial, Public, Military and Private Units	1210 Industrial, Commercial, Public, Military and Private Units	
		1220 Roads	1221 Fast Transit Roads (Arterial Roads)
			1222 Other Road (Collector Roads)
			1223 Railway
		1230 Port Area	
		1240 Airport	
	1300 Mine, Dump and Construction Sites	1310 Mineral Extraction and Dump Sites	
		1330 Construction Sites	
		1340 Land Without Current Use	
	1400 Artificial Non-Agricultural Vegetated Areas	1410 Green Urban Areas	
		1420 Sports and Leisure Facilities	
2000 Agricultural Area			
3000 Natural and Semi-natural Areas	3100 Forest and Shrublands		
	3200 Natural Areas (Grassland)		
	3300 Bare Soil		
4000 Wetlands			
5000 Water	5100 Inland Water		
	5200 Marine Water		

Table 2: LU/LC Nomenclature for GPSC Cities (Urban Cluster AOI).

Actual and Historic Nomenclature			
Level I	Level II	Level III	Level IV
1000 Artificial Surfaces	1100 Residential	1100 Residential	1110 Continuous dense urban fabric
			1121 Discontinuous dense urban fabric
			1122 Discontinuous medium density urban fabric
			1123 Discontinuous low density urban fabric
			1124 Discontinuous very low density urban fabric
			1130 Isolated Structures
		1220 Roads	1221 Fast Transit Roads (Arterial Roads)
			1222 Other Road (Collector Roads)
			1223 Railway
		1230 Port Area	
		1240 Airport	
2000 Agricultural Area			
3000 Natural and Semi-natural Areas	3100 Forest and Shrub Lands		
	3200 Natural Areas (Savannah, Grassland)		
	3300 Bare Soil		
4000 Wetlands			
5000 Water	5100 Inland water		
	5200 Marine water		

2.5 World Settlement Extent

Reliably outlining settlements is of high importance since an accurate characterization of their extent is fundamental for accurately estimating, among others, the population distribution, the use of resources (e.g. soil, energy, water, and materials), infrastructure and transport needs, socioeconomic development, human health and food security. Moreover, monitoring the change in the extent of settlements over time is of great support for properly modelling the temporal evolution of urbanization and thus, better estimating future trends and implementing suitable planning strategies.

At present, no standard exists for defining settlements and worldwide almost each country applies its own definition either based on population, administrative or geometrical criteria. The German Space Agency (DLR) were responsible for the provision of the "Settlement Extent" product; when generating the settlement extent maps from HR imagery, pixels are labelled as **settlement** if they *intersect any building, lot or – just within urbanized areas – roads and paved surface* where we define:

- **building** as any structure having a roof supported by columns or walls and intended for the shelter, housing, or enclosure of any individual, animal, process, equipment, goods, or materials of any kind;
- **lot** as the area contained within an enclosure (wall, fence, hedge) surrounding a building or a group of buildings. In cases where there are many concentric enclosures around a building, the lot is considered to stop at the inner most enclosure;
- **road** as any long, narrow stretch with a smoothed or paved surface, made for traveling by motor vehicle, carriage, etc., between two or more points;
- **paved surface** as any level horizontal surface covered with paving material (i.e., asphalt, concrete, concrete pavers, or bricks but excluding gravel, crushed rock, and similar materials).

Instead, pixels not satisfying this condition are marked as **non-settlement**.

The settlement extent product is a binary mask outlining - in the given Area of Interest (AOI) – settlements in contrast to all other land-cover classes merged together into a single information class. The settlement class and the non-settlement class are associated with values "255" and "0", respectively.

2.6 Percentage Impervious Surface

Settlement growth is associated not only to the construction of new buildings, but – more in general – to a consistent increase of all the impervious surfaces (hence also including roads, parking lots, squares, pavement, etc.), which do not allow water to penetrate, forcing it to run off. To effectively map the percentage impervious surface (PIS) is then of high importance being it related to the risk of urban floods, the urban heat island phenomenon as well as the reduction of ecological productivity. Moreover, monitoring the change in the PIS over time is of great support for understanding, together with information about the spatiotemporal settlement extent evolution, also more details about the type of urbanization occurred (e.g. if areas with sparse buildings have been replaced by highly impervious densely built-up areas or vice-versa).

In the framework of the EO4SD-Urban project, one pixel in the generated PIS maps is associated with the estimated percentage of the corresponding surface at the ground covered by buildings or paved surfaces, are defined as:

- **building** as any structure having a roof supported by columns or walls and intended for the shelter, housing, or enclosure of any individual, animal, process, equipment, goods, or materials of any kind;
- **paved surface** as any level horizontal surface covered with paving material (i.e. asphalt, concrete, concrete pavers, or bricks but excluding gravel, crushed rock, and similar materials).

The product provides for each pixel in the considered AOI the estimated PIS. Specifically, values are integer and range from 0 (no impervious surface in the given pixel) to 100 (completely impervious surface in the given pixel) with step 5.

2.7 Urban Green Area Nomenclature

Urban Green Areas were separated within the Land Use/Land Cover product only in the land use classes 1411 Urban Parks (Parks, Gardens) and 1412 Cemeteries. However, all other urbanised land use classes, like 1100 Residential, 1200 Industrial, Commercial, Public, Military, Private and Transport Units, and 1300 Mine, Dump and Construction Sites can also be partially vegetated. In order to get an overall synopsis of all Green Areas within the urbanised classed, i.e. all sub-classes under 1000 Artificial Surfaces, a further land cover classification of the VHR data was performed by applying a semi-automated classification algorithm. Forested areas, Grassland and Agricultural areas, which are part of the LULC product were not further considered in this Urban Green Areas land cover. The applied nomenclature and class coding is given in Table 2.

Table 2: Nomenclature used for the mapping and identification of Urban Green Areas.

Single date	
Code 0	Non-green area
Code 1	Urban green area
Change product	
Code 0	Non-green area. No vegetated surfaces occurring on “Artificial Surfaces”, Level I, at both points in time.
Code 1	Permanent urban green area. Vegetated surfaces in 2005 and 2017.
Code 2	Loss of urban green area. Vegetated areas in 2005, which changed to non-vegetated areas in 2017.
Code 3	New urban green area. Non-vegetated surfaces in 2005 with vegetation cover in 2017.
Code 254	Non-Urban Areas. All Areas that do not fall in the Level I class of the Land Use Land Cover product.

2.8 Terms of Access

The Dissemination of the digital data and the Report was undertaken via FTP.

3 Service Operations

The following Sections present all steps of the service operations including the necessary input data, the processing methods, the accuracy assessment and the quality control procedures. Methods are presented in a top-level and standardised manner for all the EO4SD-Urban City Reports.

3.1 Source Data

This Section presents the remote sensing and ancillary datasets that were used. Different types of data from several data providers have been acquired. A complete list of source data as well as a quality assessment is provided in Annex 2.

A summary of the main data used is provided in the following sections.

High Resolution Optical EO Data

The major data sources for the Urban Cluster current and historic mapping of urban LULC, urban extent and imperviousness were Landsat and Sentinel-2 data which were accessible and downloadable free of charge.

- **Landsat 5:** As a source of historical data one scene of Landsat TM 5 from the 8th of November 2005 has been acquired which covers the whole area of interest.
- **Sentinel-2:** The most recent data coverage comprises one Sentinel-2 data set from the 29th of October 2017. The data was downloaded and processed at Level 1C.

Very High Resolution Optical EO Data

The VHR data for the High Density Core area mapping had to be acquired and purchased through commercial EO Data Providers such as Airbus Defence and European Space Imaging.

It has to be noted that under the current collaboration project the VHR EO data had to be purchased under **mono-license agreement**s between GAF AG and the EO Data Providers. If EO data would have to be distributed to other stakeholders then further licences for multiple Users would have to be purchased.

The following VHR sensor data have been acquired to cover the entire AOI:

- **Quickbird-2:**
  - 3 scenes for 2005
- **WorldView-2 and GeoEye-1:**
  - 3 scenes for 2017

Detailed lists of the used EO data as well as their quality is documented in the attached Quality Control Sheets in Annex 2.

Ancillary Data

- Data Provided by User:
  - Bhopal_ExistingLandfill.shp: Point data of the location of the existing land fill in Bhopal area.
  - Bhopal_Proposed_Landfill.shp: Point data of the location of the proposed land fill in Bhopal area. In 2017 no land fill or the start of a land fill visible.
- Bhopal Master Plan 2005 published by the Directorate of Town and Country Planning Madhya Pradesh (Bhopal Master Plan, 2005).
- Open Street Map (OSM) data: OSM data is freely available and generated by volunteers across the globe. The so called crowd sourced data is not always complete, but has for the most parts of the world valuable spatial information. Data was downloaded to complement the Transport Network layer and further enhanced. The spatial location of the OSM based streets was used a geospatial reference.

Detailed lists of the used ancillary data as well as their quality is documented in the attached Quality Control Sheets in Annex 2.

3.2 Processing Methods

Data processing starts at an initial stage with quality checks and verification of all incoming data. This assessment is performed in order to guarantee the correctness of data before geometric or radiometric pre-processing is continued. These checks follow defined procedures in order to detect anomalies, artefacts and inconsistencies. Furthermore, all image and statistical data were visualised and interpreted by operators.

The main techniques and standards used for data analysis, processing and modelling for each product are described in Annex 1.

3.3 Accuracy Assessment of Map Products

Data and maps derived from remote sensing contain - like any other map - uncertainties which can be caused by many factors. The components, which might have an influence on the quality of the maps derived from EO include quality and suitability of satellite data, interoperability of different sensors, radiometric and geometric processing, cartographic and thematic standards, and image interpretation procedures, post-processing of the map products and finally the availability and quality of reference data. However, the accuracy of map products have a major impact on secondary products and its utility and therefore an accuracy assessment was considered as a critical component of the entire production and products delivery process. The main goal of the thematic accuracy assessment was to guarantee the quality of the mapping products with reference to the accuracy thresholds set by the user requirements.

The applied accuracy assessments were based on the use of reference data, and applying statistical sampling to deduce estimates of error in the classifications. In order to provide an efficient, reliable and robust method to implement an accuracy assessment, there are three major components that had to be defined: the **sampling design**, which determines the spatial location of the reference data, the **response design** that describes how the reference data is obtained and an **analyses design** that defines the accuracy estimates. These steps were undertaken in a harmonised manner for the validation of all the geo-spatial products.

3.3.1 The Accuracy Assessment of the LU/LC Product

Sampling Design

The sampling design specifies the sample size, sample allocation and the reference assessment units (i.e. pixels or image blocks). Generally, different sampling schemes can be used in collecting accuracy assessment data including: simple random sampling, systematic sampling, stratified random sampling, cluster sampling, and stratified systematic unaligned sampling. In the current project a **single stage stratified random sampling** based on the method described by Olofson et al (2013[1]) was applied which used the map product as the basis for stratification. This ensured that all classes, even very minor ones were included in the sample.

However, in complex LU/LC products with many classes, this usually results in a large number of strata (one stratum per LU/LC classes), of which some classes cover only very small areas (e.g. sport fields, cemeteries) and not being adequately represented in the sampling. In order to achieve a

[1] Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. Remote Sensing of Environment, 129, 122–131. doi:10.1016/j.rse.2012.10.031

representative sampling for the statistical analyses of the mapping accuracy it was decided to extend the single stage stratified random sampling. At the first stage the number of required samples was allocated within each of the Level I strata (1000 Artificial Surfaces, 2000 Agricultural Area, 3000 Natural and Semi-natural Areas, 4000 Wetlands, 5000 Water). In the second stage all Level III classes that were not covered by the first sampling, were grouped into one new stratum. Within that stratum the same number of samples was randomly allocated as the Level I strata received. To avoid a clustering of point samples within classes and to minimise the effect of spatial autocorrelation a minimum distance in between the sample points was set to be 150 m. The final sample size for each class can be considered to be as close as possible to the proportion of the area covered by each stratum considering that the target was to determine the overall accuracy of the entire map.

The total sample size per stratum was determined by the expected standard error and the estimated error rate based on the following formula, which assumes a simple random sampling (i.e. the stratification is not considered):

$$n = \frac{P*q}{(\frac{E}{z})^2}$$

n = number of samples per strata / map class
p = expected accuracy
$q = 1 - p$
E = Level of acceptable (allowable) sample error
Z = z-value (the given level of significance)

Hence, with an expected accuracy of p = 0.85, a 95% confidence level and an acceptable sampling error of 5%, the minimum sample size is 196. A 10% oversampling was applied to compensate for stratification inefficiencies and potentially inadequate samples (e.g. in case of cloudy or shady reference data). For each Level I strata 215 samples have been randomly allocated. Afterwards, within all classes of Level III (see Table 3) that did not received samples in the first run, additionally 215 samples were randomly drawn across all these classes.

Table 3: Number of sampling points for the EO4SD-Urban mapping classes after applied sampling design with information on overall land cover by class.

Class Name	Class ID	No. of Sampling Points	Km² Coverage
Residential	1100	167	127.1
Industrial, Commercial, ...	1210	22	39.2
Collector and Arterial Roads	1221, 1222	1	7.5
Port Area	1230	1	0.01
Airport	1240	20	3.6
Mining, Dump Sites	1310	1	1.1
Construction Sites	1320	7	6.7
Land without Current Use	1330	7	16.0
Green Urban Areas	1410	8	5.3
Sports and Leisure Facilities	1420	1	2.3
Agricultural Area	2000	215	240.4
Forest and Shrublands	3100	96	50.7
Natural Areas (Grassland)	3200	117	37.7
Bare Soil	3300	2	3.5
Wetlands	4000	169	1.9
Inland Water	5100	215	27.8
Total	--	**1050**	**570.81**

Response Design

The response design determines the reference information for comparing the map labels to the reference labels. Collecting reference data on the ground by means of intensive fieldwork is both costly and time consuming and in most projects not feasible. The most cost effective reference data sources are VHR satellite data with 0.5 m to 1 m spatial resolution. Czaplewski (2003)[2] indicated that visual interpretation of EO data is acceptable if the spatial resolution of EO data is sufficiently better compared to the thematic classification system. However, if there are no EO data with better spatial resolution available, the assessment results need to be checked against the imagery used in the production process.

The calculated number of necessary sampling points for each mapping category was randomly distributed among the strata and overlaid to the VHR data of each epoch. The following Figure is showing the mapping result with the overlaid sample points.

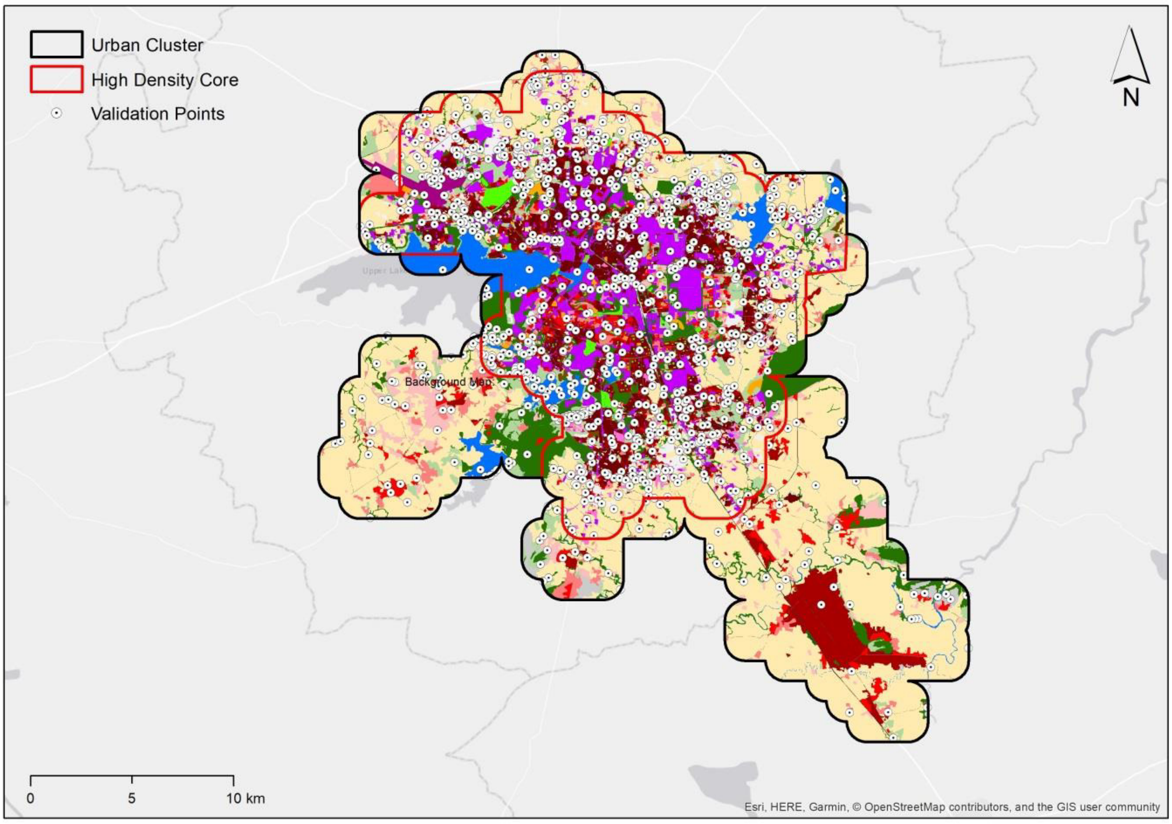


Figure 2: Mapping result of the city of Bhopal of the year 2017 overlaid with randomly distributed sample points used for accuracy assessment.

In this way a reference information could be extracted for each sample point by visual interpretation of the VHR data for all mapped classes. The size of the area to be observed had to be related to the Minimum Mapping Unit (MMU) of the map product to be assessed. The reference information of each sampling point was compared with the mapping results and the numbers of correctly and not-correctly classified observations were recorded for each class. From this information the specific error matrices and statistics were computed (see next Section).

[2] Czaplewski, R. L. (2003). Chapter 5: accuracy assessment of maps of forest condition: statistical design and methodological considerations, pp. 115–140. In Michael A.Wulder, & Steven E. Franklin (Eds.), Remote sensing of forest environments: concepts and case studies. Boston: Kluwer Academic Publishers (515 pp.).

Analysis

Each class usually has errors of both omission and commission, and in most situations, these errors for a class are not equal. In order to calculate these errors as well as the uncertainties (confidence intervals) for the area of each class a statistically sound accuracy assessment was implemented.

The confusion matrix is a common and effective way to represent quantitative errors in a categorical map, especially for maps derived from remote sensing data. The matrices for each assessment epoch were generated by comparing the "reference" information of the samples with their corresponding classes on the map. The *Reference* represented the "truth", while the *Map* provided the data obtained from the map result. Thematic accuracy for each class and overall accuracy is then presented in error matrices (see Tables below). Unequal sampling intensity resulting from the random sampling approach was accounted for by applying a weight factor (p) to each sample unit based on the ratio between the number of samples and the size of the stratum considered[3]:

$$\hat{p}_{ij} = \left(\frac{1}{M}\right) \sum_{x \in (i,j)} \frac{1}{\pi^*_{uh}}$$

Where i and j are the columns and rows in the matrix, M is the total number of possible units (population) and π is the sampling intensity for a given sample unit u in stratum h.

Overall accuracy and User and producer accuracy were computed for all thematic classes and 95% confidence intervals were calculated for each accuracy metric.

The standard error of the error rate was calculated as follows: $\sigma_h = \sqrt{\frac{p_h(1-p_h)}{n_h}}$ where n_h is the sample size for stratum h and p_h is the expected error rate. The standard error was calculated for each stratum and an overall standard error was calculated based on the following formula:

$$\sigma = \sqrt{\sum w_h^2 . \sigma_h^2}$$

In which w_h is the proportion of the total area covered by each stratum. The 95% Confidence Interval (CI) is +/- 1.96*σ.

Results

The confusion matrices are provided within the Annex 2 and showing the mapping error for each relevant class. For each class the number of samples which are correctly and not correctly classified are listed, which allows the calculation of the user and producer accuracies for each class as well as the confidence interval at 95% confidence levels based on the formulae above.

The Land Use/Land Cover product for Bhopal has an overall mapping accuracy of 94.57% with a CI ranging from 93.15% to 95.99% at a 95% CI. The specific class accuracies are given in Annex 2.

3.3.2 The Accuracy Assessment of the World Settlement Extent Product

In the following, the strategy designed for validating the World Settlement Extent (WSE) or World Settlement Footprint (WSF) 2015, i.e. a global settlement extent layer obtained as a mosaic of ~18.000 tiles of 1x1 degree size where the same technique employed in the EO4SD-Urban project is presented. In particular, specific details are given for all protocols adopted for each of the accuracy assessment components, namely response design, sampling design, and analysis; final results are discussed

[3] Selkowitz, D. J., & Stehman, S. V. (2011). Thematic accuracy of the National Land Cover Database (NLCD) 2001 land cover for Alaska. Remote Sensing of Environment, 115(6), 1401–1407. doi:10.1016/j.rse.2011.01.020.

afterwards. In the light of the quality and amount of validation points considered, it can be reasonably assumed that the corresponding quality assessment figures are also representative for any settlement extent map generated in the framework of EO4SD-Urban.

Response Design

The response design encompasses all steps of the protocol that lead to a decision regarding agreement of the reference and map classifications. The four major features of the response design are the source of information used to determine the source of reference data, the spatial unit, the labelling protocol for the reference classification, and a definition of agreement.

- **Source of Reference Data:** Google Earth (GE) satellite/aerial VHR imagery has been used given its free access and the availability for all the project test sites in the period 2014-2015. In particular, GE automatically displays the latest available data, but it allows to browse in time over all past historical images. The spatial resolution varies depending on the specific data source; in the case of SPOT imagery it is ~1.5m, for Digital Globe's WorldView-1/2 series, GeoEye-1, and Airbus' Pleiades it is in the order of ~0.5m resolution, whereas for airborne data (mostly available for North America, Europe and Japan) it is about 0.15m.
- **Spatial Assessment Unit:** A 3x3 block spatial assessment unit composed of 9 cells of 10x10m size has been used. Specifically, this choice is justified one the one hand by the fact that input data with different spatial resolutions have been used to generate the WSF2015 (i.e. 30m Landsat-8 and 10m S1). On the other hand, GE imagery exhibited in some cases a mis-registration error of the order of 10-15m, hence using a 3x3 block allows defining an agreement e.g. based on statistics computed over 9 pixels, thus reducing the impact of such shift.
- **Reference Labelling Protocol:** For each spatial assessment block any cell is finally labelled as **settlement** if *it intersects any building, lot or – just within settlements – roads and paved surface*. Instead, pixels not satisfying this condition are marked as **non-settlement**.
- **Definition of Agreement:** Given the classification and the reference labels derived as described above, three different agreement criteria have been defined:
    1) for each pixel, positive agreement occurs only for matching labels between the classification and the reference;
    2) for each block, a majority rule is applied over the corresponding 9 pixels of both the classification and the reference; if the final labels match, then the agreement is positive;
    3) for the classification a majority rule is applied over each assessment block, while for the reference each block is labelled as “settlement” only in the case it contains at least one pixel marked as “settlement”; if the final labels match, then the agreement is positive.

Crowd-sourcing was performed internally at Google. In particular, by means of an ad-hoc tool, operators have been iteratively prompted a given cell on top of the available Google Earth reference VHR scene closest in time to the year 2015 and given the possibility of assigning to each cell a label among: “building”, “lot”, “road/paved surface” and “other”. For training the operators, a representative set of 100 reference grids was prepared in collaboration between Google and DLR.

Sampling Design

<u>The stratified random sampling design</u> has been applied since it satisfies the basic accuracy assessment objectives and most of the desirable design criteria. In particular, stratified random sampling is a probability sampling design and it is one of the easier to implement; indeed, it involves first the division of the population into strata within which random sampling is performed afterwards. To include a representative population of settlement patterns, 50 out of the ~18.000 tiles of 1x1 degree size considered in the generation of the WSF2015 have been selected based on the ratio between the number of estimated settlements (i.e. disjoint clusters of pixels categorized as settlement in the WSF2015) and their area. In particular, the i-th selected tile has been chosen randomly among those whose ratio belongs to the interval $]P_{2(i-1)}; P_{2i}], i \in [1; 50] \subset \mathbb{N}$ (where P_x denotes the x-th percentile of the ratio).

Table 4: Accuracies exhibited by the WSF2015 according to the three considered agreement criteria for different definitions of settlement.

Settlement =	Accuracy Measure	Agreement Criterion					
		1		2		3	
buildings	*OA%*	86.96		87.86		91.15	
	AA%	88.57		90.35		88.91	
	Kappa	0.6071		0.6369		0.7658	
	$UA_{NS}\%$ - $UA_S\%$	98.11	54.69	98.73	56.76	94.84	80.58
	$PA_{NS}\%$ - $PA_S\%$	86.24	90.90	86.72	93.98	93.32	84.51
buildings + lots	*OA*	88.08		88.94		91.26	
	AA%	88.64		90.19		88.71	
	Kappa	0.6510		0.6784		**0.7716**	
	$UA_{NS}\%$ - $UA_S\%$	97.54	60.71	98.13	62.66	94.29	82.62
	$PA_{NS}\%$ - $PA_S\%$	87.79	89.49	88.26	92.12	93.95	83.48
buildings + lots + roads / paved surface	*OA*	88.77		90.09		88.51	
	AA%	86.34		88.28		84.27	
	Kappa	**0.6938**		**0.7317**		0.7219	
	$UA_{NS}\%$ - $UA_S\%$	94.49	72.20	95.35	75.06	88.13	89.60
	$PA_{NS}\%$ - $PA_S\%$	90.78	81.91	91.62	84.94	96.04	72.51

As the settlement class covers a sensibly small proportion of area compared to the merger of all other non-settlement classes (~1% of Earth's emerged surface), an equal allocation reduces the standard error of its class-specific accuracy. Moreover, such an approach allows to best address user's accuracy estimation, which corresponds to the map "reliability" and is indicative of the probability that a pixel classified on the map actually represents the corresponding category on the ground. Accordingly, in this framework for each of the 50 selected tiles we randomly extracted 1000 settlement and 1000 non-settlement samples from the WSF2015 and used these as centre cells of the 3x3 reference block assessment units to label by photointerpretation. Such a strategy resulted in an overall amount of $(1000 + 1000) \times 9 \times 50 = 900.000$ cells labelled by the crowd.

Analysis

As measures for assessing the accuracy of the settlement extent maps, we considered:

- the percentage overall accuracy *OA%*;
- the Kappa coefficient;
- the percentage producer's ($PA_S\%$, $PA_{NS}\%$) and user's ($UA_S\%$, $UA_{NS}\%$) accuracies for both the settlement and non-settlement class;
- the percentage average accuracy *AA%* (i.e., the average between $PA_S\%$ and $PA_{NS}\%$).

Results

Table 5 reports the accuracies exhibited by the WSF2015 according to the three considered agreement criteria for different definitions of settlement; specifically, we considered as "settlement" all areas covered by: i) buildings; ii) buildings or building lots; or iii) buildings, building lots or roads / paved surfaces. As one can notice, accuracies are always particularly high, thus confirming the effectiveness of the employed approach and the reliability of the final settlement extent maps. The best performances in terms of kappa are obtained when considering settlements as composed by buildings, building lots and roads / paved surfaces for criteria 1 and 2 (i.e., 0.6938 and 0.7317, respectively) and by buildings and building lots for criteria 3 (0.7716); the *OA%* follows a similar trend. This is in line with the adopted settlement definition. Moreover, agreement criteria 3 results in accuracies particularly high with respect to criteria 1 and 2 when considering as settlement just buildings or the combination of buildings and lots. This can be explained by the fact that when the detection is mainly driven by Landsat data then the whole 3x3 assessment unit tends to be labelled as settlement if a building or a lot intersect the corresponding 30m resolution pixel.

3.3.3 The Accuracy Assessment of the Percentage Impervious Surface Product

In the following, the strategy designed for validating the PIS product is presented; specifically, details are given for all protocols adopted for each of the accuracy assessment components, namely response design, sampling design, and analysis. Results are discussed afterwards.

Response Design

The response design encompasses all steps of the protocol that lead to a decision regarding agreement of the reference and map classifications. The four major features of the response design are the source of information used to determine the source of reference data, the spatial unit, the labelling protocol for the reference classification, and a definition of agreement.

- **Source of Reference Data:** Cloud-free VHR multi-spectral imagery (Visible + Near Infrared) acquired at 2m spatial resolution (or higher) covering a portion of the AOI for which the Landsat-based PIS product has been generated;
- **Spatial Assessment Unit:** A 30x30m size unit has been chosen according to the spatial resolution of the Landsat imagery employed to generate the PIS product;
- **Reference Labelling Protocol:** As a first step, the NDVI is computed for each VHR scene followed by a manual identification of the most suitable threshold that allows to exclude all the vegetated areas (i.e. non-impervious). Then, the resulting mask is refined by extensive photointerpretation.
- **Definition of Agreement:** The above-mentioned masks are aggregated at 30m spatial resolution and compared per-pixel with the resulting VHR-based reference PIS to the corresponding portion of the Landsat-based PIS product.

Sampling Design

The entirety of pixels covered by the available VHR imagery over the given AOI is employed for assessing the quality of the Landsat-based PIS product.

Analysis

As measures for assessing the accuracy of the PIS maps, following indices are computed:

- the *Pearson's Correlation coefficient*: it measures the strength of the linear relationship between two variables and it is defined as the covariance of the two variables divided by the product of their standard deviations; in particular, it is largely employed in the literature for validating the output of regression models;
- The *Mean Error (ME)*: it is calculated as the difference between the estimated value (i.e., the Landsat-based PIS) and the reference value (i.e., the VHR-based reference PIS) averaged over all the pixels of the image;
- The *Mean Absolute Error (MAE)*: it is calculated as the absolute difference between the estimated value (i.e., the Landsat-based PIS) and the reference value (i.e., the VHR-based reference) averaged over all the pixels of the image.

Results

To assess the effectiveness of the method developed to generate the PIS maps, its performances over 5 test sites is analysed (i.e. Antwerp, Helsinki, London, Madrid and Milan) by means of WorldView-2 (WV2) scenes acquired in 2013-2014 at 2m spatial resolution. In particular, given the spatial detail offered by WV2 imagery, it was possible to delineate with a very high degree of confidence all the buildings and other impervious surfaces included in the different investigated areas. Details about acquisition date and size are reported in Table 5, along with the overall number of final 30x30m validation samples derived for the validation exercise. Such a task demanded a lot of manual interactions and transferring it to other AOIs would require extensive efforts; however, it can be reasonably assumed that the final quality assessment figures (computed on the basis of more than 1.9 million validation samples) shall be considered representative also for PIS maps generated in the framework of EO4SD-Urban. Table 5 reports the quantitative results of the comparison between the PIS maps generated using Landsat-7/8 data acquired in 2013-2014 and the WV2-based reference PIS maps. In particular, the considered approach allowed to obtain a mean correlation of 0.8271 and average ME and MAE equal to -0.09 and 13.33, respectively, hence assessing the great effectiveness of the Landsat-based PIS products. However, it is worth also pointing out that due to the different acquisition geometries, WV2 and LS8 images generally exhibit a very small shift. Nevertheless, despite limited, such displacement often results in a one-pixel shift between the Landsat-based PIS and the WV2-based reference PIS aggregated at 30m resolution. This somehow affects the computation of the MAE and of the correlation coefficient (which however yet resulted in highly satisfactory values). Instead, the bias does not alter the ME, which always exhibited values close to 0, thus confirming the capabilities of the technique and the reliability of the final products.

Table 5: Acquisition dates and size of the WV2 images available for the 5 test sites analysed in the validation exercise along with the number of corresponding 30x30m validation samples.

	Acquisition Date [DD.MM.YYYY]	Original Size [2x2m pixel]	Validation Samples [30x30m unit]
Antwerp	31.07.2014	5404 x 7844	188.280
Helsinki	21.04.2014	12468 x 9323	516.882
London	28.08.2013	7992 x 8832	313.937
Madrid	20.12.2013	10094 x 13105	588.202
Milan	14.05.2014	8418 x 7957	297.330

3.3.4 The Accuracy Assessment of Urban Green Areas

The validation of the Green Area mapping results are done in a similar way as the validation for the Land Use Land Cover product. The necessary amount of sampling points are calculated according to the formula of Goodchild et al. (1994), which is given in Table 6.

Table 6: Calculation of the minimum number of samples according to Goodchild et al. (1994).

Variables	Values
p	0.85
q	0.15
E	0.05
z	1.96
$n = \frac{p * q}{(E / z)^2}$	**196**
n with 10% oversampling	**215**
with:	
p = required accuracy of the data	
q = 1-p	
E = Level of acceptable (allowable) sample error	
Z = value from table (for the given level of significance)	

The calculated number of 215 sample points were randomly distributed among the entire map and overlaid on the VHR data of each epoch. The following Figure shows the mapping result with the overlaid sample points.

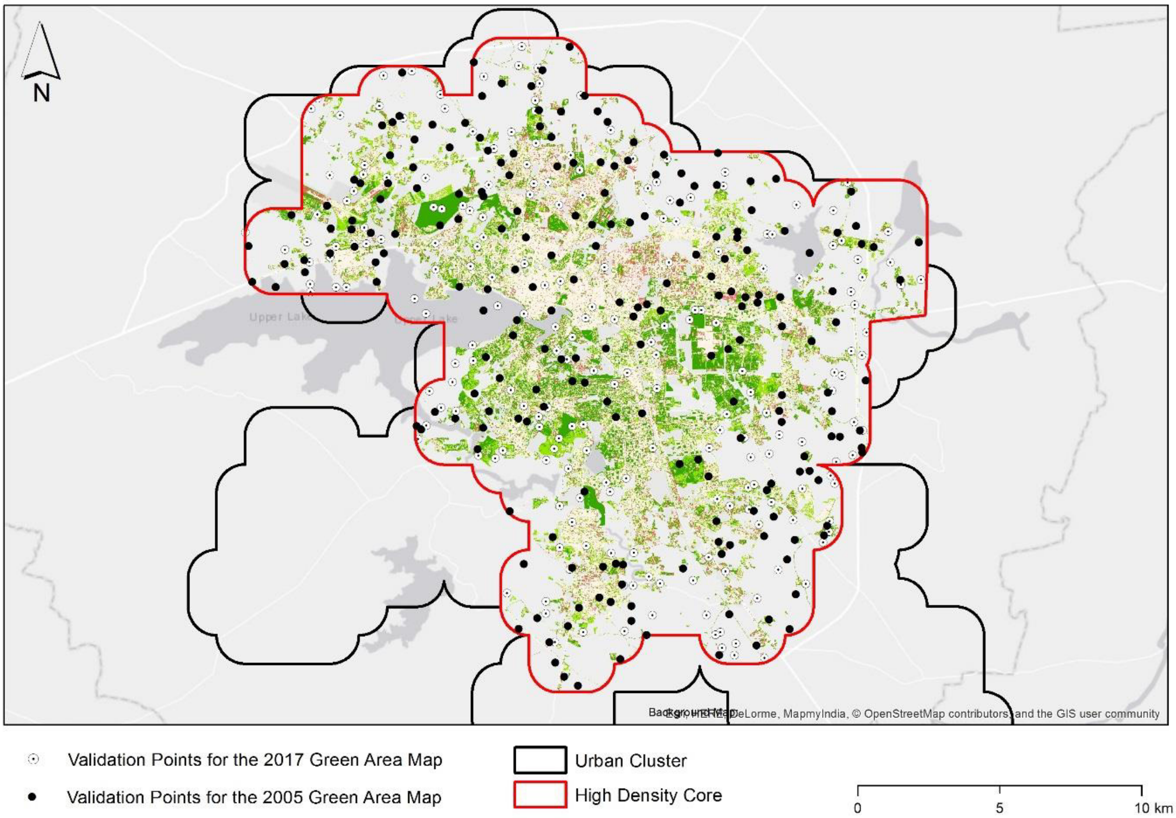


Figure 3: Result of the Urban Green Area mapping in Bhopal (change product) with sampling points used for product validation.

At each sample point location the reference data was collected by visual interpretation of the VHR data. The size of the area to be observed had to be related to the Minimum Mapping Unit (MMU) of the map product to be assessed. Finally, visual interpreted land cover type was compared with the mapping results and the numbers of correctly and not-correctly classified observations were recorded. From this information the specific error matrices and statistics were computed.

The confusion matrices show the mapping error for each relevant class. For each class the number of samples, which are correctly and not correctly classified, are listed in the Tables below. They allow the calculation of the user and producer accuracies for each class as well as the confidence interval at 95% confidence levels based on the formulae above. The results of the accuracy assessment are listed in Table 7 and Table 8 below, for 2005 and 2017 respectively.

Table 7: Results of the Accuracy Assessment of Urban Green Areas in Bhopal, 2005. Overall Accuracy 88.37 %.

Urban Green 2005	Reference Data		Totals
	0 - Non-Urban Green Area	1 - Urban Green Area	
0 - Non-Urban Green Area	107	15	122
1 - Urban Green Area	10	83	93
Totals	117	98	**215**

Table 8: Results of the Accuracy Assessment of Urban Green Areas in Bhopal, 2017. Overall Accuracy 86.98%.

Urban Green 2017	Reference Data		Totals
	0 - Non-Urban Green Area	1 - Urban Green Area	
0 - Non-Urban Green Area	136	27	163
1 - Urban Green Area	1	51	52
Totals	137	78	**215**

The confusion matrices are additionally provided within the Quality Control documentation in Annex 2 and showing the mapping error for each relevant class. For each class the number of samples which are correctly and not correctly classified are listed, which allows the calculation of the user and producer accuracies for each class as well as the confidence interval at 95% confidence levels.

3.4 Quality Control/Assurance

A detailed Quality Control and Quality Assurance (QC/QA) system has been developed which records and documents all quality relevant processes ranging from the agreed product requirements, the different types of input data and their quality as well as the subsequent processing and accuracy assessment steps. The main goal of the QC/QA procedures was the verification of the completeness, logical consistency, geometric and thematic accuracy and that metadata are following ISO standards on geographic data quality and INSPIRE data specifications. These assessments were recorded in Data Quality Sheets which are provided in Annex 2. The QC/QA procedures were based on an assessment of a series of relevant data elements and processing steps which are part of the categories listed below:

- Product requirements;
- Specifications of input data: EO data, in-situ data, ancillary data;
- Data quality checks: EO data quality, in-situ data quality, ancillary data quality;
- Pre-Processing: gGeometric correction, geometric accuracy, data fusion (if applicable), data processing;
- Thematic processing: classification, plausibility checks;
- Accuracy: thematic accuracy, error matrices
- Delivery checks: completeness, compliancy with requirements

After each intermediate processing step, a QC/QA was performed to evaluate products appropriateness for the subsequent processing (see Figure 4).

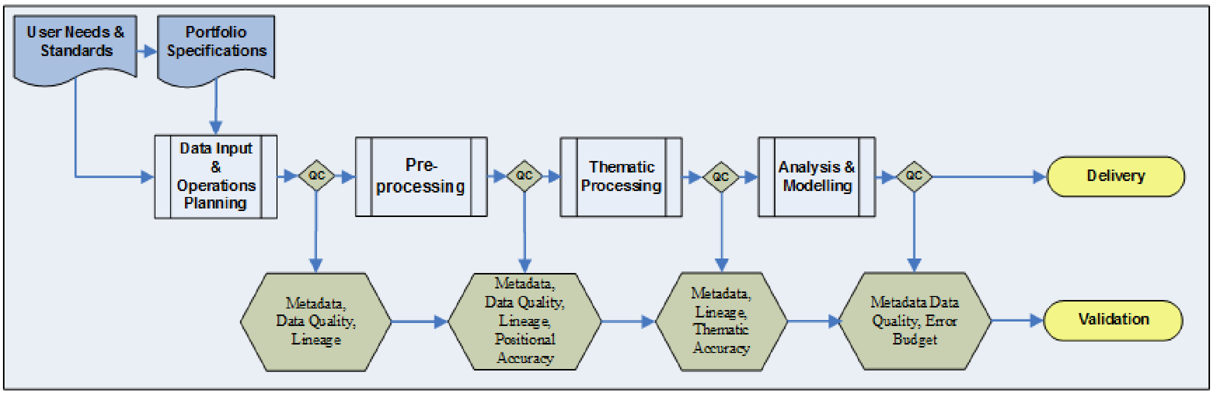


Figure 4: Quality Control process for EO4SD-Urban product generation. At each intermediate processing step output properties are compared against pre-defined requirements.

After the initial definition of the product specifications (output) necessary input data were defined and acquired. Input data include all satellite data and reference data e.g. in-situ data, reference maps, topographic data, relevant studies, existing standards and specifications, statistics. These input data were the baseline for the subsequent processing and therefore all input data had to be checked for **completeness**, **accuracy** and **consistency**. The evaluation of the quality of input data provides confidence of their suitability for further use (e.g. comparison with actual data) in the subsequent processing line. Data processing towards the end-product required multiple intermediate processing steps. To guarantee a traceable and quality assured map production the QC/QA assessment was performed and documented by personnel responsible for the Quality Control/Assurance. The results of all relevant steps provided information of the acceptance status of a dataset/product.

The documentation is furthermore important to provide a comprehensive and transparent summary of each production step and the changes made to the input data. With this information the user will be able to evaluate the provided services and products. Especially the accuracy assessment of map products and the related error matrices are highly important to rate the quality and compare map products from different service providers.

The finalised QC/QA forms are attached in Annex 2.

3.5 Metadata

Metadata provides additional information about the delivered products to enable it to be better understood. In the current project, a harmonised approach to provide metadata in a standardised format applicable to all products and end-users was adopted. Metadata are provided as XML files, compliant to the ISO standard 19115 "Metadata" and ISO 19139 "XML Scheme Implementation". The metadata files have been created and validated by the GIS/IP-operator for each map product with the Infrastructure for Spatial Information in Europe (INSPIRE) Metadata Editor available at: http://inspire-geoportal.ec.europa.eu/editor/.

The European Community enacted a Directive in 2007 for the creation of a common geo-data infrastructure to provide a consistent metadata scheme for geospatial services and products that could be used not only in Europe but also globally. The geospatial infrastructure called INSPIRE was built in a close relation to existing International Organization for Standardization (ISO) standards. These are ISO 191115, ISO 19119 and ISO 15836. The primary incentive of INSPIRE is to facilitate the use and sharing of spatial information by providing key elements and guidelines for the creation of metadata for geospatial products and services.

The INSPIRE Metadata provides a core set of metadata elements which are part of all the delivered geo-spatial products to the users. Furthermore, the metadata elements provide elements that are necessary to perform queries, store and relocate data in an efficient manner. The minimum required information is specified in the Commission Regulation (EC) No 1205/2008 of 3 December 2008 and contains 10 elements:

- Information on overall Product in terms of: Point of contact for product generation, date of creation
- Identification of Product: Resource title, Abstract (a short description of product) and Locator
- Classification of Spatial Data
- Keywords (that define the product)
- Geographic information: Area Coverage of the Product
- Temporal Reference: Temporal extent; date of publication; date of last revision; date of creation
- Quality and Validity: Lineage, spatial resolution
- Conformity: degree of conformance to specifications
- Data access constraints or Limitations
- Responsible party: contact details and role of contact group/person

These elements (not exhaustive) constitute the core information that has to be provided to meet the minimum requirements for Metadata compliancy. Each element and its sub-categories or elements have specific definitions; for example in the element “Quality” there is a component called “Lineage” which has a specific definition as follows: “a statement on process history and/or overall quality of the spatial data set. Where appropriate it may include a statement whether the data set has been validated or quality assured, whether it is the official version (if multiple versions exist), and whether it has legal validity. The value domain of this element is free text,” (INSPIRE Metadata Technical Guidelines, 2013). The detailed information on the Metadata elements and their definitions can be found in the “INSPIRE Metadata Implementing Rules: Technical Guidelines,” (2013). Each of the EO4SD-Urban products will be accompanied by such a descriptive metadata file. It should be noted that the internal use of metadata in these institutions might not be established at an operational level, but the file format (*.xml) and the web accessibility of data viewers enable for the full utility of the metadata.

4 Analysis of Mapping Results

This Chapter will present and assess all results, which have been produced within the framework of the current project, in the context of presentation of the Settlement Extent product, the LU/LC products and the Urban Green Area product. Furthermore, the sections that follow will provide the results of some standard analytics undertaken with these products including the following:

- Settlement Extent – Developments from 1990, 1995, 2000, 2005, 2010 to 2015
- Land Use/ Land Cover - Status and Trends between 2005 and 2017
- Urban Green Areas – Status and Change between 2005 and 2017

It is envisaged that these analytics provide information on general trends and developments in the High Density Core and Urban Cluster areas which can then be further interpreted and used by Urban planners and the City Authorities for city planning.

It should be noted that all digital data sets for these products are provided in concurrence with this City Report with all the related metadata and Quality Control documentation

4.1 Settlement Extent – Developments 1990, 1995, 2000, 2005, 2010 and 2015

The Urban or World Settlement Extent (WSE) product in the EO4SD-Urban project is provided by the German Aerospace Centre (DLR) and is provided for 6 points in time; this product and its accuracy was described in Section 2.5 and 3.3.2. In the current project, the Urban Extent product for Bhopal was first used to assess historical developments from 1990-2015. Further analysis by overlaying administrative boundaries can be performed to assess urbanisation extent patterns based on administrative units.

Results:

The first result provided (see Figure 5 and 6) uses the different Settlement Extent products from 1990 to 2015 shows the urban development in the High Density Core and Urban Cluster areas as well as surrounding regions of Bhopal. The settlement extent developments after 1990 can be examined by Urban Planners to identify different patterns of growth such as “Edge Growth” or “Leapfrog Growth” depending on the location of the developments.

From the depiction of settlement extent developments between 1990 and 2015 illustrated in Figure 5 and Figure 6, the settlement extent development occurred in Bhopal in large blocks around existing residential areas and also stretches in two lines towards the south. The urban development until 2005 stretches towards the east in very small fragmented patches. The same patterns appear in the next epoch 2005 to 2010 whereas additionally larger built-up areas occur in the western as well as in the eastern outskirts of Bhopal. In 2010, the urban area further increased around already existing urban areas, but most of the expansion occurred in the very south of the High Density Core area and stretches in very small fragmented patterns in all directions.

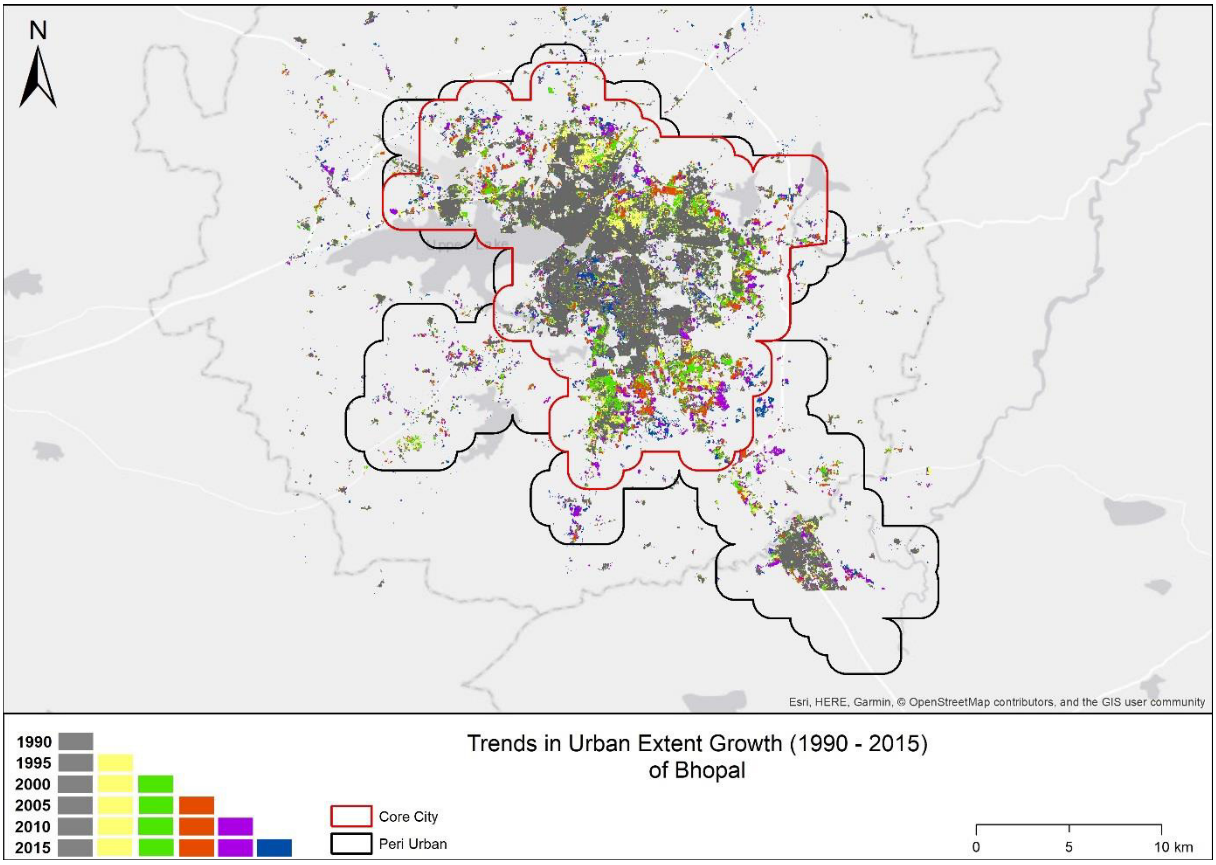


Figure 5: Settlement Extent developments in the epochs from 1990 to 1995, from 1995 to 2000, from 2000 to 2005, from 2005 to 2010, and from 2010 to 2015 in Bhopal and surrounding region.

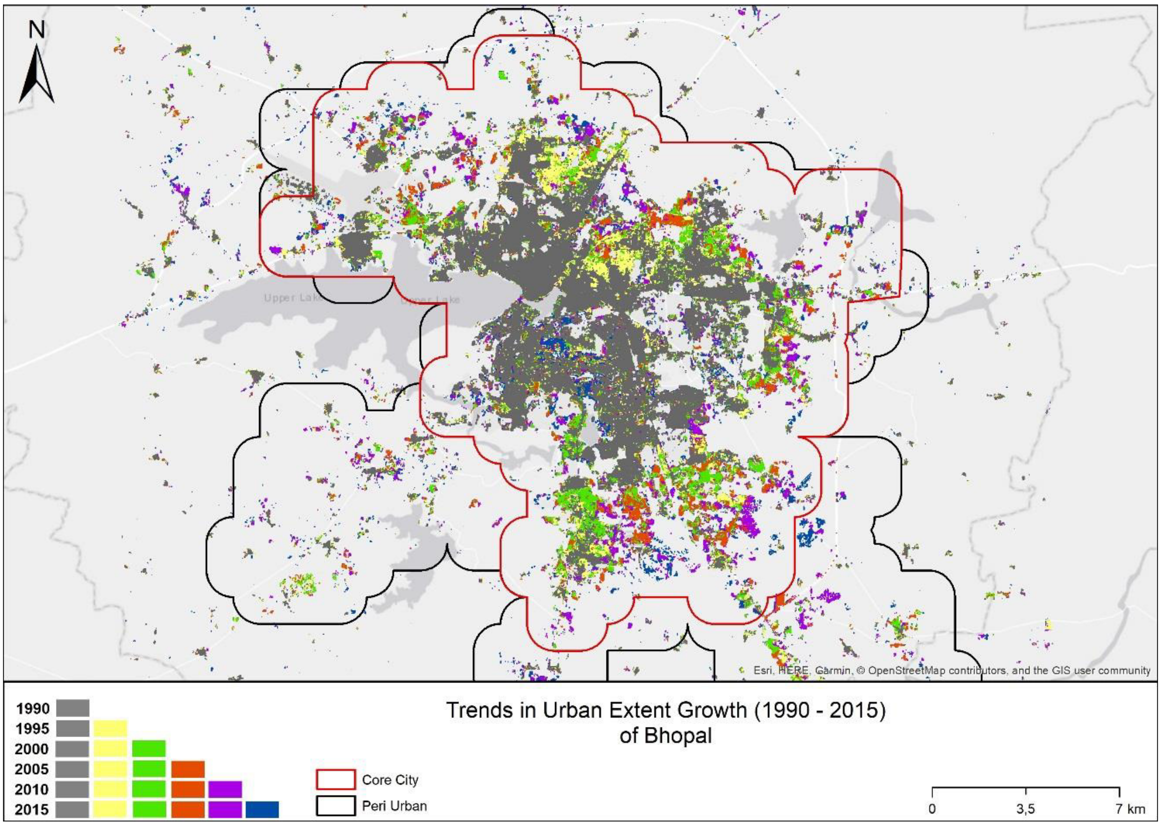


Figure 6: Settlement Extent developments in the epochs from 1990 to 1995, from 1995 to 2000, from 2000 to 2005, from 2005 to 2010, and from 2010 to 2015 in the High Density Core area of Bhopal.

4.2 Land Use / Land Cover 2005 and 2017

This Section will present the results of the LU/LC mapping for 2005 and 2017 as well the statistical information on the changes between these two epochs. The LU/LC overview map for 2017 is depicted in Figure 7 and a cartographic version of the map layout is provided as a pdf file in addition to the geo-spatial product.

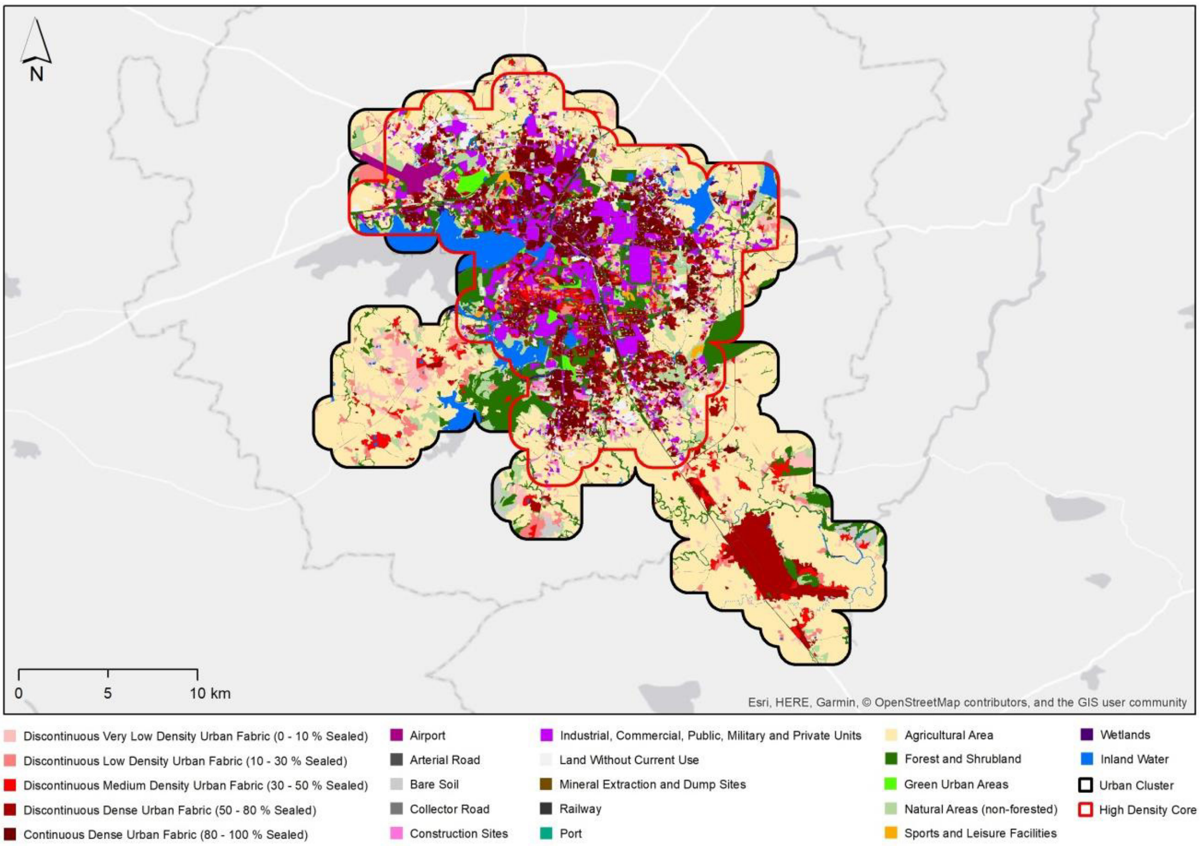


Figure 7: Detailed Land Use/ Land Cover for 2017 in Bhopal.

In the 2005 epoch the most dominant LU/LC classes occurring in the whole area were Agriculture (48.77% of the total area), Residential (15.77 % of the total area), Natural areas (9.37 % of the total area) and Forest areas (8.51% of the total area). By 2017 these classes remained as the most dominant with some slight changes. For instance, the Residential class increased by 6.45% (36.9 km^2). Further, information on the class disaggregation and area coverage is presented in Figure 8 and Figure 9 for the epochs 2005 and 2017 respectively.

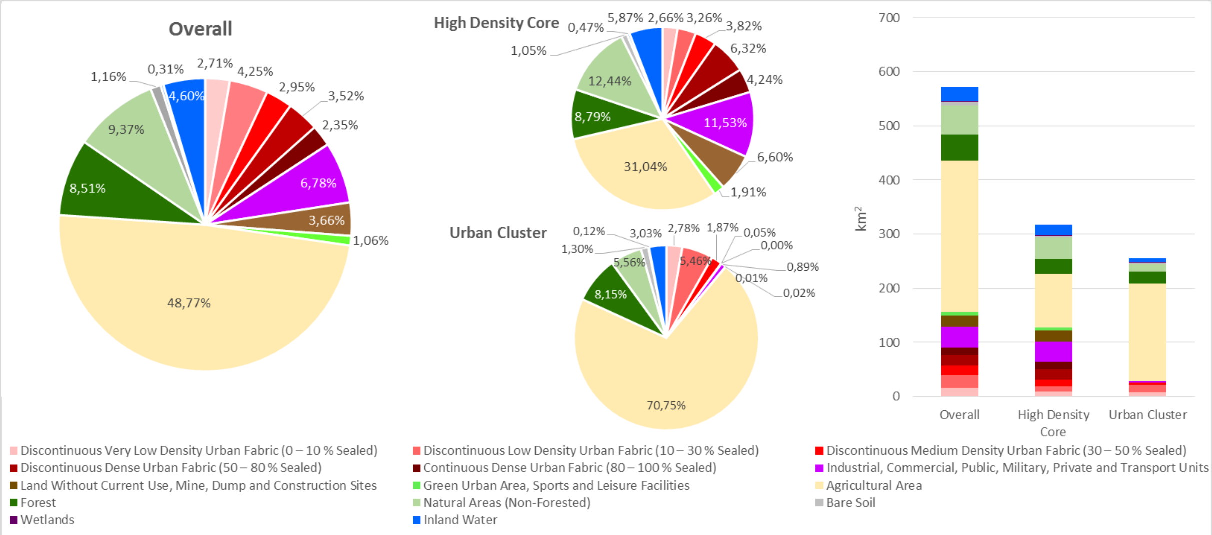


Figure 8: Detailed Land Use/Land Cover 2005 structure: Presented as Overall, High Density Core and Urban Cluster in % (left) and km² (right).

Similarly, to the Overall area, Agriculture was the most dominant class in 2005 in both the High Density Core and the Urban Cluster with 31.04% and 70.75%, respectively. The main difference between these two areas is the coverage and density of the Residential class and the extent of the commercial and industrial areas. The Residential areas in the Urban Cluster belong to the low density classes and are scattered over larger areas.

By 2017 (see Figure 9), several trends were observed in the class distribution and the area coverage. For instance, the Agriculture class decreased by 6.76% for the period 2005 - 2017, by losing 38.71 km² from its initial area of 279.21 km² in 2005. The Residential class, which represented 15.77% (90.31 km²) from the Overall area in 2005, increased by 6.45% thus accounting for 127.2 km² from the Overall area by 2017. Detailed information on the area, percentage distribution and changes can be further observed in Table 9.

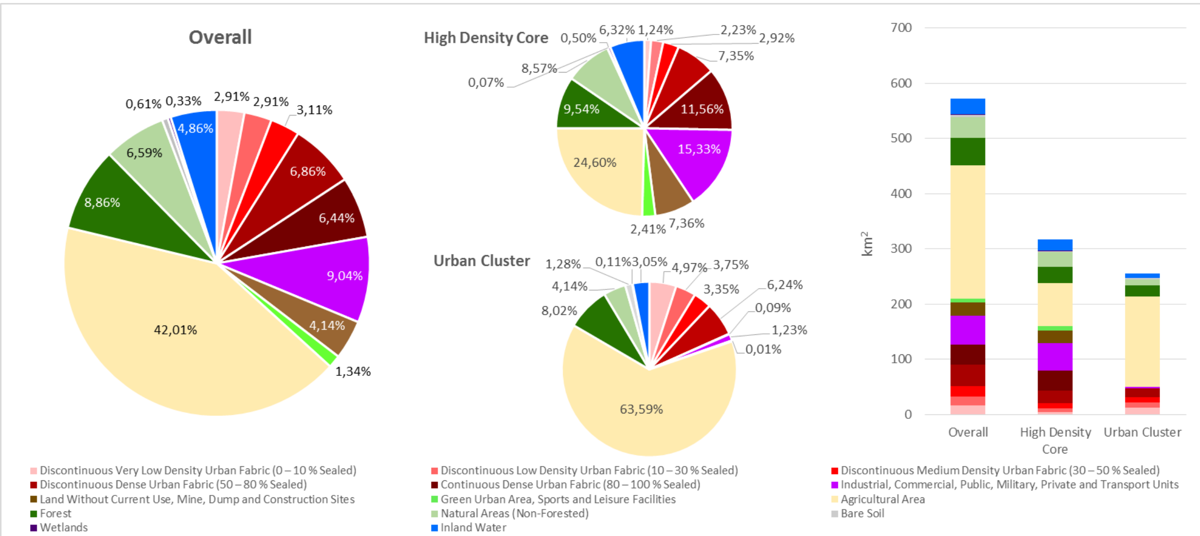


Figure 9: Detailed Land Use/Land Cover 2017 structure: Presented as Overall, High Density Core and Urban Cluster in % (left) and km² (right).

The next Section will highlight the LU/LC change information between the two epochs in more detail.

<u>Description of LULC Changes:</u>

In addition to the overall LU/LC classification for the two epochs, it is interesting to assess the different trends between classes over the 12 year time period. To get an overview the quantitative figures for each class (combined High Density Core and Urban Cluster) are provided in Table 9.

Table 9: Detailed information on area and percentage of Overall area for each class for 2005 and 2017 as well as the changes.

LU/LC Classes	2017		2005		Change		Change per Year	
	sqkm	% of total	sqkm	% of total	sqkm	%	sqkm	%
Discontinuous Very Low Density Urban Fabric (0 – 10 % Sealed)	16.54	2.89%	15.46	2.70%	1.08	0.19%	0.09	0.02%
Discontinuous Low Density Urban Fabric (10 – 30 % Sealed)	16.66	2.91%	24.32	4.25%	-7.65	-1.34%	-0.64	-0.11%
Discontinuous Medium Density Urban Fabric (30 – 50 % Sealed)	17.80	3.11%	16.87	2.95%	0.93	0.16%	0.08	0.01%
Discontinuous Dense Urban Fabric (50 – 80 % Sealed)	39.25	6.86%	20.14	3.52%	19.11	3.34%	1.59	0.28%
Continuous Dense Urban Fabric (80 – 100 % Sealed)	36.86	6.44%	13.45	2.35%	23.41	4.09%	1.95	0.34%
Isolated Structures	0.11	0.02%	0.08	0.01%	0.03	0.00%	0.00	0.00%
Industrial, Commercial, Public	39.19	6.84%	28.92	5.05%	10.26	1.79%	0.86	0.15%
Arterial Road	1.82	0.32%	1.54	0.27%	0.28	0.05%	0.02	0.00%
Collector Road	5.71	1.00%	4.94	0.86%	0.77	0.14%	0.06	0.01%
Railway	1.44	0.25%	1.43	0.25%	0.01	0.00%	0.00	0.00%
Port	0.01	0.00%	0.01	0.00%	0.00	0.00%	0.00	0.00%
Airport	3.55	0.62%	1.98	0.35%	1.57	0.27%	0.13	0.02%
Mining Area, Dump Sites	1.08	0.19%	1.59	0.28%	-0.51	-0.09%	-0.04	-0.01%
Construction Sites	6.73	1.18%	4.49	0.78%	2.24	0.39%	0.19	0.03%
Land Without Current Use	15.91	2.78%	14.89	2.60%	1.02	0.18%	0.09	0.01%
Green Urban Area	5.31	0.93%	4.58	0.80%	0.74	0.13%	0.06	0.01%
Sports and Leisure Facilities	2.34	0.41%	1.51	0.26%	0.83	0.15%	0.07	0.01%
Agricultural Area	240.50	42.01%	279.21	48.77%	-38.71	-6.76%	-3.23	-0.56%
Forest	50.72	8.86%	48.70	8.51%	2.02	0.35%	0.17	0.03%
Natural Areas (Grassland)	37.73	6.59%	53.62	9.37%	-15.89	-2.77%	-1.32	-0.23%
Bare Soil	3.52	0.61%	6.64	1.16%	-3.12	-0.54%	-0.26	-0.05%
Wetlands	1.86	0.33%	1.78	0.31%	0.08	0.01%	0.01	0.00%
Inland Water	27.84	4.86%	26.35	4.60%	1.49	0.26%	0.12	0.02%
Total	**572.48**	**100.00%**	**572.48**	**100.00%**				

The area statistics of the LU/LC classes show a lot of change dynamics within the Residential density classes. For example, it can be noted that there is an evident loss of area in the Low Density class (10-30 %) with 7.65% and an increase in all other density classes.

4.2.1 Spatial Distribution of Main LU/LC Change Categories

In order to better analyse the growth trend and the spatial distribution of changes, meaningful aggregations of the LU/LC classes in both epochs were used. The following categories were developed:

- Urban Densification: Changes from lower Residential Density class into a higher Residential Density class;
- Urban Residential Expansion: all changes from Non-Urban Residential classes to a Residential class;
- Other Urban Land Use Expansion: all changes from Non-Residential Urban classes to Other Urban and Non-Urban classes.

- Changes within Natural and Semi-Natural Areas: all changes in between the natural and semi-natural classes (e.g. Forest into Agriculture).

The overlay analysis of these aggregated categories of the epochs 2005 and 2017 is depicted in Figure 10.

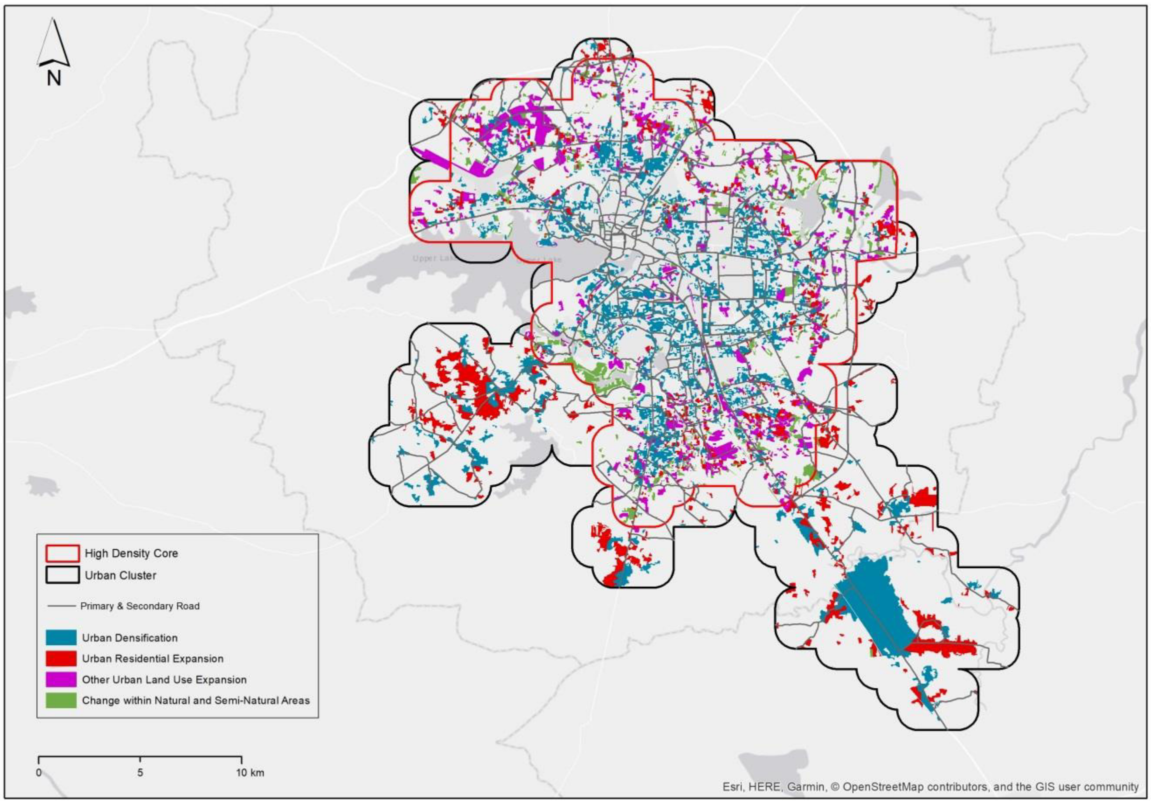


Figure 10: Land Use/Land Cover Change Types - Spatial Distribution.

The spatial distribution of the change types as depicted in Figure 10 shows that the urban densification in the 12 year period mainly happened in the city centre of Bhopal and in the southern part of the Urban Cluster along the main roads. The Expansion of the Residential areas (red colour in Figure 10) occurred mainly in the south-eastern and eastern part of the High Density Core. Small scattered areas in the northern part of the Core city experienced Residential extension as well.

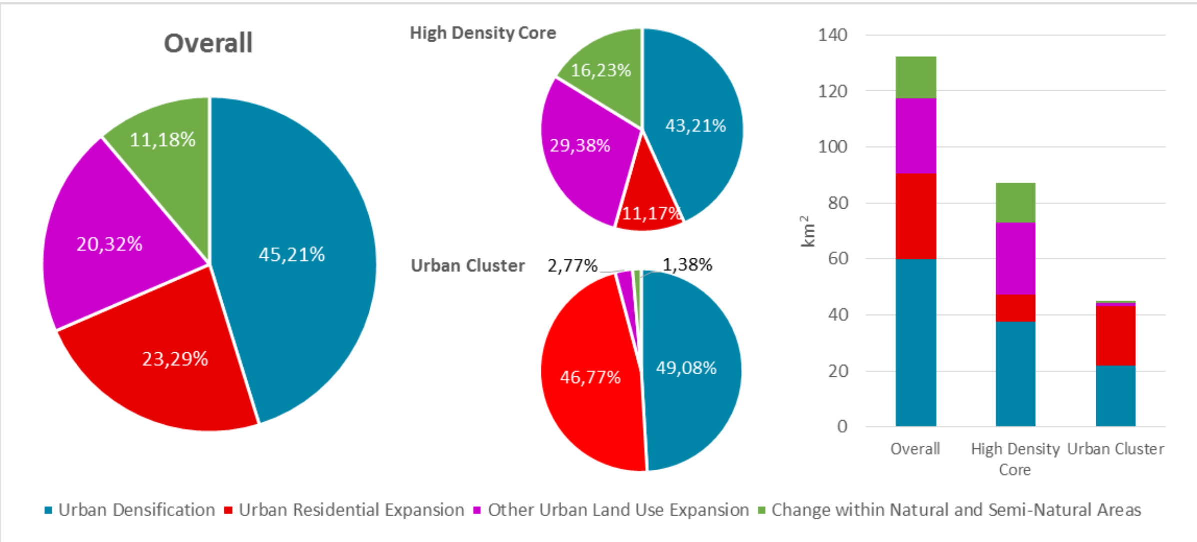


Figure 11: Land Cover Land Use Change Types 2005-2017 - Overall, in High Density Core and in Urban Cluster in % (left) and km² (right) in Bhopal.

The statistics of the Change categories are presented in Figure 11 and ad Table 10. The statistics in Figure 11 provide a quantitative aspects to the LU change classes; for example it's interesting to note that Urban Densification was the most dominant change class in both the High Density Core and Urban Cluster with 43.21% and 49,08%, respectively.

Regarding the Overall area of Bhopal, the most dynamic changes which occurred between 2005 – 2017 were represented by the Urban Densification class, i.e. changes from lower to higher Residential Density classes with 45.21 % from the total area as presented in Figure 11. The second largest block of changes can be observed within the Urban Residential Expansion, followed by Other Urban Land Use Expansion.

The main difference between the High Density Core and the Urban Cluster in Bhopal was that only 11.17% from the High Density Core was used for residential expansion, whereas 46.77% of land conversion in the Urban Cluster was related to Urban Residential Expansion, which represents the second highest value of the land conversion. The quantitative data is presented in Table 10.

Table 10: Overall LU/LC Statistics.

Change Classes	Change Overall		Change High Density Core		Change Urban Cluster	
	sqkm	%	sqkm	%	sqkm	%
Urban Densification	59.80	45.21%	37.70	43.21%	22.10	49.08%
Urban Residential Expansion	30.81	23.29%	9.75	11.17%	21.06	46.77%
Other Urban Land Use Expansion	26.88	20.32%	25.63	29.38%	1.25	2.77%
Change within Natural and Semi-Natural Areas	14.78	11.18%	14.16	16.23%	0.62	1.38%
Total	**132.27**	**100.00%**	**87.24**	**100.00%**	**45.03**	**100.00%**

4.2.2 Changes of Agricultural Areas

In order to analyse the relatively large loss of Agricultural areas as noted in the earlier part of Section 4.2, further change analysis was performed. The following change categories were developed for this analysis:

- Agriculture to Residential area
- Agriculture to Industry, Commercial; Public or Military area
- Agriculture to Plantations

The spatial distribution of these changes is displayed in Figure 12.

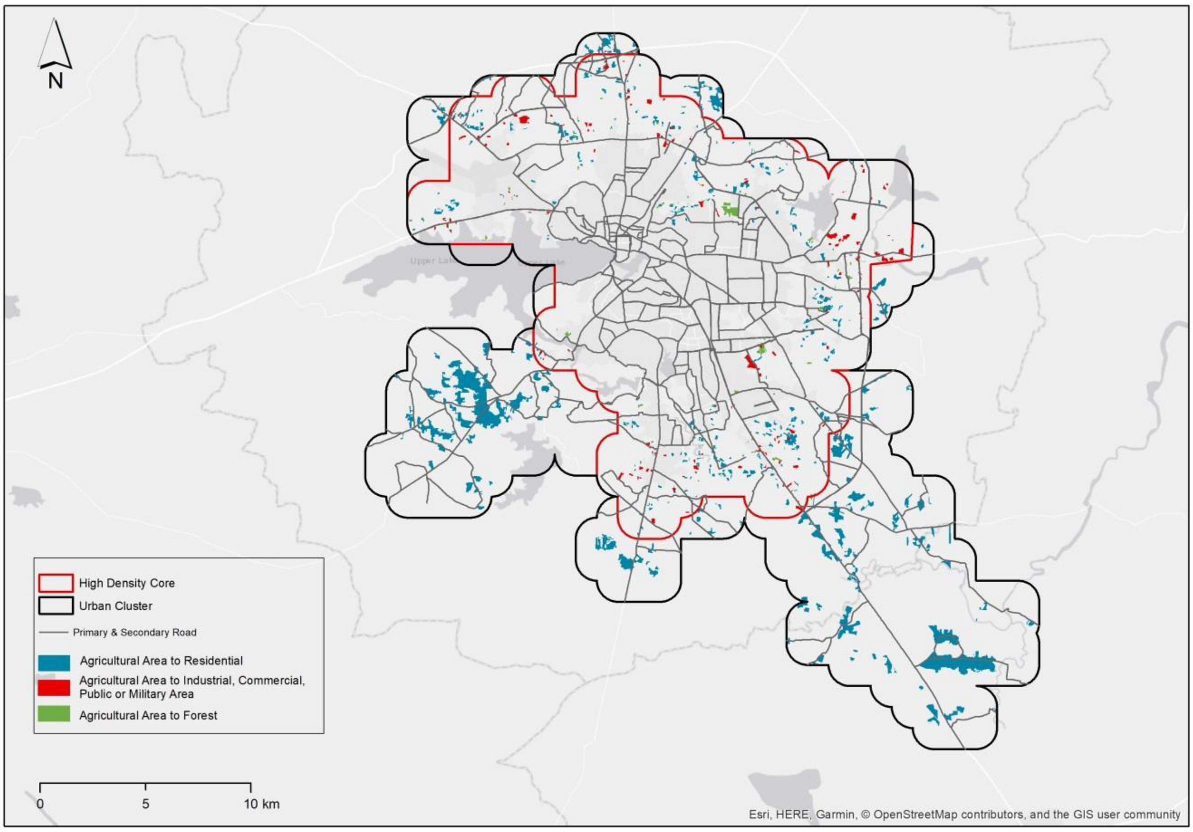


Figure 12: Spatial distribution of changes from Agricultural Areas to other Classes between 2005 and 2017.

The conversion of agricultural areas into other LU/LC classes was mainly caused by the residential and industrial or commercial expansion in Bhopal. These two conversion types are shown in Figure 12 in blue and red colors respectively. Especially in the southern and south-western area of Bhopal, large agricultural areas were replaced by urban settlements.

Figure 13 and Table 11 provide a quantitative overview of the changes of the agricultural areas into other LU classes between 2005 and 2017 in Bhopal. As it can be observed in Figure 12, most of the agricultural areas subject to change were converted to residential areas (blue color). A few larger areas in the eastern and northern part of Bhopal were converted into industrial or commercial land use (red color). Within the core region most of this conversion type are scattered throughout the entire city along the transition from the High Density Core area to the Urban Cluster (see Figure 12, red color). The third change class in Figure 12 depicts changes from agricultural to forested areas, which only have a minor contribution to the LU/LC changes in the period between 2005 – 2017. The percentage of each change type is presented in Figure 13 and Table 11.

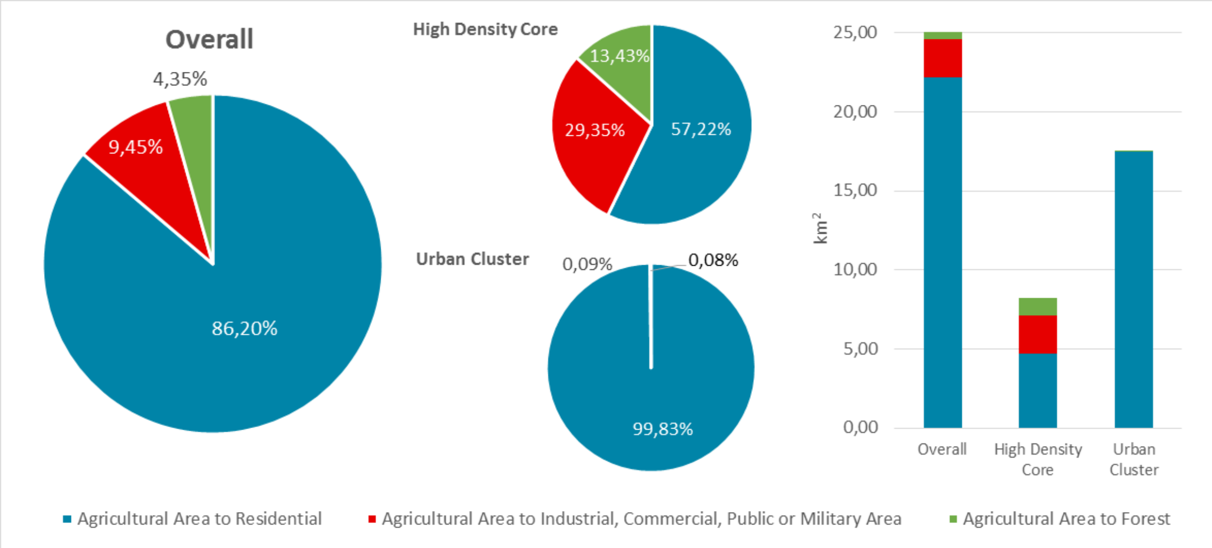


Figure 13: Changes of Agricultural areas into other LU/LC classes between 2005 and 2017; Presented as Overall, High Density Core and Urban Cluster in % (left) and km^2 (right).

The statistics in Figure 13 and Table 11 show that the majority of agricultural areas in the High Density Core and the Urban Cluster zone have been converted into residential areas in the 2005 – 2017 period, followed by the expansion of industrial or commercial land use.

Table 11: Statistics of changes of Agricultural areas.

Change Classes	Change Overall		Change High Density Core		Change Urban Cluster	
	sqkm	**%**	**sqkm**	**%**	**sqkm**	**%**
Agricultural Area to Residential	22.18	86.20%	4.71	57.22%	17.47	99.83%
Agricultural Area to Industrila, Commercial, Public or Military Area	2.43	9.45%	2.42	29.35%	0.02	0.09%
Agricultural Area to Forest	1.12	4.35%	1.11	13.43%	0.01	0.08%
Total	**25.74**	**100.00%**	**8.23**	**100.00%**	**17.50**	**100.00%**

4.3 Urban Green Areas

The location and extent of green areas are determined within the product of urban land use/ land cover at Level I. Urban green areas refer to land within and on the edges of a city that is partly or completely covered with grass, trees, shrubs, or other vegetation. The product delivered provides accurate information (1 m resolution) on the spatial location and extent of green areas located within the Urban Extent (Level I class: 1000) derived from the baseline LU/LC information product. Detecting and monitoring urban green coverage needs very high resolution optical satellite images, which explains the product generation over the High Density Core area of Bhopal only.

The overview map in Figure 14 gives an overview of the mapping result and the structure of the map, which is designed for a print out at DIN A0 paper size (84.1 x 118.9 cm).

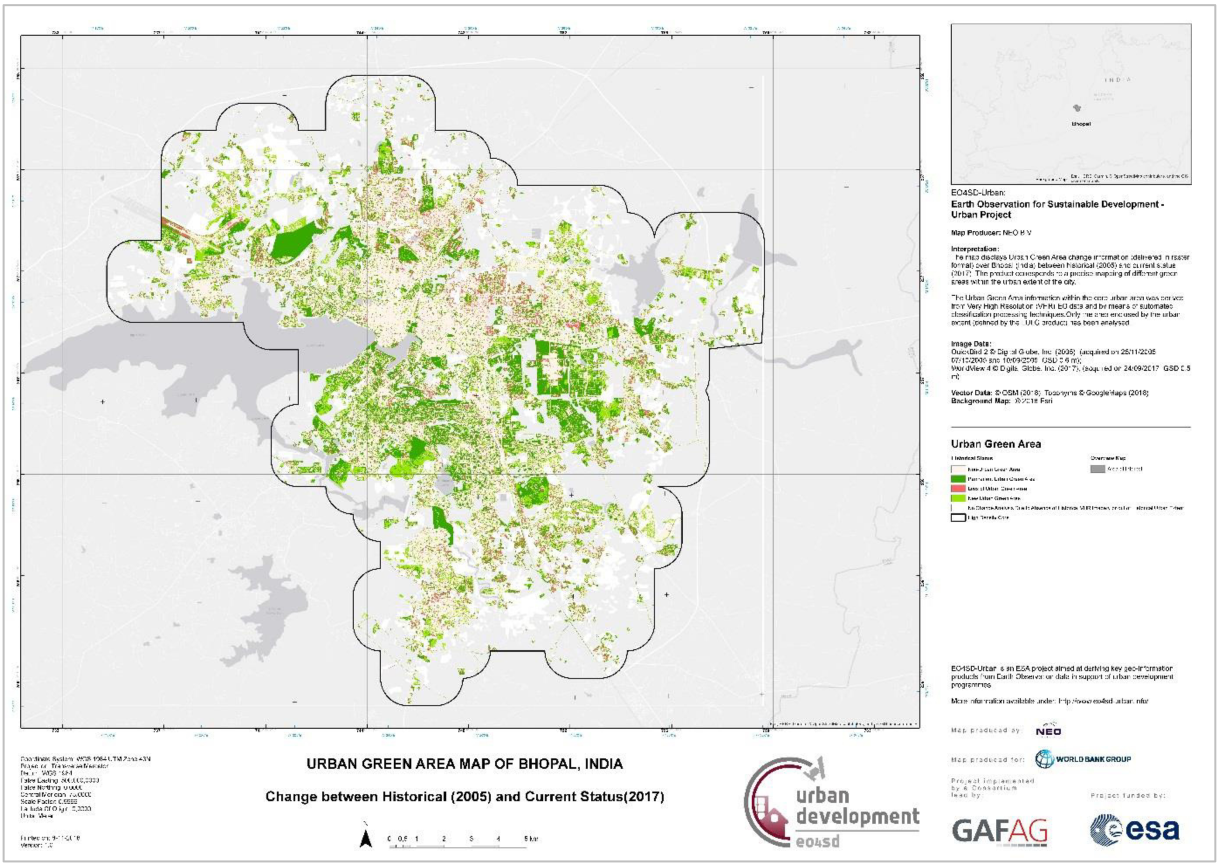


Figure 14: Map overview of Urban Green Areas in Bhopal. Green area loss, gain and stable green areas can be identified. The map is delivered as separate product of high resolution for printing at paper size DIN A0, which is 84.1 cm x 118.9 cm.

The spatial distribution of the change types as depicted in Figure 14 shows that changes are distributed across the entire city centre area of Bhopal. The surrounding areas are mostly covered by Agriculture and/or Natural or semi-Natural areas. Overall 17.96% of the entire area was covered by vegetation in 2005 and 2017. The percentage of gain of green area (12.93%) is higher than the percentage of loss of green area (7.06%) resulting in an increase of urban green areas in Bhopal. About 38.01% of the Overall area was covered by the Artificial class (Level I class).

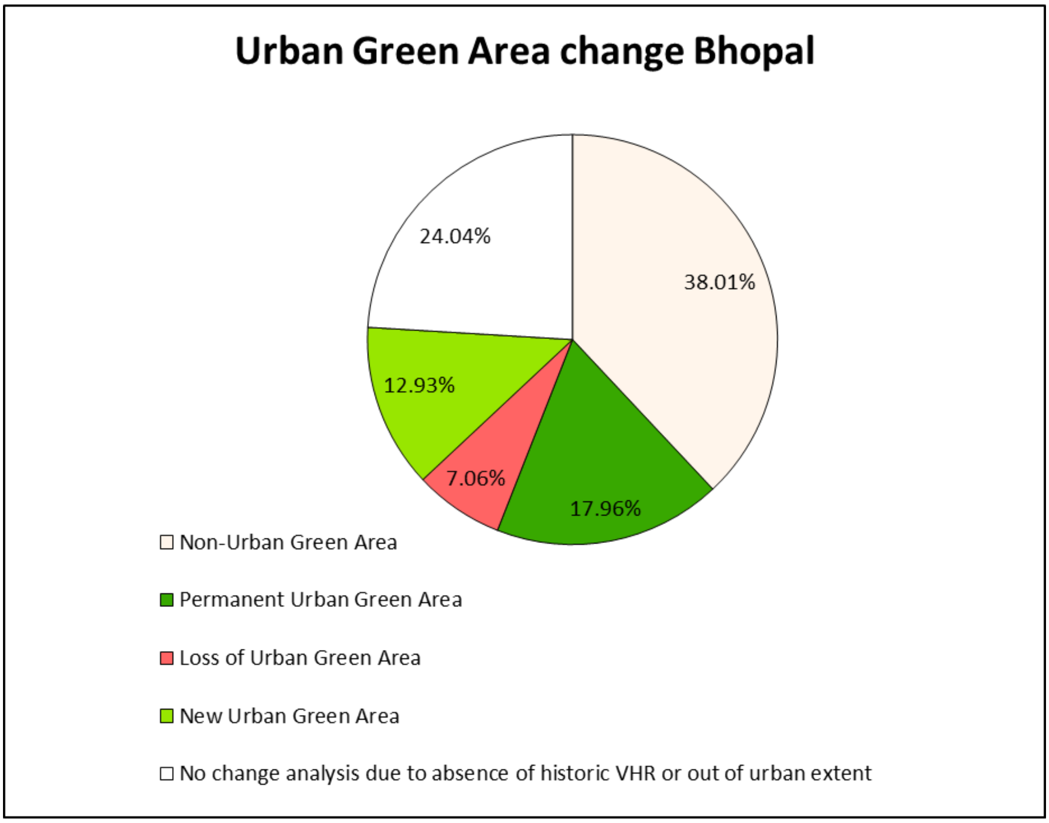


Figure 15: Percentage of Urban Green areas within the High Density Core area of Bhopal. The pie chart illustrates the status and change of Urban Green areas in-between 2005 and 2017.

The changes within the Urban Green areas can be illustrated as an overall area coverage. Figure 16 represents the green area coverage in square kilometers in 2005 and 2017, compared to the amount of the Artificial areas class. Both classes demonstrated a relatively equal growth within the 12 year period. Artificial (Urban) areas showed an increase of 4.51 km² (from 86.07 km² to 90.58 km²) and Urban Green areas an increase of 27.48 km² (from 42.17 km² to 69.65 km²).

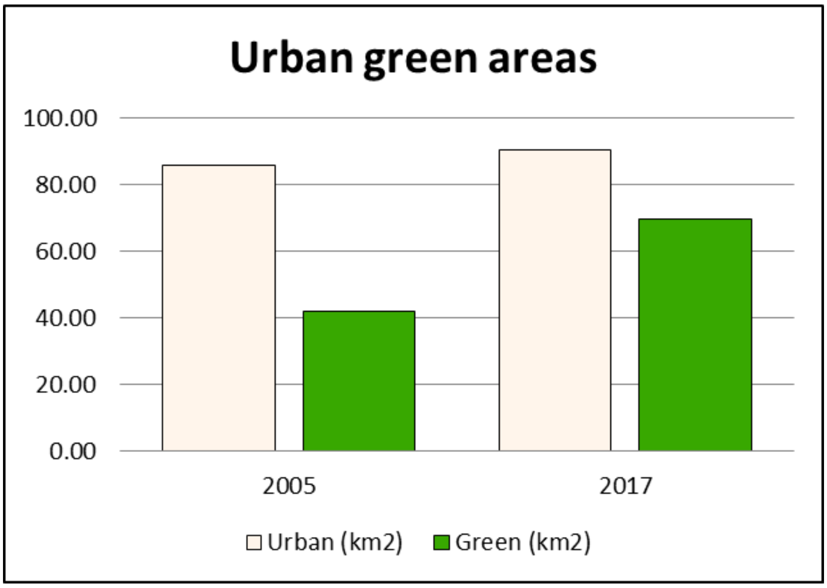


Figure 16: Bar charts for both points in time presenting the Overall area of urban greenery versus non-green areas.

4.4 Spatial Analytics for Urban Planning

The following chapters illustrate three different metrics in order to quantitatively describe the form and growth of metropolitan areas. All analyses presented below are based on the World Settlement Footprint (WSF) product provided by the German Aerospace Centre (DLR) for 6 points in time. Further details about the product and its accuracy can be seen in section 2.5 and 3.3.2.

For the following analytics the World Settlement Footprint for Bhopal was used to assess development trends in terms of urban expansion, the level of fragmentation and directional distribution for six time intervals: 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2015 and 1990-2015.

4.4.1 Urban Expansion

The Urban Expansion metric described in this study can be divided in two categories: on the one hand, it is appropriate to clearly delineate city limits and derive a size measure based on such boundary. On the other hand, it is useful to understand and visualise different patterns of growing settlements. In this case, two main categories are described to divide the city´s growth: edge growth (including infill) as well as leapfrog growth. The crucial criteria for the detection of edge growth is the location of newly developed patches between two points in time – those are adjacent to already build up areas, newly developed areas that form an extension of the city limit. Whereas leapfrog growth indicates newly developed polygons that are not in touch with the old city limits. Urban developments at a distance from the Core with unused land in-between. Compared to each other, it can be assumed that leapfrog growth triggers urban fragmentation and poses various problems, while edge and infill growth promote a more compact city shape.

The map below (see Figure 17) illustrates the growth of Bhopal´s urban footprint from the year 1990 (black) until 2015 (green and red). Edge and infill developments are presented in green, leapfrogging in red. The results show mainly densification and compaction around the Core City Area as well as pronounced scattering developments in the outskirt districts. It is conspicuous that suburbs are commonly aligned to major road infrastructure in form of linear strips, which can be seen especially alongside Hoshangabad Road southward. Similarly, the process of suburbanisation is guided by the reachability of regions. Furthermore, it can be stated that nearly all developments are classified as edge or infill respectively, whereas only few areas have been assigned to leapfrog growth and merely occurs in smaller patches throughout the entire city area.

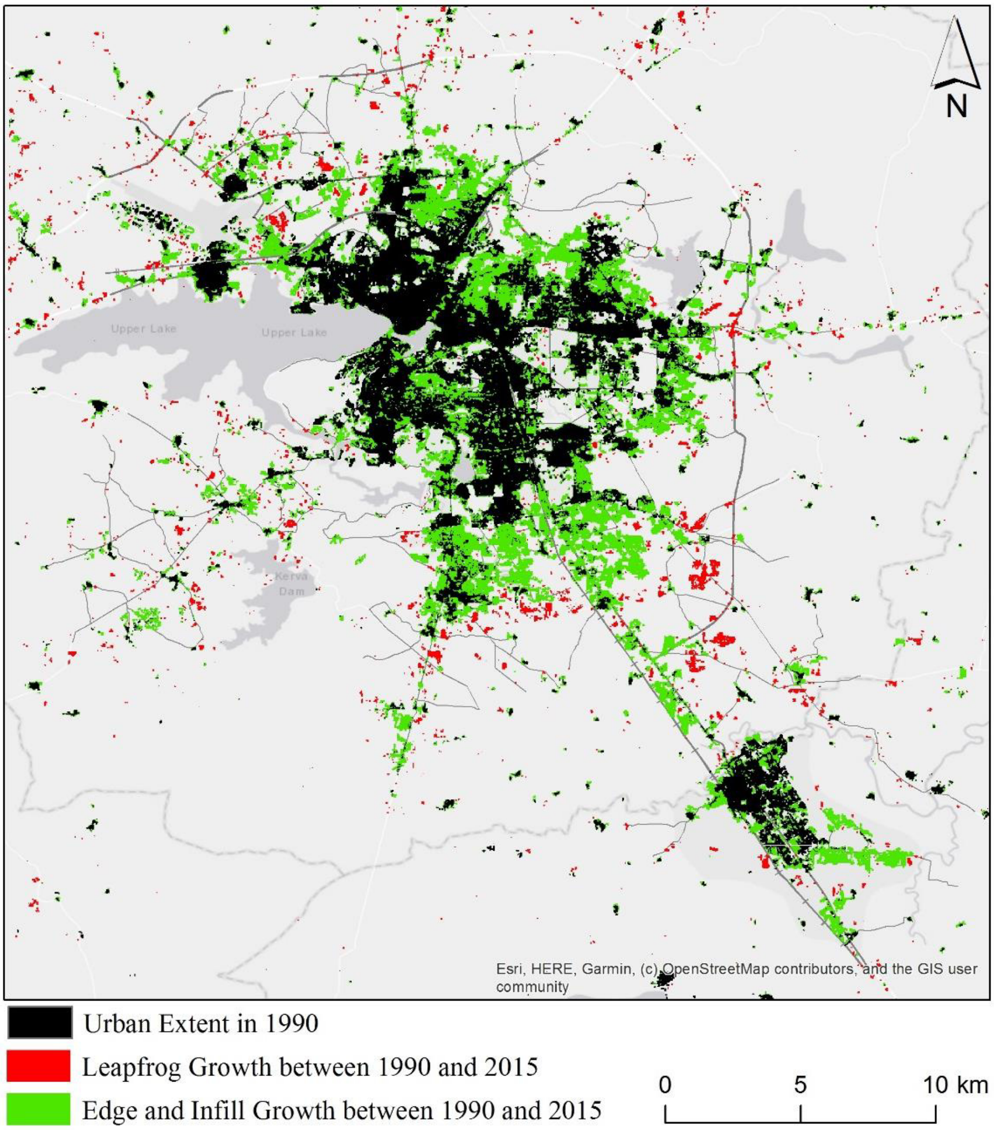


Figure 17: Growth categorisation results in Bhopal from 1990 – 2015.

The following chart (see Figure 18) and table (see Table 12) depict the increase in urban area over the years measured in square kilometres as well as individual shares of edge and leapfrog growth of this area increase. The area of the urban extent, characterised by the amount of sealed surfaces, has increased constantly within the 25 year time period from almost 82 km^2 to over 170 km^2 and has more than doubled since then. Bhopal has grown about 13% - 19% in every five-year period as seen in the grey line in Figure 18. Only between 2000 and 2005 the growth has decelerated slightly. As already mentioned above, the proportion of edge and infill growth is considerably larger compared to leapfrog growth. For the entire period of 25 years, 14.7% of total growth can be attributed to leapfrog growth, whereas 85.3% of the total growth was categorized as edge and infill growth.

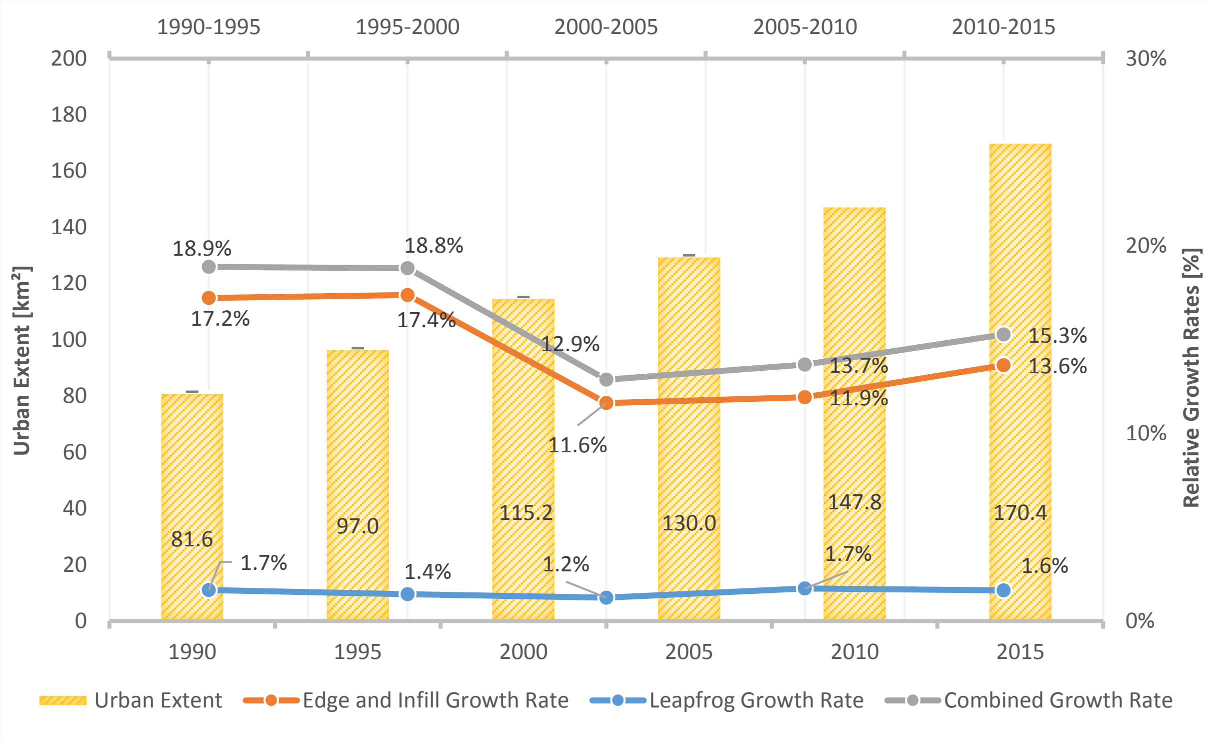


Figure 18: Growth analysis results in Bhopal from 1990 – 2015.

Table 12: Quantitative results of the growth analysis.

Year		1990-1995	1995-2000	2000-2005	2005-2010	2010-2015	1990-2015
Total Growth	Total Growth [km²]	15.4	18.24	14.83	17.78	22.59	88.83
	Relative Total Growth [%]	18.9	18.8	12.9	13.7	15.3	108.9
Edge and Infill Growth	Absolute Edge/Infill Growth [km²]	14.05	16.86	13.39	15.52	20.17	75.77
	Share of Total Growth [%]	91.2	92.4	90.3	87.3	89.3	85.3
	Relative Edge/Infill Growth [%]	17.2	17.4	11.6	11.9	13.6	92.9
Leapfrog Growth	Absolute Leapfrog Growth [km²]	1.35	1.38	1.44	2.26	2.41	13.06
	Share of Total Growth [%]	8.8	7.6	9.7	12.7	10.7	14.7
	Relative Leapfrog Growth [%]	1.7	1.4	1.2	1.7	1.6	16.0

4.4.2 Discontiguity (Fragmentation)

Fragmentation can be seen as one key attribute of urban sprawl. Fragmented urban footprints are characterised by unused open spaces interpenetrating the city resulting in a more scattered and/or leapfrogged form.

In its progress report on urban form and land use measures from 2012, the City Form Lab at MIT presents a Discontiguity Index that measures fragmentation by examining the rank order and size proportions of discontinuous urban developments. An ArcGIS toolbox, containing the Discontiguity Index Tool has been published under the License of Creative Commons Attribution 4.0 International on the City Form Lab Website cityform.mit.edu. This tool has been used for the purposes of this work. The

Metropolitan Form Analysis Discontiguity tool calculates the ratios between the area of each cluster and the area of the largest cluster and sums up these ratios - weighted by their share of the total urban area:

$$Discontiguity = \sum_{n=1}^{N} \left(\frac{\sum_{i=n+1}^{N} A_i}{A_n}\right)\left(\frac{\sum_{i=n}^{N} A_i}{A_{total}}\right)$$

A_n Area of cluster n
A_{total} Joint area of the built-up extent
N Number of urbanised clusters (City Form Lab, October 2012)

In summary, it can be said that if more built up area is concentrated into a single largest cluster, the more contiguous is the city.

The line chart in Figure 19 and Table 13 below depict the calculation results for the Discontiguity Index. A higher number indicate a higher degree of fragmentation. The dashed line presents a smoothing function of the curve and thus represents the overall fragmentation trend. Additionally, the bars present the relative index changes, separately for the 5 intervals 1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2015. Figure 19 clearly shows a slight decreasing trend of fragmentation in the dataset. For this reason, a densification process can be concluded for the period of 1990 to 2005, whereby core compaction has been the dominant development characteristic. During this time span, edge and infill developments grew significantly and consequently the fragmentation index drops by almost 30%. This assumption has already been mentioned in section 4.4.1 and is also visible in Figure 17. The densification process stopped between 2005 and 2010, where a slight increase in fragmentation of 1.2% was determined. However, the highest increase in fragmentation of 29% was achieved during 2010 and 2015. Nonetheless, the degree of fragmentation in 2015 (86.4) is still below the degree of fragmentation in 1990 (88.6). Especially low-density developments in the Larger Urban Area is contributing to this trend. This type of scattering development with large residential subdivisions is characterised by few buildings, occupying large parcels. The indicator detects such non-contiguous structures and rates them as particularly fragmented.

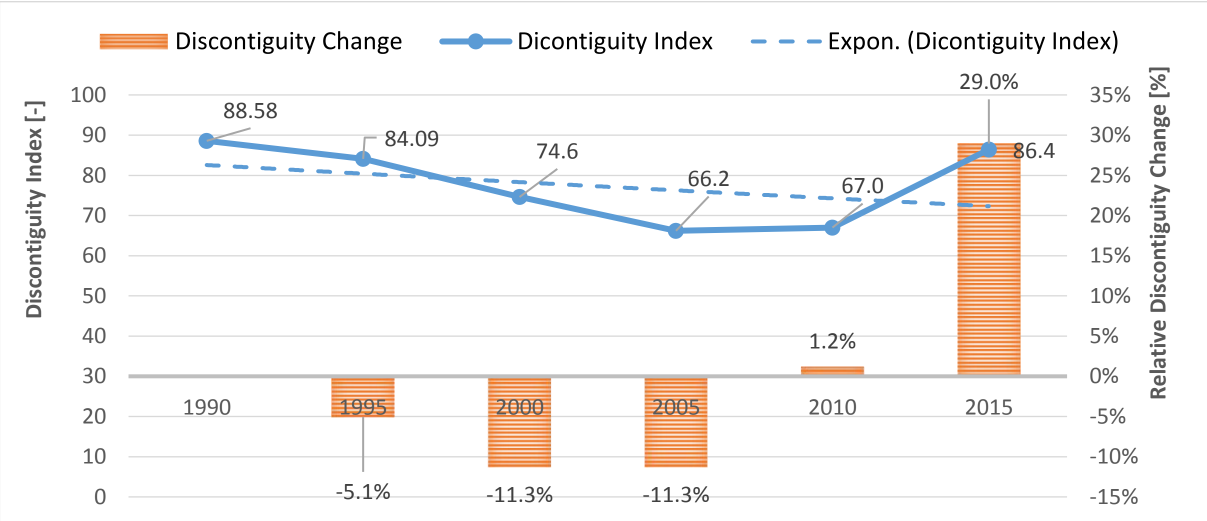


Figure 19: Discontiguity Index results for Bhopal from 1990 – 2015.

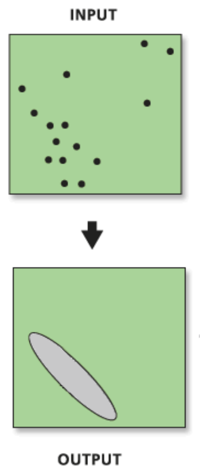
Table 13: Quantitative results of the discontiguity analysis.

Year	1990	1995	2000	2005	2010	2015
Discontiguity Index	88.58	84.09	74.6	66.2	67.0	86.4
Change absolute		-4	-9	-8	1	19
Discontiguity change		-5.1%	-11.3%	-11.3%	1.2%	29.0%

4.4.3 Directional Distribution

In order to find out whether a distribution of geographic features is compact or rather dispersed is to compute the standard deviational distances to a central point. On the basis of the *Directional Distribution (Standard Deviational Ellipses)* tool provided by ArcMap, it is possible to compute this distance separately in x- and y- directions. The results for each direction are used to define the axes of an ellipse that represents the compactness of the distribution of input features. It also shows whether the features are elongated and have a particular orientation. The resulting maps visualise the spatial characteristics (central tendency, dispersion and directional trend) and the changes over time and provide helpful information in the context of urban development.

The Standard Deviational Ellipse is given as:



$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{X})^2}{n}}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \overline{Y})^2}{n}}$$

x_i, y_i Coordinates of polygon i
$\overline{X}, \overline{Y}$ Mean center of all polygons
n Number of polygons

(Mitchell, 2005)

The following map (see Figure 20) illustrates Standard Deviational Ellipses for six points in time: 1990, 1995, 2000, 2005, 2010 and 2015. Beginning with black in the year 1990 and ending with dark pink in the year 2015, changes in size and orientation reflect the growing behaviour of Bhopal. The locations of the polygons representing urban areas have been used as geographic features. In order to take the relative importance of larger areas into account, each polygon has been weighted by its size.

First, as it can be seen in Figure 20, a south to south-eastern growth of the city is obvious. However, the standard deviation of distances between new residencies and the city´s core show merely low growth rates, which indicates a low dispersion or de-compaction of the overall shape (see Figure 21). New buildings mainly in the south alongside the Hoshangabad Road contribute to an overall elongation of the city´s shape in south to south-eastern direction. Nonetheless, the mean centre has shifted only marginally towards south.

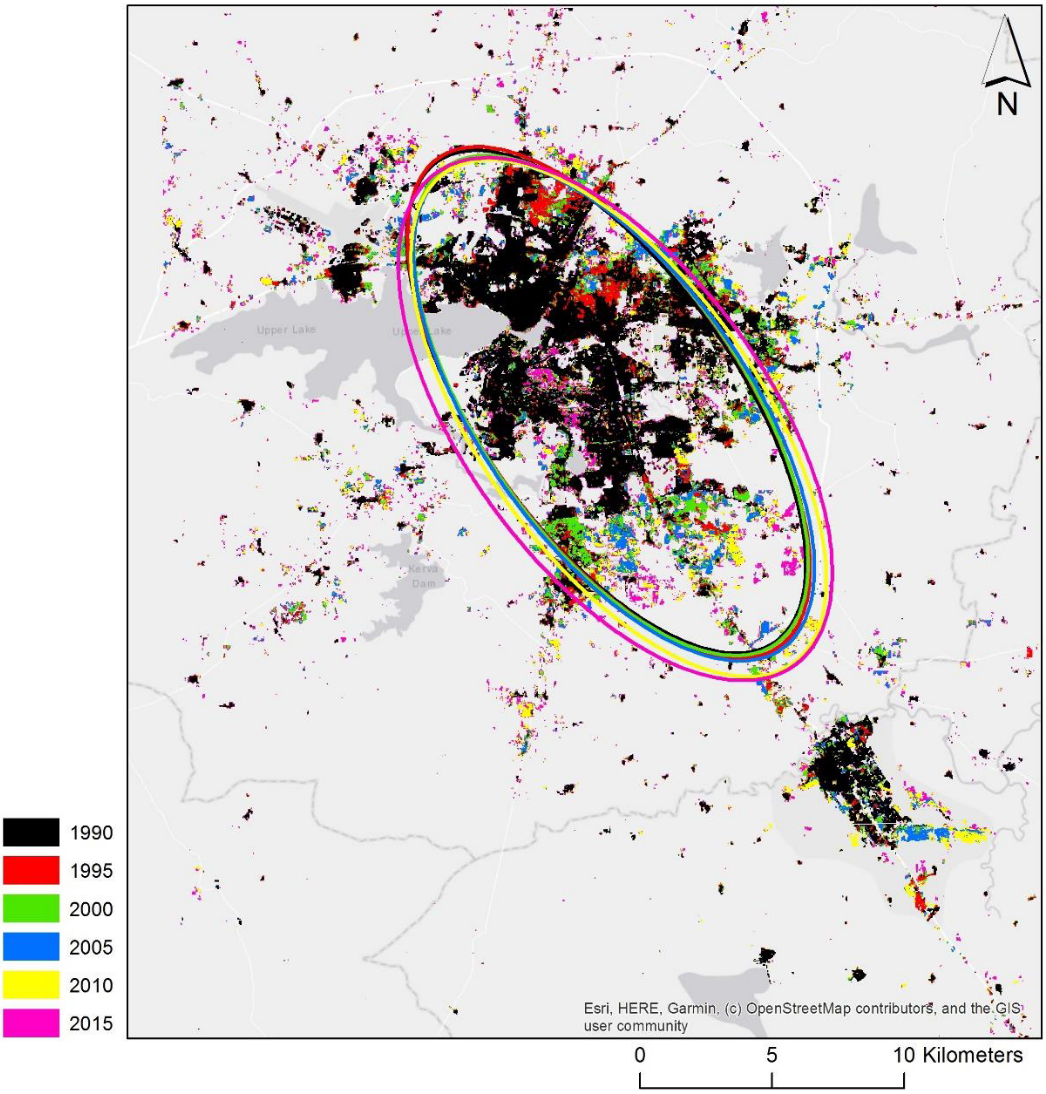


Figure 20: Standard deviational ellipses in Bhopal from 1990 – 2015.

The statistical evaluation diagram below (see Figure 21) depicts the length of the ellipse's half-axes, separately for the x-direction and the y-direction half-axes. The absolute values are represented by the lines, while the relative changes per time interval are again presented by the bars.

While the first three time intervals (1990-1995, 1995-2000 & 2000-2005), changes in the axis length do not exceed 3%, which means no major variations or no dispersion respectively, the last two periods (2005-2010 and 2010-2015) show a substantial growth of up to 8.1%. This means a dispersion increase, most pronounced in eastern direction. Furthermore, it can be seen that standard distances in y-direction more than doubles the values in x-direction during the whole timespan of analysis. The implication is that Bhopal´s shape is elongated in north-south extent, since the standard deviation of distances to the mean is more than 10 kilometres longer in height than in width.

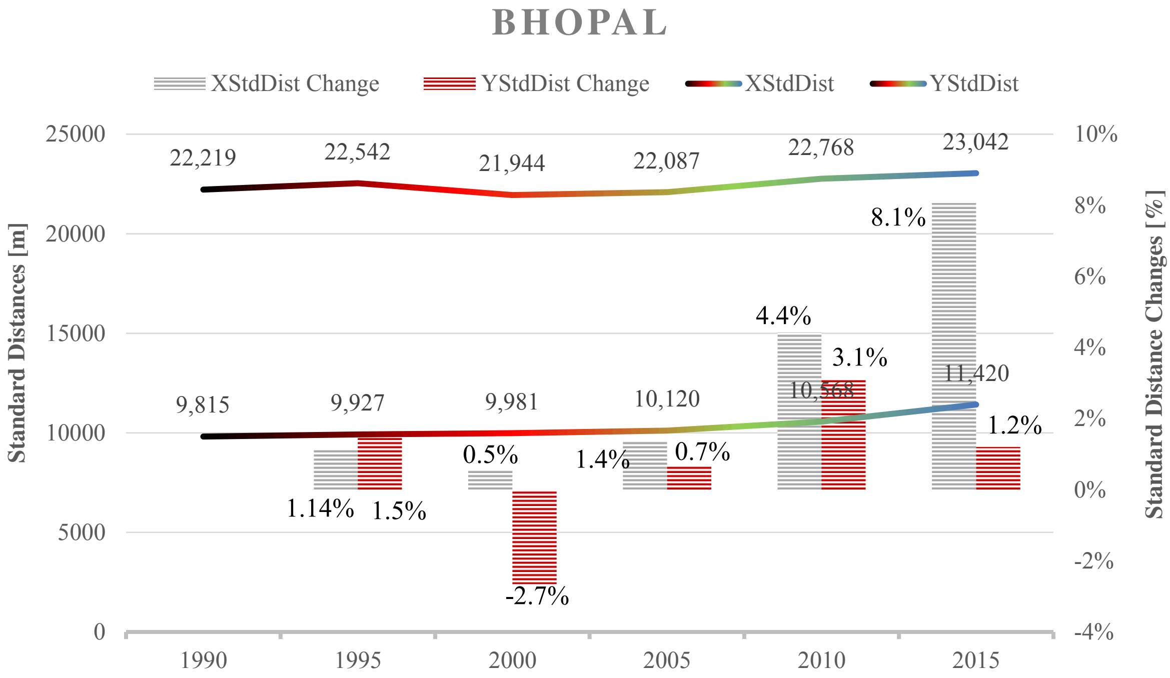


Figure 21: Standard Distance Results in x- and y-directions (length of ellipse axes) in Bhopal from 1990 – 2015.

4.5 Sustainable Development Goal 11 Indicators

A main objective of the EO4SD-Urban Product Portfolio is to support the reporting requirements of Urban Development Policies and Strategies. One of the most important policy frameworks that countries are trying to implement are the UN Sustainable Development Goals (SDGs). Seventeen SDGs were developed with a focus on “ending extreme poverty; fighting inequality & injustice; and addressing climate change,” by 2030. To achieve the 17 goals there are 169 targets and for each target, indicators will be used to assess the level of achievement of the countries.

The SDG Goal 11 “Make cities and human settlements inclusive, safe, resilient and sustainable” is specifically dedicated to Sustainable Urban Development. A list of Urban Sustainability Indicators specific to the SDG Goal 11, have been defined in March 2016 by the UN and are described in the UN-Habitat “SDG Goal 11 Monitoring Framework Report (UN, 2016a)”.

The EO4SD-Urban project supports seven GPSC cities, namely Bhopal and Vijayawada in India, Campeche in Mexico, Saint-Louis and Dakar in Senegal, Abidjan in Ivory Coast and Lima in Peru. For these seven cities, the indicators for which the needed input data is available were calculated and are described in the following subsections. The EO4SD-Urban products can be fully or partly used for the calculation of four SDG 11 indicators (see Table 14).

Table 14: SDG 11 indicators measurable with the support of EO4SD-Urban products.

TARGETS	INDICATORS
Target 11.1: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	11.1.1: Proportion of urban population living in slums, informal settlements or inadequate housing
Target 11.2: By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons	11.2.1: Proportion of the population that has convenient access to public transport by sex, age and persons with disabilities
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	11.3.1: Ratio of land consumption rate to population growth rate
Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	11.7.1: Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities

A short description of the calculation as well as the needed input data and the achieved outputs are described in the next sections for the indicators 11.3.1 and 11.7.1. For Bhopal, it is only possible to calculate the Indicators 11.1.1 and 11.2.1, as the needed input data is not available.

More information including the exact calculation steps of each indicator are described in the UN-Habitat Methodological Guidance document to monitor and report on the SDG Goal 11 indicators (UN-Habitat, 2016).

4.5.1 SDG 11 Indicator 11.3.1

The 11.3.1 Indicator calculates the ***Ratio of land consumption rate to population growth rate*** and describes the 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.”

The indicator needs the definition of the two components population growth and land consumption rate. According to the UN-Habitat Methodological Guidance document (UN-Habitat, 2016) the population growth rate (PGR) is the increase of population in a country during a specific period, usually one year. The PGR is expressed as a percentage of the population at the start of that period.

Further, the land consumption rate includes a) the expansion of build-up area that can be directly measured and b) the absolute extent of land that is subject to exploitation by agriculture, forestry or other economic activities and c) the over-intensive exploitation of land that is used for agriculture and forestry.

The indicator is calculated by using following formula:

$$\text{Ratio of land consumption rate to population growth rate (LCRPGR)} = \frac{\text{Land consumption rate}}{\text{Annual population growth rate}}$$

The ratio of land consumption rate to population growth rate is an indicator for measuring land use efficiently and is intended to answer the questions of whether the remaining undeveloped urban land is being developed at a rate that is less than or greater than the prevailing rate of population growth. As the ratio of land consumption rate to population growth rate is dimensionless and not straightforward in

its interpretation, several countries report the urban expansion and the population growth rate in terms of percentage change instead of using the ratio values (Nicolau et. al., 2018).
In the following, the ratio (see Figure 22) and the percentage change values (see Figure 23) for all GPSC cities were calculated. For the calculation of the population growth rate the Global Human Settlement Population Layer available for the years 2000 and 2015 were used. For the calculation of the land consumption rate the built-up area extracted from the Urban Cluster Area LU/LC classification is taken by dissolving all artificial classes.

Figure 22 shows the ratio of land consumption rate to population growth rate for all GPSC cities. All GPSC cities are visualised in the bar chart for comparative reasons. Bhopal and Vijayawada have both a value around one, which means that the land consumption rate and the population growth rate have about the same value and let assume that the land is efficiently used.
Cities with values significantly above one have a higher land consumption rate than a population growth rate. This indicates that the land is not as efficiently used as for example in Bhopal and Vijayawada
Cities with values significantly below one have a higher population growth rate than a land consumption rate. This indicates that the land is efficiently used.
European countries, for comparison very often have values below zero. This means that either the population or the land consumption shows a decrease.

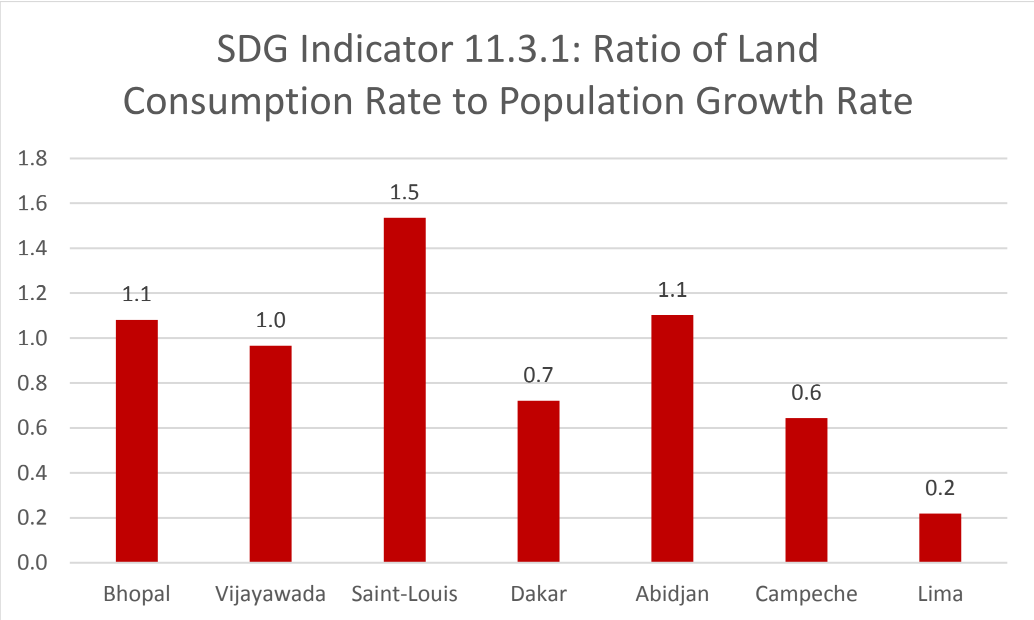


Figure 22: Ratio of land consumption rate to population growth rate for Bhopal between 2005 and 2015.

Looking at the percentage change values of population and land consumption between 2000/2005 and 2015/2017 all cities have a growing population and a growing urban extent, which is typical for cities in developing countries. Bhopal's population grew by 41% between 2000 and 2015. Its land consumption grew by 35% between 2005 and 2017. This means that the population grew faster than the built-up area of the city. This indicates that the city seems to grow in a compact way. In Vijayawada the population and the land consumption grew by about the same amount, this also indicates a more compact growth.
In Saint-Louis for example, it is the other way around. Here the land consumption grew by 21% while the population grew by only 15%. This indicates that the city had a less compact growth in the last years.

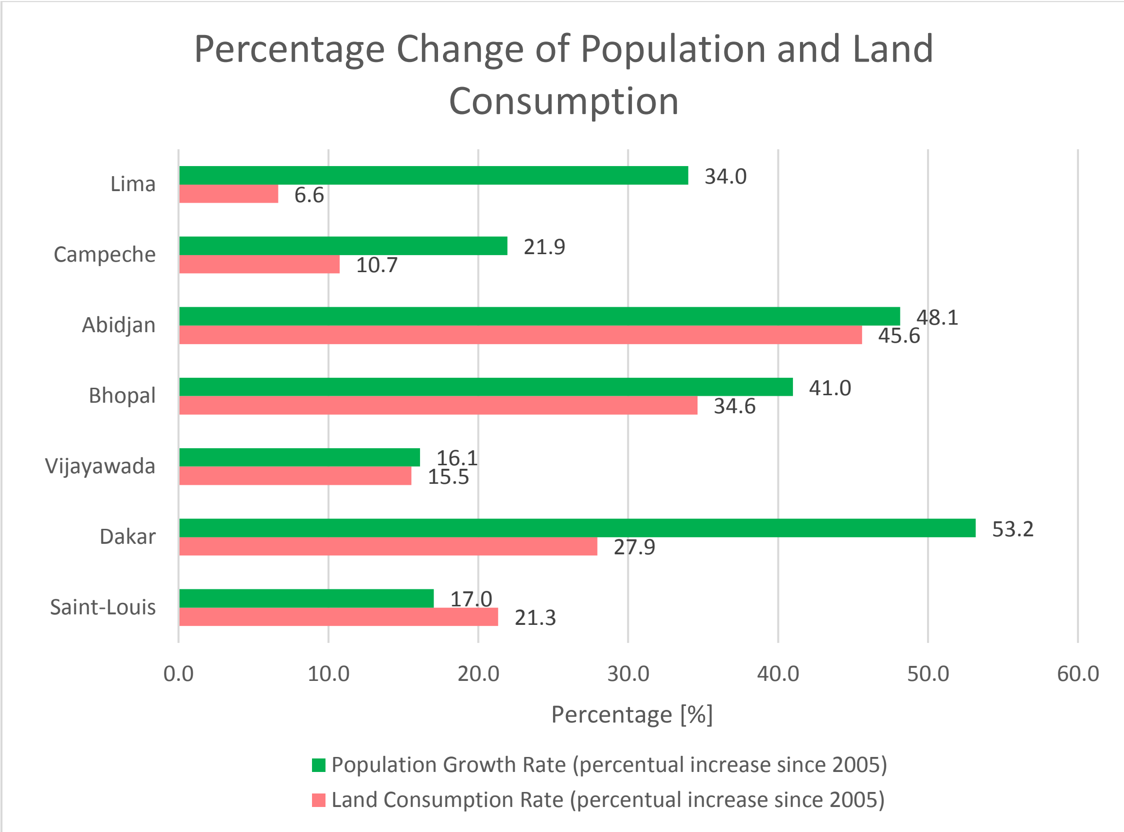


Figure 23: Percentage change of population and land consumption for Bhopal between 2005 and 2015.

A significant limitation of this indicator is that the approach captures only the urban extent change, not the internal city dynamics.

4.5.2 SDG 11 Indicator 11.7.1

The SDG 11 Indicator 11.7.1 ***"Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities"*** refers to the Target 11.7.: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

The indicator aims to monitor the amount of land that is dedicated by cities for public space. According to the UN-Habitat Methodological Guidance document (UN-Habitat, 2016) public space includes open spaces and streets and should be accessible by all.

The indicator is calculated by using following formula:

$$\%\text{ of land that is dedicated by cities for public space (open spaces and streets)} = \frac{(\text{Total surface of open public space} + \text{Total surface of land allocated to streets})}{\text{Total surface of built up area of the urban agglomeration}}$$

The share of land in public open spaces cannot be obtained directly from the use of high-resolution satellite imagery, because it is not possible to determine the ownership or use of open spaces by remote sensing. Additional metadata that helps to describe the land use patterns in the locale is additionally required to map out land that is for public and non-public use.
As this information is not available, the LU/LC classes *Urban Green Areas* and *Sports and Leisure Facilities*, which are available in the High Density Core Urban LU/LC classification, were taken with the assumption that these places are public places and accessible by all.
To calculate the total surface of land allocated to streets, the road network was used. Different buffers were applied for three different road types (6m for Arterial Roads, 5m for Collector Roads and 3m for

Local Roads) to assess the total surface of streets. The total surface of built-up area of the urban agglomeration is extracted from the LU/LC classification by summarising all artificial classes of the High Density Core Area.

The results are presented in Figure 24 below. For comparative reasons the graphic shows the indicator results for all GPSC cities, but Lima.
The indicator was calculated for two points in time i.e. around 2005 and 2015. In Bhopal, the average share of built-up area decreases from 29% in 2005 to 24% in 2017. Vijayawada, Campeche and Saint-Louis also show a decrease, while Abidjan and Dakar show an increase in open spaces.

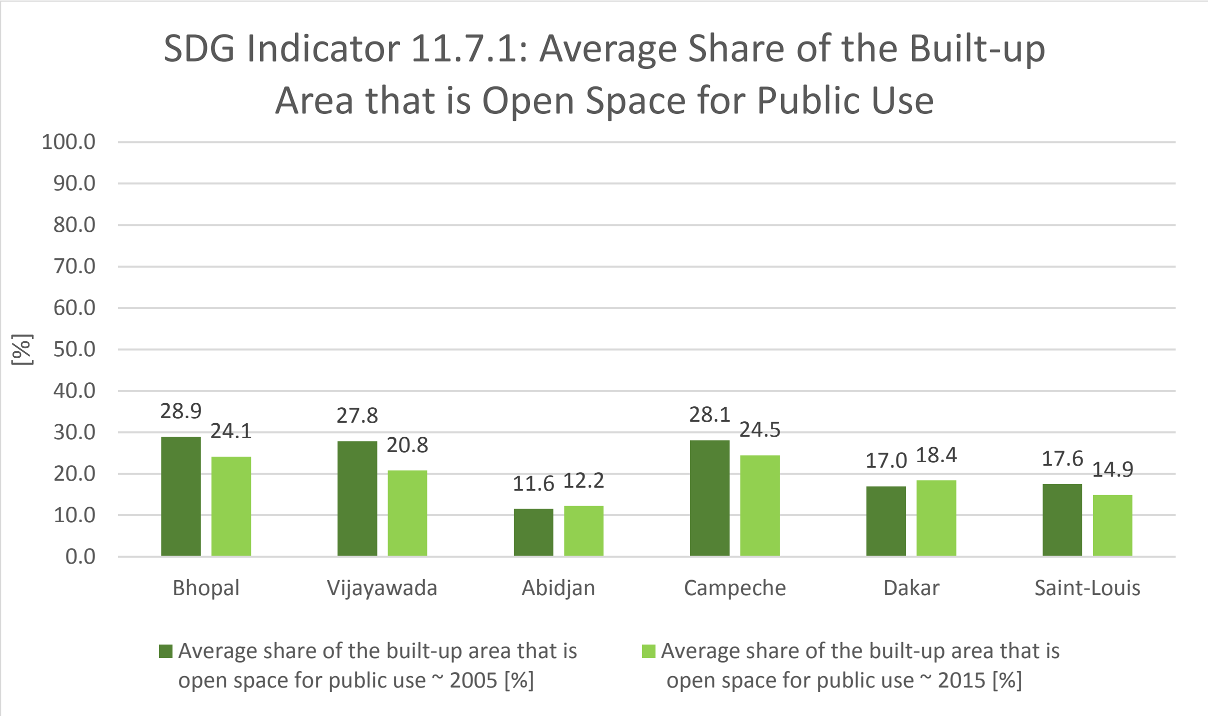


Figure 24: Average share of the built-up area that is open space for public use for Bhopal.

4.6 Concluding Points

This Chapter 4 presented only a summary and overview of what is possible in term of analytics with the geo-spatial datasets provided for Bhopal in the current project. This Report is a living document and will be complemented with further analysis during the project.

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Annex 1 – AOI Calculation based on the DG Regio Approach

AOI Calculation Methodology based on the DG Regio Approach

So far, no internationally accepted definition for the term “Urban Area” and the related Peri-Urban area exists. Different initiatives are currently trying to address a standardised approach for defining the term “Urban Area”. During discussions with the GPSC Co-ordinator, it was considered important to use a uniform definition for the GPSC cities in order for the cities to exchange information and share products/experiences and conduct potential comparative studies.

In this context, it was decided to use an international approach for the demarcation of the Areas of Interest (AOI) for mapping the GPSC cities in terms of Core Urban area and Peri-Urban area. Thus, the approach is based on the European Union’s Directorate-General for Regional and Urban Policy (DG REGIO) method and the definitions are described in the Regional Working Paper 2014 from the European Commission on “A harmonised definition of cities and rural areas: the new degree of urbanisation” (European Commission, 2014). Following the naming of the DG Regio approach, the Urban Core is named as “High Density Core” and the Peri-Urban area is termed as “Urban Cluster”. Within the DG REGIO approach, the High Density Core is defined as contiguous grid cells of 1 km^2 with a density of at least 1 500 inhabitants per km^2 and a minimum population of 50 000. The Urban Cluster is defined as clusters of contiguous grid cells of 1 km^2 with a density of at least 300 inhabitants per km^2 and a minimum population of 5 000.

The DG REGIO methodology used in the EO4SD-Urban project was slightly adjusted to Non-European countries. For the GPSC cities (namely Bhopal, Vijayawada, Saint-Louis, Dakar, Abidjan and Campeche) produced within the project, the Global Human Settlement Population (GHSP) grid with a spatial resolution of 1 km were used for the classification into “High Density Core” and ”Urban Cluster”. The raster dataset is available for the years 1975, 1990, 2000, 2015. This dataset depicts the distribution and density of population, expressed as the number of people per cell. The data can be downloaded under following link http://data.jrc.ec.europa.eu/dataset/jrc-ghsl-ghs_pop_gpw4_globe_r2015a.

In the following, a more detailed description of the calculation methodology for the High-Density Core and the Urban Cluster follows. The calculation is exemplary described on the AOI generation for the city of Abidjan.

To start with, Figure 1 shows the city of Abidjan and the surrounding area. Figure 2 shows the population distribution grid over Abidjan produced by the European Commission.

Figure 1: Satellite image showing Abidjan and the surrounding area.

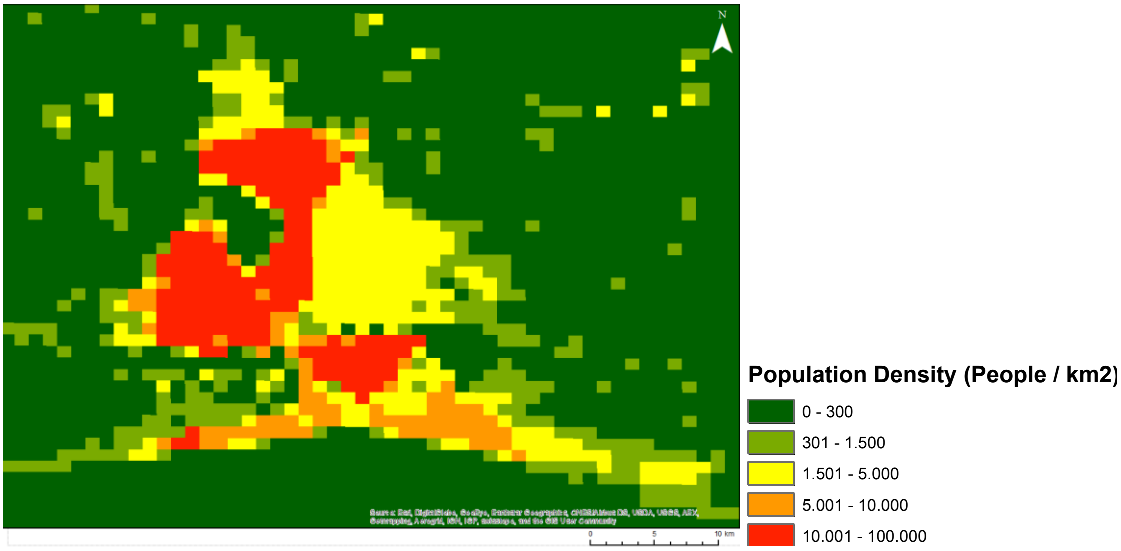

Figure 2: Global Human Settlement Population Layer (spatial resolution of 1 km).

The High Density Core area for a city is created by merging the contiguous grid cells of 1 km^2 with a density of at least 1 500 inhabitants per km^2 and a minimum population of 50 000. In the definition of the High Density Core area, the contiguity is only allowed via a vertical or horizontal connection. In a next step, gaps are filled. Due to the coarse resolution of the population grid cells additional grid cells were in a last step added for under estimated settlement areas. The same was done for over estimations, here grid cells were removed.

Figure 3 shows the High Density Core area (blue line) overlaid on the GHSL population layer (left) and on a RGB satellite image (right).

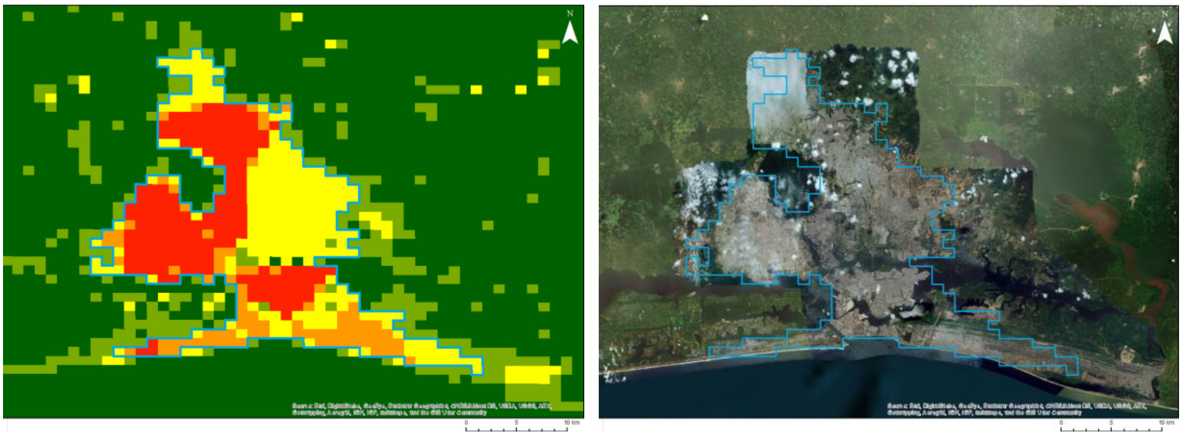

Figure 3: High Density Core area of Abidjan calculated based on GHSL population layer. The image on the left shows the AOI overlaid on the GHSL population layer. On the right, the AOI is overlaid on a RGB satellite image.

The Urban Cluster area is created very similar to the High Density Core area. Continuous grid cells of 1 km^2 with a density of at least 300 inhabitants per km^2 and a minimum population of 500 are merged together to form the Urban Cluster area. The contiguity within the Urban Custer area can also be diagonal. After gaps are filled, areas, which were over or under estimated by the population grid were removed or added to the AOI. Figure 4 shows the Urban Cluster area (magenta line) overlaid on the GHSL population layer (left) and on a RGB satellite image (right).

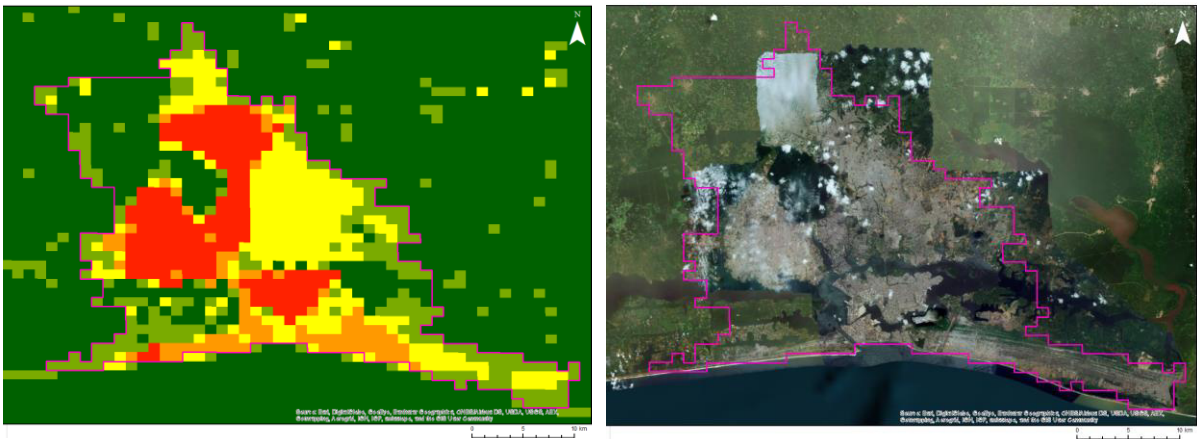

Figure 6: Urban Cluster area of Abidjan calculated based on the aggregated GHSL population layer.

In some cases, the city counterparts requested that the AOIs for the High Density Core area and the Urban Cluster area follow the municipal or administrative boundary of the city. In this case, the municipal/administrative boundary was used but enlarged in areas where the AOI created according to the adjusted DG Regio approach was bigger.

By making sure that the DG Regio AOIs fit into the mapping AOIs, comparative studies with other cities worldwide are possible and can be conducted at any time.

Annex 2 – Processing Methods for EO4SD-Urban Products

Summary of Processing Methods

High Density Core and Urban Cluster Land Use/Land Cover and Change

The input includes Very High Spatial Resolution (VHR) imagery from different sensors acquired at different time. The data is pre-processed to ensure a high level of geometric and radiometric quality (ortho-rectification, radiometric calibration, pan-sharpening).

The complexity when dealing with VHR images comes from the internal variability of the information for a single land-use. For instance, an urban area is represented by a high number of heterogeneous pixel values hampering the use of automated pixel-based classification techniques.

For these VHR images, it is possible to identify textures (or pattern) inside an entity such as an agricultural parcel or an urban lot. In other words, whereas pixel-based techniques focus on the local information of each single pixel (including intensity / DN value), texture analysis provides global information in a group of neighbouring pixels (including distribution of a group intensity / DN values but also spatial arrangement of these values). Texture and spectral information are combined with a segmentation algorithm in an Object Based Image Analysis (OBIA) approach to reach a high degree of automation for most of the Urban Cluster rural classes. However, within urban land, land use information is often difficult to obtain from the imagery alone and ancillary/in situ data needs to be used. The heterogeneity and format of these data mean that another information extraction method based on Computer Aided Photo-Interpretation techniques (CAPI) need to be used to fully characterise the LULC classes in urban areas. Therefore, a mix of automated (OBIA) and CAPI are used to optimise the cost/quality ratio for the production of the LULC/LUCC product. The output format is typically in vector form which makes it easier for integration in a GIS and for subsequent analysis.

Level 4 of the nomenclature can be obtained based on additional information. These can be generated by more detailed CAPI (e.g. identification of waste sites) or by an automated approach based on derived/additional products. An example is illustration by categorising the density of the urban fabric which is related to population density and can then subsequently used for disaggregating population data.

Information on urban fabric density can be obtained through several manners with increasing level of complexity. The Imperviousness Degree (IMD) or Soil Sealing (SL) layer (see separate product) can be produced relatively easily based on the urban extent derived from the LULC product and a linear model between imperviousness areas and vegetation vigour that can be obtained from Sentinel 2 or equivalent NDVI time series. This additional layer can be used to identify continuous and discontinuous urban fabric classes. Five urban fabric classes can be extracted based on a fully automated procedure:

- Continuous Dense Urban Fabric (Sealing Layer-S.L. > 80%)
- Discontinuous Dense Urban Fabric (S.L. 50% - 80%)
- Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)
- Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)
- Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
- Isolated Structures

Manual enhancement is the final post-processing step of the production framework. It will aim to validate the detected classes and adjust classes' polygon geometry if necessary to ensure that the correct MMU is applied. Finally, a thorough completeness and logical consistency check is applied to ensure the topological integrity and coherence of the product.

Change detection: Four important aspects have to be considered to monitor land use/land cover change effectively with remote sensing images: (1) detecting that changes have occurred, (2) identifying the nature of the change, (3) characterising the areal extent of the change and (4) assessing the spatial pattern of the change.

The change detection layer can be derived based on an image-to-image approach provided the same sensor is used. An original and efficient image processing chain is promoted to compare two dates' images and provide multi-labelled changes. The approach mainly relies on texture analysis, which has the benefits to deal easily with heterogeneous data and VHR images. The applied change mapping approach is based on spectral information of both dates' images and more accurate than a map-to-map comparison.

Summary of Processing Methods

World Settlement Extent

The rationale of the adopted methodology is that given a series of radar/optical satellite images for the investigated AOI, the temporal dynamics of human settlements are sensibly different than those of all other land-cover classes.

While addressing settlement-extent mapping for the period 2014-2015 multitemporal S1 IW GRDH and Landsat-8 data acquired at 10 and 30m spatial resolution were taken into account. Concerning radar data, each S1 scene is pre-processed by means of the SNAP software available from ESA; specifically, this task includes: orbit correction, thermal noise removal, radiometric calibration, Range-Doppler terrain correction and conversion to dB values. Scenes acquired with ascending and descending pass are processed separately due to the strong influence of the viewing angle in the backscattering of built-up areas. As a means for characterizing the behaviour over time, the backscattering temporal maximum, minimum, mean, standard deviation and mean slope are derived for each pixel. Texture information is also extracted to ease the identification of lower-density residential areas. As regards optical data, only Landsat-8 scenes with cloud cover lower than 60% are taken into consideration (indeed, further rising this threshold often results in accounting for images with non-negligible misregistration error). Data are calibrated and atmospherically corrected using the LEDAPS tool available from USGS and the CFMASK software is applied for removing pixels affected by cloud-cover and cloud-shadow. Next, a series of 6 spectral indices suitable for an effective delineation of settlements (identified through extensive experimental analysis) are extracted; these include – among others – the Normalized Difference Built-Up Index (NDBI), the Modified Normalized Difference Water Index (MNDWI) and the Normalized Difference Vegetation Index (NDVI). For all of them, the same set of 5 key temporal statistics used in the case of S1 data are generated for each pixel in the AOI. Moreover, to improve the detection of suburban areas, for each of the 6 temporal mean indices also here texture information is computed. For matching the spatial resolution of Sentinel data, the whole stack of Landsat-based features is finally resampled to 10m spatial resolution.

To identify reliable training points for the settlement and non-settlement class, a strategy has been designed which jointly exploits the temporal statistics computed for both S1 and Landsat data, along with additional ancillary information. In the case of optical data, in general the most of settlement pixels can be effectively outlined by properly jointly thresholding the corresponding NDBI, NDVI, and MNDWI temporal mean; likewise, this holds also for non-settlement pixels. Regarding radar data, it generally occurs that the temporal mean backscattering of most settlement samples is sensibly higher than that of all other non-settlement classes. Nevertheless, in complex topography regions: i) radar data show high backscattering comparable to that of urban areas; and ii) bare rocks are present, which often exhibit a behaviour similar to that of settlements in the Landsat-based temporal statistics. Accordingly, to exclude these from the analysis, all pixels are masked whose slope - computed based on SRTM 30m DEM for latitudes between -60° and +60° and the ASTER DEM elsewhere - is higher than 10 degrees.

Support Vector Machines (SVM) are used in the classification process. However, as the criteria defined above for outlining training samples might results in a high number of candidate points, for AOIs up to a size of ~10000 km² the most effective choice proved extracting 1000 samples for both the settlement and non-settlement class. Nonetheless, since results might vary depending on the specific selected training points, as a means for further improving the final performances and obtain more robust classification maps, 20 different training sets are randomly generated and given as input to an ensemble of as many SVM classifiers; then, a majority voting is applied. Afterwards, the stacks of Landsat-8-based and S1-based temporal features are classified separately as this proved more effective than performing a single classification on their merger. In both cases, a grid search with a 5-fold cross validation approach is employed to identify for each training set the optimal values for the learning. Here, those resulting in the highest cross-validation overall accuracy are then selected and used for classifying the corresponding study region.

A final post-classification phase is dedicated to properly combining the Landsat- and S1-based classification maps and automatically identifying and deleting potential false alarms. To this purpose, an advanced post-editing object-based approach has been specifically designed.

The above-described methodology has been further adapted for outlining the settlement extent in the past solely based on Landsat-5/7 imagery available since 1984; indeed, no long-term SAR data archive at comparable spatial resolution is freely accessible for the same timeframe (e.g., ESA ERS-1/2 data are available from 1991 without systematic world coverage and often proved too complicated to pre-process). In particular, for the given target period and AOI, all available Landsat imagery with cloud cover lower than 60% is pre-processed in the same fashion as described in the previous paragraphs and the same set of temporal statistics and texture features are extracted. Based on the hypothesis that settlement growth occurred over time (meaning that a pixel cannot be marked as settlement at an earlier time if it has been defined as non-settlement at a later time), all pixels categorized as non-settlement in the 2014-2015 extent map are excluded from the analysis. Then, training samples are derived by thresholding the temporal mean NDBI, MNDWI and NDVI; specifically, a dedicated strategy has been implemented for automatically determining the thresholds for the 3 indices by comparing their cumulative distribution function (CDF) for the target period with that exhibited for the period 2014-2015. Also in this case, an ensemble of 20 SVMs is used, each one trained on a different subset of 2000 samples (i.e., 1000 for the settlement and 1000 for the non-settlement class) and majority voting is then employed for generating the final map. It is worth noting that, when deriving the past settlement extent for multiple times, both the masking and threshold adaptation are performed on the basis of the results derived for the next target period.

Summary of Processing Methods

Urban Green Areas

The location and extent of green areas are determined within the product of urban land use/ land cover at Level I. Urban green areas refer to land within and on the edges of a city that is partly or completely covered with grass, trees, shrubs, or other vegetation. This includes public parks, private gardens, cemeteries, forested areas as well as trees, river alignments, hedges etc. The product delivered within EO4SD-Urban project thus provides accurate information (1 m resolution) on the spatial location and extent of the green areas located within the Urban Extent (Level I class: 1000) derived from the baseline LULC information product.

Detecting and monitoring urban green coverage needs very high resolution optical satellite images, which explains the product generation over the High Density Core Area of AOI only. The same images have been logically used for generating the LULC information product. Consequently, the usual preliminary quality check and pre-processing tasks were already implemented.

Urban Green Areas have been detected using automated non-supervised classification method. More precisely, each single multispectral VHR scene has been classified by specifying the most appropriate algorithm and class number. Then, pixel units from the classes considered as representing green areas have been combined into 1 single class. From this operation results the required binary raster product. At this stage, it only remains necessary to apply some post-processing steps:

- Morphological filter is applied to fill small gaps within the green areas (caused by shadow)
- Resampling of the data to the provided spatial resolution of 1m
- Removing small pixel groups under the minimum mapping unit.
- Integrating the information provided by the LULC product (e.g. class Urban Parks, Cemeteries).
- Validation of Mapping results

Furthermore, using archive very high resolution images, current and historic extent of urban green areas are compared to identify their temporal evolution – extent growth or reduction. Quality control and accuracy assessment tasks are performed by means of visual interpretation considering also the LULC dataset.

Annex 3 – Filled Quality Control Sheets

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Earth Observation for Sustainable Development – Urban

Quality Assurance and Quality Control Sheets

These QA/QC Templates were prepared by GAF AG compliant with ISO 9001:2015 Quality Management System standards and can only be used by Partners in the current EO4SD-Urban Project.

Project Title: EO4SD-Urban
Project Leader: GAF AG
Service Provider: GAF AG
Client: GPSC, World Bank
Product: LULC Product
Editor: DA; AB
Date: 22.11.2018

Overview of QC-Sheets and Processing Steps	***Sheet used***	***Sheet filled in***
Requirements		
0.1 Requirements	Yes	Yes
Specifications of Input Data		
1.1 List of EO Data	Yes	Yes
1.2 List of In-situ Data	Yes	Yes
1.3 List of Ancillary Data	Yes	Yes
Data Quality Checks		
2.1 EO Data Quality	Yes	Yes
2.2 In-situ Data Quality	Yes	Yes
2.3 Ancillary Data Quality	Yes	Yes
Pre-Processing of EO Data		
3.1 Geometric Correction	Yes	Yes
3.1.1 Data Fusion	Yes	Yes
3.2 Data Processing	Yes	Yes
Thematic Processing		
4.1 Classification	Yes	Yes
4.2 Intermediate Quality Control of Land Use Data	Yes	Yes
Accuracy Assessment		
5.1 Thematic Accuracy	Yes	Yes
5.2 Error Matrices	Yes	Yes
Delivery Checks / Delivery		
6.1 Completeness	Yes	Yes
6.2 Compliancy	Yes	Yes

Glossary (index numbers in the QA/QC tables refer to the glossary at the end of this document)

Further QC-relevant Documents:

Comments / Characteristics:

0.1 Requirements			
Product 1 (28)	Urban Land Use/ Land Cover and Change		
Abstract			
The Land Use/Land Cover (LU/LC) product contains spatial explicit information on the different occurring land use and land cover in both the High Density Cluster and Urban Cluster of the City of Bhopal for the years 2005 and 2017. The High Density Cluster area has a very detailed LU/LC nomenclature whereas the Urban Cluster area LU/LC nomenclature is at an aggregated Level. The input data for the High Density Cluster area was the Very High Resolution data (WorldView-4 for 2017 and Quickbird-2 for 2005) and the input data for the Urban Cluster area was Sentinel 2 (2017) and Landsat-5 (2005) data. The LU/LC product is the Baseline Product from which the Urban Green Areas product is derived.			
Service / Product Specifications			
Area Coverage			
Country:	India	A) Wall-to-wall: n/a	
City:	Bhopal	Selected Sites: High Density Cluster and Urban Cluster	
Area km²	High Density Core: 316 km²	B) Sampling based: n/a	
	Urban Cluster: 256 km²		
Time Period - Update Frequency			
A) Baseline Year(s): 2005 and 2017		B) Update Frequency 2 points in time, no future update	
Comments: /			
Geographic Reference System			
EPSG: 32643. WGS 84 / UTM 43N			
Mapping Classes and Definitions			
Residential	Built-up areas and their associated land, such as gardens, parks, planted areas and non-surfaced public areas and the infrastructure, if these areas are not suitable to be mapped separately with regard to the minimum mapping unit size. **Continuous dense urban fabric**: Average degree of soil sealing: 80 -100% Residential buildings, roads and other artificially surfaced areas. **Discontinuous dense urban fabric**: Average degree of soil sealing: > 50 - 80% Residential buildings, roads and other artificially surfaced areas. **Discontinuous medium density urban fabric**: Average degree of soil sealing: > 30 - 50% Residential buildings, roads and other artificially surfaced areas. The vegetated areas are predominant, but the land is not dedicated to forestry or agriculture. **Discontinuous low density urban fabric**: Average degree of soil sealing: 10 - 30% Residential buildings, roads and other artificially surfaced areas. The vegetated areas are predominant, but the land is not dedicated to forestry or agriculture. **Discontinuous very low density urban fabric:** Average degree of soil sealing: <10 % Residential buildings, roads and other artificially surfaced areas. The vegetated areas are predominant, but the land is not dedicated to forestry or agriculture. Example: exclusive residential areas with large gardens. **Isolated Structures:** Isolated artificial structures with a residential component, such as (small) individual farm houses and related buildings. The mapping unit will never be surrounded by any urban class other than transportation network. The mapping unit is no larger than 2 ha. Exception: border blocks / polygons in housing developments (they may be adjacent to roads and non-urban classes).		

Industrial, Commercial, Public, Military and Private Units	Industrial, commercial, public, military or private units. The administrative boundaries of the production or service unit are mapped, including associated features larger than the MinMU (e.g. sports areas or transport structures).
Arterial Roads (Fast Transit Roads)	Highways, connecting the city with other cities
Collector Roads (Connecting Road)	Bigger Connecting roads within the city
Railway	Railway facilities including stations, cargo stations and associated land.
Port	Port and associated area.
Airport	Administrative area of airports, mostly fenced. Included are all airport installations: runways, buildings and associated land.
Mineral Extraction and Dump Sites	Open pit extraction sites (sand, quarries) including water surface, if <Minimum Mapping Unit (MMU), open-cast mines, inland salinas, oil and gas fields; Dump sites and associated land
Construction Sites	Spaces under construction or development, soil or bedrock excavations for construction purposes or other earthworks visible in the image.
Land Without Current Use	Areas in the vicinity of artificial surfaces still waiting to be used or re-used. The area is obviously in a transitional position, “waiting to be used”.
Green Urban Areas	Public green areas for predominantly recreational use such as gardens, zoos, parks, castle parks. Suburban natural areas that have become and are managed as urban parks.
Sports and Leisure Facilities	All sports and leisure facilities including associated land, whether public or commercially managed: Golf courses, Sports fields (also outside the settlement area), Camp grounds, Riding grounds, Racecourses, Amusement parks, Swimming resorts etc., Glider or sports airports.
Agricultural Area	Cultivated areas non-irrigated or permanently irrigated including rice fields: arable land (annual crops), permanent crops, complex or mixed cultivation, orchards; pasture and meadow under agricultural use, grazed or mechanically harvested.
Forest and Shrub Lands	High woody vegetation in natural forests; transitional woodland; low thickets. Includes Plantations
Natural Areas (Savannah, Grassland)	Natural area where there is little vegetation
Bare Soil	Bare Soil Areas (not within the urban area)
Wetlands	Areas flooded or liable to flooding during a large part of the year by fresh, brackish or standing water with specific vegetation coverage made of low shrub, semi-ligneous or herbaceous species; shallow water areas covered with reed.
Inland water	Visible water areas like lakes, rivers, ponds (natural, artificial).
Marine water	Saline waters
Cloud and Cloud Shadow Detection and Removal	
Information for the entire AOI is required and therefore cloudy areas are replaced by other suitable Earth Observation (EO) data.	
Spatial Resolution	
n.a. (Product provided as Shapefile)	
Minimum Mapping Unit (MMU)	
Minimum Mapping Unit within high density core is 0.25 ha. The Urban Cluster is mapped with a MMU of 0.5 ha	
Data Type & Format	
Shapefile *.shp and GeoPDF	
Bit Depth	
n.a	
Class Coding	

Class Code	*Class Name*	*RGB Code*
Single date		
1100	Residential	255; 0; 0 (main class only)
1210	Industrial, Commercial, Public, Military and Private Units	197; 0; 255
1221	Fast Transit Roads (Arterial Roads)	78; 78; 78
1222	Other Road (Collector Roads)	120; 120; 120
1223	Railway	52; 52; 52
1230	Port	0; 168; 132
1240	Airport	168; 0; 132
1310	Mineral Extraction and Dump Sites	115; 76; 0
1330	Construction Sites	255; 115; 223
1340	Land Without Current Use	242; 242; 242
1410	Green Urban Areas	85; 255; 0
1420	Sports and Leisure Facilities	255; 170; 0
2000	Agricultural Area	255; 235; 175
3100	Forest and Shrub Lands	38; 115; 0
3200	Natural Areas (Savannah, Grassland)	180; 215; 158
3300	Bare Soil	204; 204; 204
4000	Wetlands	76; 0; 115
5100	Inland Water	0; 112; 255
5200	Marine Water	0; 60; 240
LULC Change product		
1	Urban Densification	0; 132; 168
2	Urban Residential Expansion	230; 0; 0
3	Other Urban Land Use Expansion	204; 0; 204
4	Change within Natural and Semi-Natural Areas	112; 173; 71
Agricultural Change		
1	Agricultural Area to Residential	0; 132; 168
2	Agricultural Area to Industrial, Commercial, Public or Military Area	230; 0; 0
3	Agricultural Area to Forest	112; 173; 71

Metadata
Provided as INSPIRE conformant *xml data set, covering at least the mandatory elements.
Service / Product Quality
Thematic Accuracy
Overall Accuracy: >85 %
Positional Accuracy
RMSE < 15 m.
Delivery Procedure
Service Provision
Online via FTP

Delivery Date
End of November 2018.

1.1 List of EO Data

Sensoren [8]	Landsat 5, Sentinel-2, QB-2, WV-4	Incoming Date	Acquisition Date	Proc. Level	Path / Row	AOI - City / Region / Country	Spatial Res.	No. of Bands	Cloud Cover (Data Provider)	Projection / Spheroid [16]	Data Format [3]	Bit Depth [5]	Header / Metadata [2]
File Name [e.g yymmdd; tbd...]													
Sentinel-2													
1.	S2B_MSIL2A_20171029T051919_N0206_R062_T43QGF_20171029T103813	11.07.2018	29.10.2017	1C	43/QGF	Bhopal, IND	10m	4	0.4%	WGS 84/UTM zone 43N	.tiff	16 Bit	.xml
Landsat-5													
2.	LT05_L1TP_145044_20051108_20161123_01_T1	11.07.2018	08.11.2005	T1	145/044	Bhopal, IND	30m	9	0%	WGS 84/UTM zone 43N	.tiff	8 bit & 16 bit	.xml
WV-4													
3.	17SEP24053406-M2AS_058163933010_01_P001	16.07.2018	24.09.2017	LV2A	P001	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	0%	UTM zone 43N	.tiff	16 Bit	.xml
4.	17SEP24053341-M2AS-058163933010_01_P002	16.07.2018	24.09.2017	LV2A	P002	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	4.0e-03%	UTM zone 43N	.tiff	16 Bit	.xml
5.	17SEP24053353-M2AS_R1C1-058163933010_01_P003	16.07.2018	24.09.2017	LV2A	P003	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	1.0e-03%	UTM zone 43N	.tiff	16 Bit	.xml
Quickbird-2													
6.	05NOV25054424-M2AS-058160620010_01_P001	16.07.2018	25.11.2005	LV2A	P001	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml
7.	05OCT07054718-M2AS-058160620010_01_P002	16.07.2018	07.10.2005	LV2A	P002	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml
8.	05SEP01054530-M2AS-058160620010_01_P003	16.07.2018	01.09.2005	LV2A	P003	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml

1.2 List of In-situ Data

Dataset 1 (14)	Incoming Date	Acquisition Date	AOI - City / Region / Country	Data Type (4)	Projection / Spheroid (16)	No. of Sample Plots	Sampling Design (22)	Positional Accuracy (11)	Purpose (9)
No In-situ Data Used									

1.3 List of Ancillary Data

Dataset 1 [14]	OSM	Date of Receipt from Client	Metadata [2]	Reference Mapping Date / Date of Creation	Geographic Area/- City / Region / Country	Area Coverage	Data Type [4]	Data Format [3]	Projection / Spheroid [16]	Positional Accuracy [11]	No. of Classes	Thematic Accuracy	Availability of Class Definitions
OSM_Data_Bhopal_India		n.a.	not available	n.a. /21.03.2017	Bhopal (municipality boundary)	100%	Vector	*.shp	WGS 84	unknown	n.a.	unknown	n.a.
Lineage[29]:		*OSM data is crowed source data with contribution from volunteers and freely available.*											
Source [30]:		https://www.openstreetmap.org/node/245712627											

Dataset 2 [14]	GHSL	Date of Receipt from Client	Metadata [2]	Reference Mapping Date / Date of Creation	Geographic Area / City / Region / Country	Area Coverage	Data Type [4]	Data Format [3]	Projection / Spheroid [16]	Positional Accuracy [11]	No. of Classes	Thematic Accuracy	Class Definitions
GHS_POP_GPW4_GLOBE_R2015A		n.a.	*.pdf / *.ssd	1975, 1990, 2000 and 2015	India	100%	Raster	*.tif	World Mollweide (EPSG:54009)	unknown	n.a.	unknown	n.a.
Lineage[29]:		*"The Global Human Settlement Layer (GHSL) project is supported by European Commission, Joint Research Center and Directorate-General for Regional and Urban Policy. The GHSL produces new global spatial information, evidence-based analytics, and knowledge describing the human presence in the planet. The GHSL relies on the design and implementation of new spatial data mining technologies allowing to process automatically and extract analytics and knowledge from large amount of heterogeneous data including: global, fine-scale satellite image data streams, census data, and crowd sources or volunteering geographic information sources. Spatial data reporting objectively and systematically about the presence of population and built-up infrastructures are necessary for any evidence-based modelling or assessing of i) human and physical exposure to threats as environmental contamination and degradation, natural disasters and conflicts, ii) impact of human activities on ecosystems, and iii) access to resources. The project produces thematic information and evidence-based analytical knowledge supporting the implementation of EU regional urban policy and the 4 international post-2015 frameworks, namely: Sustainable Development Goals, Global Urban Agenda, Climate Change and the Sendai Framework for Disaster Risk Reduction. Also, the project supports international scientific partnerships facilitating science-policy interface in the frame of the Group of Earth Observation (GI-21: Human Planet Initiative https://www.earthobservations.org/activity.php?id=51), and bi-lateral scientific collaborations with space agencies and scientific organizations of Brazil, China and South Africa.*											
Source [30]::		European Commission, Joint Research Centre; Columbia University, Center for International Earth Science Information Network (2015): GHS population grid, derived from GPW4, multitemporal (1975, 1990, 2000, 2015). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-ghsl-ghs_pop_gpw4_globe_r2015a											

Dataset 3 [14]	Waste sites	Date of Receipt from Client	Metadata [2]	Reference Mapping Date / Date of Creation	Geographic Area / City / Region / Country	Area Coverage	Data Type [4]	Data Format [3]	Projection / Spheroid [16]	Positional Accuracy [11]	No. of Classes	Thematic Accuracy	Class Definitions
Bhopal_ExistingLandfill.shp; Bhopal_Proposed_Landfill.shp		13.01.2017	Not available	Unknown / Unknown	Bhopal Municipality	100%	Vector (point data)	*.shp	GCS_WGS_1984	unknown	1	unknown	n.a.
Lineage[29]:													
Source [30]::		Received from Katarina BARUNICA (UNIDO)											

Dataset 4 [14]	Master Plan	Date of Receipt from Client	Metadata [2]	Reference Mapping Date / Date of Creation	Geographic Area / City / Region / Country	Area Coverage	Data Type [4]	Data Format [3]	Projection / Spheroid [16]	Positional Accuracy [11]	No. of Classes	Thematic Accuracy	Class Definitions
Bhopal Master Plan 2005		n.a.	n.a.	2005 / unknown	Bhopal	100%	Document	*.pdf	n.a.	unknown	31	unknown	n.a.
Lineage[29]:													
Source [30]::		http://emptownplan.gov.in:9999/MasterPlanBhopal/index.html											

2.1 EO Data Quality

Sensoren[8]: Landsat-5, Sentinel-2, QB-2, WV-4

	File Name [e.g yymmdd; tbd...]	Backup	Readability [1]	Check Header / Metadata [2]	Band Specifications: No. of Bands	Band Specifications: Band Registration	Band Specifications: Spectral/Spatial Resolution	Projection / Spheroid [16]	Scene Location	Completeness of Additional Data	Data Format [3]	Bit Depth [5]	Cloud Cover (internal check)	Radiometry	Topography	Dropped Lines / Artefacts [7]	Acceptance Status	Comments
Sentinel-2																		
1.	S2B_MSIL2A_20171029T051919_N0206_R062_T43QGF_20171029T103813	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
Landsat-5																		
2.	LT05_L1TP_145044_20051108_20161123_01_T1	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
WV-4																		
3.	17SEP24053406-M2AS_R1C1-058163933010_01_P001	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
4.	17SEP24053341-M2AS-058163933010_01_P002	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
5.	17SEP24053353-M2AS_R1C1-058163933010_01_P003	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
Quickbird-2																		
6.	05NOV25054424-M2AS-058160620010_01_P001	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
7.	05OCT07054718-M2AS-058160620010_01_P002	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
8.	05SEP01054530-M2AS-058160620010_01_P003	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none

2.2 In-situ Data Quality

Dataset 1 (14)	Field Data	Backup	Readability (1)	Check Header / Metadata (2)	Extent	Projection / Spheroid (16)	Spatial Resolution	Data Format (3)	Bit Depth (5)	Location	Completeness	Geom. Misalignment	Plausibility	Dropped Lines / Artefacts (7)	Acceptance Status	Comments
File Name [e.g yymmdd; tbd…]																
No in-situ data used																

2.3 Ancillary Data Quality

Dataset 1 (14) OSM File Name [e.g yymmdd; tbd…]	Readability (1)	Check Header /Metadata (2)	Data Coverage Matches Service Area (%)	Projection / Spheroid , EPSG(16)	Spatial Resolution and unit (e.g. m, km)	Data Format (3)	Bit Depth (5)	Completeness (Vector: Attribute Table; Raster: Thematic Values)	Geom. Misalignment	Dropped Lines / Artefacts (EO data only)(7)	Utility for Current Project
OSM_Data_Bhopal_India	☒ Yes ☐ No	☐ Complete (INSPIRE/ISO19119) ☐ Incomplete ☒ not available	☒ Yes ☐ No ☐ Unknown If no: xxx%	☒ Correct ☐ Incorrect ☐ Unknown EPSG: 32643	n.a.	*.shp	n.a.	☐ Complete ☒ Incomplete	☐ No ☐ Yes ☒ Unknown If yes: XX m	☐ No ☐ Yes ☒ n.a. If yes: xxx %	☐ None ☒ Partial ☐ Full
Comments:	Due to missing Metadata the Accuracy and Completeness of the data set is unknown.										

Dataset 2 (14) GHSL File Name [e.g yymmdd; tbd…]	Readability (1)	Check Header /Metadata (2)	Data Coverage Matches Service Area (%)	Projection / Spheroid , EPSG(16)	Spatial Resolution and unit (e.g. m, km)	Data Format (3)	Bit Depth (5)	Completeness (Vector: Attribute Table; Raster: Thematic Values)	Geom. Misalignment	Dropped Lines / Artefacts (EO data only)(7)	Utility for Current Project
GHS_POP_GPW4_GLOBE_R2015A	☒ Yes ☐ No	☒ Complete (INSPIRE/ISO19119) ☐ Incomplete ☐ not available	☒ Yes ☐ No ☐ Unknown If no: xxx%	☒ Correct ☐ Incorrect ☐ Unknown EPSG: 54009	1km	*.tif	64 bit floating point	☒ Complete ☐Incomplete	☒ No ☐ Yes ☐ Unknown If yes: XX m	☐ No ☐ Yes ☒ n.a. If yes: xxx %	☐ None ☐ Partial ☒ Full
Comments:	/										

Dataset 3 (14) Waste Sites File Name [e.g yymmdd; tbd…]	Readability (1)	Check Header /Metadata (2)	Data Coverage Matches Service Area (%)	Projection / Spheroid, EPSG(16)	Spatial Resolution and unit (e.g. m, km)	Data Format (3)	Bit Depth (5)	Completeness (Vector: Attribute Table; Raster: Thematic Values)	Geom. Misalignment	Dropped Lines / Artefacts (EO data only)(7)	Utility for Current Project
Bhopal_ExistingLandfill.shp; Bhopal_Proposed_Landfill.shp	☒ Yes ☐ No	☐ Complete (INSPIRE/ISO19119) ☐ Incomplete ☒ not available	☐ Yes ☐ No ☒ Unknown If no: xxx%	☒ Correct ☐ Incorrect ☐ Unknown EPSG: 54009	n.a.	*.shp	n.a.	☒ Complete ☐Incomplete	☒ No ☐ Yes ☐ Unknown If yes: XX m	☐ No ☐ Yes ☒ n.a. If yes: xxx %	☐ None ☒ Partial ☐ Full
Comments:	Due to missing Metadata the Accuracy and Completeness of the data set is unknown.										

Dataset 4 (14) Master Plan File Name [e.g yymmdd; tbd…]	Readability (1)	Check Header /Metadata (2)	Data Coverage Matches Service Area (%)	Projection / Spheroid, EPSG(16)	Spatial Resolution and unit (e.g. m, km)	Data Format (3)	Bit Depth (5)	Completeness (Vector: Attribute Table; Raster: Thematic Values)	Geom. Misalignment	Dropped Lines / Artefacts (EO data only)(7)	Utility for Current Project
Bhopal Master Plan 2005	☒ Yes ☐ No	☐ Complete (INSPIRE/ISO19119) ☐ Incomplete ☒ not available	☐ Yes ☐ No ☒ Unknown If no: xxx%	☐ Correct ☐ Incorrect ☒ Unknown EPSG: 54009	unknown	*.pdf	n.a.	☐ Complete ☐ Incomplete ☒ n.a.	☐ No ☐ Yes ☒ Unknown If yes: XX m	☐ No ☐ Yes ☒ n.a. If yes: xxx %	☐ None ☒ Partial ☐ Full
Comments:	Due to missing Metadata the Accuracy and Completeness of the data set is unknown.										

3.1 Geometric Correction

Sensor [8]	Landsat-5, Sentinel-2, QB-2, WV-4												
No.	File Name [e.g yymmdd; tbd…]	Processing Date	AOI City / Region / Country	Projection / Spheroid [16]	No. & RMS (m) of GCPs [17]	No. & RMS (m) of TPs [18]	No. & RMS (m) of CPs [19]	Digital Elevation Model (DEM)	Model / Algorithm [13]	Resampling Method [20]	Validation Reports	Acceptance Status	Output File Name [e.g yymmdd; tbd…]
Sentinel-2													
1.	S2B_MSIL2A_20171029T051919_N0206_R062_T43QGF_20171029T103813	20.07.2018	Bhopal IND	UTM 43N/WGS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	L2A_T43QGF_A003377_20171029T051919_b2b3b4b8b11b12
Landsat-5													
2.	LT05_L1TP_145044_20051108_20161123_01_T1	20.07.2018	Bhopal IND	UTM 43N/WGS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	LT05_L1TP_145044_20051108_20161123_01_T1_sr_b1b2b3b4b5
WV-4													
3.	17SEP24053406-M2AS_058163933010_01_P001	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x0.92; y1.39	18; RMSE x0.56; y0.29	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053406-PMS_058163933010_01_P001_toa
4.	17SEP24053341-M2AS-058163933010_01_P002	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x0.95; y1.59	9; RMSE x0.17; y0.22	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053341-PMS-058163933010_01_P002_toa
5.	17SEP24053353-M2AS_058163933010_01_P003	20.07.2018	Bhopal IND	UTM 43N/WGS	4; RMSE x1.98; y1.39	31; RMSE x0.27; y0.32	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053353-PMS_058163933010_01_P003_toa
Quickbird-2													
6.	05NOV25054424-M2AS-058160620010_01_P001	20.07.2018	Bhopal IND	UTM 43N/WGS	5; RMSE x1.99; y1.65	31; RMSE x0.60; y0.70	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05NOV25054424-PMS-058160620010_01_P001_toa
7.	05OCT07054718-M2AS-058160620010_01_P002	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x1.11; y0.83	10; RMSE x1.05; y0.99	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05OCT07054718-PMS-058160620010_01_P002_toa

8.	05SEP01054530-M2AS-058160620010_01_P003	20.07.2018	Bhopal IND	UTM 43N/WGS	0; RMSE xNaN; yNaN	9; RMSE x0.15; y0.26	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05SEP01054530-PMS-058160620010_01_P003_toa

3.1.1 Data Fusion

Dataset 1 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053406-M2AS_058163933010_01_P001		17SEP24053406-P2AS_058163933010_01_P001		17SEP24053406-PMS_058163933010_01_P001_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	2m	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 2 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053341-M2AS-058163933010_01_P002		17SEP24053341-P2AS-058163933010_01_P002		17SEP24053341-PMS-058163933010_01_P002_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 3 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053353-M2AS_058163933010_01_P003		17SEP24053353-P2AS_058163933010_01_P003		17SEP24053353-PMS_058163933010_01_P003_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 4 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05NOV25054424-M2AS-058160620010_01_P001		05NOV25054424-P2AS-058160620010_01_P001		05NOV25054424-PMS-058160620010_01_P001_toa			none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 5 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05OCT07054718-M2AS-058160620010_01_P002		05OCT07054718-P2AS-058160620010_01_P002		05OCT07054718-PMS-058160620010_01_P002_toa			none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 6 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05SEP01054530-M2AS-058160620010_01_P003		05SEP01054530-P2AS-058160620010_01_P003		05SEP01054530-PMS-058160620010_01_P003_toa			none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

3.2 Data Processing

Sensor (8)	Landsat-5, Sentinel-2, QB-2, WV-4	Processing Date	Atmospheric Correction		Radiometric Processing (15)		Topographic Normalisation		OTHER Calculation:		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd...]		processed	Software / Method	processed	Software / Method	processed	Software / Method	processed	Software / Method			
Sentinel-2													
1.	S2B_MSIL2A_20171029T051919_N0206_R062_T43QGF_20171029T103813	17.07.2018	No	N/A	No	N/A	No	N/A	No	N/A	Yes	Yes	none
Landsat-5													
2.	LT05_L1TP_145044_20051108_20161123_01_T1	17.07.2018	No	N/A	No	N/A	No	N/A	No	N/A	Yes	Yes	none
WV-4													
3.	17SEP24053406-M2AS_058163933010_01_P001	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
4.	17SEP24053341-M2AS-058163933010_01_P002	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
5.	17SEP24053353-M2AS_058163933010_01_P003	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
Quickbird-2													
6.	05NOV25054424-M2AS-058160620010_01_P001	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
7.	05OCT07054718-M2AS-058160620010_01_P002	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
8.	05SEP01054530-M2AS-058160620010_01_P003	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none

4.1 Classification

Sensors (8)	Sentinel-2, Landsat, WV-4, QB	Processing Date	Cloud Masking		Thematic Classification		Manual Enhancement		Border Matching		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd...]		processed	Software/ Method	processed	Software/ Method	processed	Software/ Method	processed	Software/ Method			
1.	S2B_MSIL2A_20171029T051919_N0206_R062_T43QGF_20171029T103813	05.09.2018	No	No clouds	Yes	eCognition /semi-automatic approach	Yes	eCognition and GAFMap/ Visual Interpretation	Yes	ArcGIS 10 / Mosaic Dataset with manual neatline selection	Y	Y	
2.	LT05_L1TP_145044_20051108_20161123_01_T1	10.09.2018	No	No clouds	Yes	eCognition /semi-automatic approach	Yes	eCognition and GAFMap/ Visual Interpretation	Yes	ArcGIS 10 / Mosaic Dataset with manual neatline selection	Y	Y	
3.	17SEP24053406-M2AS_058163933010_01_P001 17SEP24053341-M2AS-058163933010_01_P002 17SEP24053353-M2AS_058163933010_01_P003	14.09.2018	No	No clouds	Y	GAFMap and ArcMap/visual mapping	Y	GAFMap and ArcMap/Visual interpretation	Y	ArcGIS 10 / Mosaic Dataset with manual neatline selection	Y	Y	
4.	05NOV25054424-M2AS-058160620010_01_P001 05OCT07054718-M2AS-058160620010_01_P002 05SEP01054530-M2AS-058160620010_01_P003	14.09.2018	No	No clouds	Y	GAFMap and ArcMap/visual mapping	Y	GAFMap and ArcMap/Visual interpretation	Y	ArcGIS 10 / Mosaic Dataset with manual neatline selection	Y	Y	

4.2 Intermediate Quality Control of LCLU Data

No.	x = ok (checked/performed) o = not performed n/a = not applicable Description of QC item	Compliant	Each item was checked during production and if necessary the source of error was identified and corrected. Comment
1	Data in predefined coordinate system? (e.g. UTM WGS84 system)	x	
2	Do all features have attributes?	x	
3	All feature attributes are valid (attribute value range, flags, correct comments)? 1) Do all features have a valid class name?	x	
4	All feature attributes present and filled in?	x	
5	Data coherence at the border of the urban area checked?	x	
6	Positional Accuracy of the features according to User Specifications?	x	
7	All feature geometries valid?	x	
8	Vertices of feature geometries adjusted? (e.g. missing, duplicated/ very close vertices)	x	
9	Multipart features resolved (Ring loops)?	x	
10	No data gaps? (Clean Gaps only if there are over ~200 gaps)	x	
11	No data overlaps? (Clean Overlaps only if there are over ~200 gaps)	x	
12	Feature geometries optimized (e.g. spikes, cutbacks minimized) (Find acute angles, remove angles < 15°)	x	
13	Minimum Mapping Area checked? (Urban 0.25ha, peri-urban 0.5ha)	x	
14	Minimum Mapping Width checked?	x	
15	Data checked for unnecessary polygon boundaries? (after final dissolve)	x	
16	Service Area completely covered by requested data (no data gaps)?	x	
17	No data outside delivery AoI?	x	
18	Add two new columns with the code and the name of the class.(Name them: code_year and name_year of the actual classification"	x	
19	Feature attribution and feature relations plausible? (Plausibility Check) --> Change product	x	
20	Calculation of area [AREA_km2] adjusted to final data?	x	
21	Re-calculation of [ID] (FID + 1)?	x	
22	LCLU product file naming and versioning according to specifications? (City_program_product_referenceDate_CoordinateSystem)	x	

5.1 Thematic Accuracy

No.	Product Name	Processing Date	Area Coverage	No. of Classes	Reference Data	Sample Size	Sampling Unit (21)	Sampling Design (22)	Sample Exclusion Criteria (23)	Thematic Accuracy (24)	Acceptance Status	Comment
1.	Urban Land Use/ Land Cover and Change (2005 – 2017)	25.10.2018	Bhopal (572 km²)	19	VHR data sources for urban area. Bing Maps by Microsoft and Google Imagery for Peri Urban area.	215 per strata (Level 1 classes)	Point	Stratified random sampling	None, all used	94.57%	**Yes**	1 class did not occur: '5200 Marine water'

5.2 Error Matrix

Reference Data																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Class Name		Residential	Isolated Structures	Industrial, Commercial, Public	Arterial Road	Port Area	Airport	Mineral Extraction, Dump Sites	Construction Sites	Land Without Current Use	Green Urban Area	Sports and Leisure Facilities	Agricultural Area	Forest and Shrublands	Natural Areas_Grassland	Bare Soil	Wetlands	Inland Water	
	Class ID	11	113	121	1221	123	124	131	133	134	141	142	2	31	32	33	4	51	Totals
Residential	11	161	0	1	0	0	0	0	0	0	0	0	3	0	2	0	0	0	167
Isolated Structures	113	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Industrial_Commercial_Public	121	1	0	19	0	0	0	0	0	2	0	0	0	0	0	0	0	0	22
Arterial Road	1221	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Port Area	123	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Airport	124	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	20
Mineral Extraction_Dump Sites	131	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Construction Sites	133	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7
Land Without Current Use	134	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	7
Green Urban Area	141	0	0	0	0	0	0	0	0	1	7	0	0	0	0	0	0	0	8
Sports and Leisure Facilities	142	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Agricultural Area	2	3	0	0	0	0	0	0	0	2	0	0	206	0	4	0	0	0	215
Forest and Shrublands	31	0	0	0	0	0	0	0	0	0	0	0	3	87	6	0	0	0	96
Natural Areas_Grassland	32	0	0	0	0	0	0	0	0	3	0	0	3	2	109	0	0	0	117
Bare Soil	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
Wetlands	4	0	0	0	0	0	0	0	0	0	0	0	1	0	14	0	153	1	169
Inland Water	51	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	211	215
	Totals	166	0	20	1	1	20	1	7	15	7	1	216	90	136	3	154	212	1050

Overall Accuracy: 94.57%
95% Confidence Interval: 93.15% - 95.99%

ID	Producer´s Accuracy	95% Confidence Interval		User´s Accuracy	95% Confidence Interval	
11	**96.99%**	94.09%	99.89%	**96.41%**	93.29%	99.53%
113	**0.00%**	0.00%	0.00%	**0.00%**	-50.00%	50.00%
121	**95.00%**	82.95%	107.05%	**86.36%**	69.75%	102.98%
1221	**100.00%**	97.50%	102.50%	**100.00%**	50.00%	150.00%
123	**100.00%**	50.00%	150.00%	**100.00%**	50.00%	150.00%
124	**100.00%**	97.50%	102.50%	**100.00%**	97.50%	102.50%
131	**100.00%**	50.00%	150.00%	**100.00%**	50.00%	150.00%
133	**100.00%**	92.86%	107.14%	**100.00%**	92.86%	107.14%
134	**46.67%**	18.09%	75.25%	**100.00%**	92.86%	107.14%
141	**100.00%**	92.86%	107.14%	**87.50%**	58.33%	116.67%
142	**100.00%**	50.00%	150.00%	**100.00%**	50.00%	150.00%
2	**95.37%**	92.34%	98.40%	**95.81%**	92.90%	98.72%
31	**96.67%**	92.40%	100.93%	**90.63%**	84.27%	96.98%
32	**80.15%**	73.08%	87.22%	**93.16%**	88.16%	98.16%
33	**66.67%**	-3.34%	136.68%	**100.00%**	75.00%	125.00%
4	**99.35%**	97.76%	100.94%	**90.53%**	85.82%	95.24%
51	**99.53%**	98.37%	100.69%	**98.14%**	96.10%	100.18%

6.1 Completeness

INPUT DATA

No.	Item	AOI Coverage [km²]	Area Coverage [km²]	Completeness of Coverage (25)	No. of Scenes	Scenes used in Production	Completeness of Verification (27)	Metadata	Comments
1.	HR EO Data	572 km²	256 km2	100%	2	2	100%	Yes	none
2.	VHR EO Data		316 km2	100%	6	6	100%	Yes	none
3.	In-situ Data		N/A	N/A	N/A	N/A	100%	Yes	none
4.	Ancillary Data		572 km2	100%	N/A	N/A	N/A	Yes	none

No.	Product (28)	AOI Coverage [km²]	Product Coverage [km²]	Completeness of Coverage (25)	Completeness of Classification (26)	Unclassifiable Area [%]	Completeness of Verification (27)	Metadata	Comments
1.	Urban and Peri-Urban Areas 2005 & 2017	572 km²	572 km²	100%	100%	N/A	100%	Yes	none

6.2 Compliancy

Product 1 (28)	Urban Land Use/ Land Cover and Change

Abstract

The Land Use/Land Cover (LU/LC) product contains spatial explicit information on the different occurring land use and land cover in both the High Density Cluster and Urban Cluster of the City of Bhopal for the years 2005 and 2017. The High Density Cluster area has a very detailed LU/LC nomenclature whereas the Urban Cluster area LU/LC nomenclature is at an aggregated Level. The input data for the High Density Cluster area was the Very High Resolution data (WorldView-4 for 2017 and Quickbird-2 for 2005) and the input data for the Urban Cluster area was Sentinel 2 (2017) and Landsat-5 (2005) data. The LU/LC product is the Baseline Product from which the Urban Green Areas product is derived.

Service / Product Specifications

Area Coverage

Requirements		Achieved Specifications		Compliancy	Comments
Country 1:	India	Country 1:	India	100%	
A) Wall-to-wall: Bhopal city High Density Core (316 km2) and Urban Cluster (256 km2)		A) Wall-to-wall: Full coverage of both AOIs		100%	
Area of approx. ***572 km²****, defined by the national user.*					
B) Sampling based: N/A		B) Sampling based: N/A			

Time Period - Update Frequency

Requirements	Achieved Specifications	Compliancy	Comments
Baseline Year(s): 2005 (+/- 1 years) 2018 (+/- 1 years)	Baseline Year(s): **2005** **2017**	Y	EO data used differs from specified Baseline Years, within accepted range
B) Update Frequency No update	B) Update Frequency No update	---	----

Geographic Reference System

Requirements	Achieved Specifications	Compliancy	Comments
WGS84 / UTM zone 43N	WGS84 / UTM zone 43N	Yes	---

Mapping Classes and Definitions (Definitions see REDD+ MRV Design Document)

Requirements	Achieved Specifications	Compliancy
20 Main classes (see 0.1 Requirements sheet)	19 classes were mapped according to their definition. One class did not occur: '5200 Marine water'	yes

Cloud and Shadow Detection and Removal

Requirements	Achieved Specifications	Compliancy	Comments
Cloud free	Full AOI coverage with spatial explicit LULC cover information	Yes	—

Spatial Resolution

Requirements	Achieved Specifications	Compliancy	Comments
NA	NA	NA	Only applicable for raster data
Minimum Mapping Unit (MMU)			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
0.25 ha and 0.5 ha	MMU of 0.25 ha and 0.5 ha	Yes	---
Data Type			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Vector	Vector	Yes	---
GeoPDF	None were set	Na	---
Bit Depth			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
None	NA	NA	--
Data Format			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
*.shp Shapefile (open cross-platform format)	Shapefile	Yes	---
Class Coding (Raster Data Only)			
Requirements	**Achieved Specifications**	**Compliancy**	
NA	NA	---	
Metadata			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
INSPIRE compliant	INSPIRE compliant and attached to product	Yes	---
Service / Product Quality			
Thematic Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Overall Accuracy: >85%	94.57%	Y	---
Positional Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
RMSE < 15 m	15m		
Delivery Procedure			
Service Provision			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
online via FTP	Uploaded to FTP	Yes	---
Delivery Date			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**

End of November 2018	End of November 2018	Yes	---

Glossary

Quality Checks		
Prefix	*Suffix*	*Explanation*
Y (Yes)	- V	*Visually checked*
N (No)	- Q	*Quantitatively/qualitatively checked*
N/A	- V Q	*Visually and quantitatively/qualitatively checked*
	- N/A	*Not applicable*

Readability (1)	Check readability of all required input data. Can the data be stored again?
Header / Metadata (2)	Check Image Header Information and/or Metadata for completeness / distinctive features.
Data Format (3)	For digital data, please give file format (e.g. *.tiff, *.shp).
Data Type (4)	Please specify the type of the data (e.g. raster, vector or analogue).
Bit Depth (5)	Please give pixel depth and sign of raster data (e.g. 8 bit unsigned integer).
Dynamic Range (6)	Check dynamic range of all image bands. Visual check of dynamic range should be accompanied by histograms and statistics.
Dropped Lines & Artefacts (7)	Check Image for dropped lines and other artefacts. If such occurs, please give description of extent and influence in the Comments section.
Sensor 1, 2, … (8)	Please delete / add additional sensor sections as necessary.
Purpose (9)	The purpose and use of the given auxiliary or reference data should be stated: ORHTOrectification, GEOmetric correction, REFerence, VERification source, POSitional ACCuracy assessment, THEmatic ACCuracy assessment.
Sampling Methodology (10)	Methodology of in situ or reference/auxiliary data sampling scheme should be outlined. In case of sample plots, also state how the plot positions have been determined (e.g. from GPS measurements, topographic maps, terrestrial triangulation, EO data, etc.) and how the sampling grid was established.
Positional Accuracy (11)	Positional accuracy of collected in situ data should be given. For reference/auxiliary data it MUST be given. If unknown, the data's use must be explained. For DEM or other data with 3D information please specify both vertical and horizontal Positional Accuracy. For analogue data (e.g. maps) try to give approximate accuracy related to mapping scale.
Completeness (12)	Data should be checked for spatial/temporal/content gaps.
Model / Algorithm (13)	Give the name of the software and its version. Specify the software module/algorithm used for: a) geometric correction, e.g., Polynomial and its degree, Rational Functions, Thin Plate Spline, etc. b) classification, e.g., ISODATA, Maximum Likelihood, Neural Networks, etc.
Dataset 1, 2, … (14)	Please delete / add additional dataset sections as necessary.
Radiometric Processing (15)	State whether (and which) radiometric processing was applied (e.g., contrast enhancement, histogram matching, bundle block adjustment, radiometric normalisation, filtering, etc.).

Projection; Spheroid / Ellipsoid (16)	Always specify completely, i.e. at minimum the Projection (+Zone, if applicable), Spheroid / Ellipsoid, Map Datum. Give additional information if necessary to unambiguously define the reference system.
Ground Control Points (GCPs) (17)	Give the number, distribution and RMS of used Ground Control Points (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of GCPs should be attached as a snapshot, or described in the Comments section.
Tie Points (TPs) (18)	In case of mosaicking, give the number of used Tie Points and their total RMS (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of TPs should be attached as a snapshot, or described in the Comments section.
Check Points (CPs) (19)	The real measure of positional accuracy and the only measure which should be examined as to its Acceptable Range. Give the independent Check Points' total RMS (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of CP's should be attached as a snapshot, or described in the Comments section.
Resampling Method (20)	Specify, if / which resampling algorithm has been used (e.g. NN=Nearest Neighbour, BIL=Bilinear Interpolation, CC=Cubic Convolution).
Sampling unit (21)	Specify sampling unit of Accuracy Assessment as POINT, FRAME, POLYGON and how it is treated (e.g. pixel center, polygon centre, etc.).
Sampling Design (22)	SYST=Systematic, RAND=Random, STRAT=Stratified, SBCLASS=Stratified by class, SBAREA=Stratified by area
Sample exclusion criteria (23)	Describe which criteria you apply for sampling point selection resp. exclusion of certain points. For example, if the point is too close to a class boundary (less than 1 pixel), it is excluded. If the selected sample point is not representative of the class , it is excluded. For these reasons, it is recommended to oversample by 10% to compensate for sample point exclusion.
Thematic Accuracy (24)	Provide a detailed description of the Accuracy Assessment results in the form of error matrices showing commission and omission errors, user's , producer's and overall accuracies and other measures of Thematic Accuracy, as the confidence level (usually fixed at 95%) and the respective confidence interval, at least for the overall accuracy. If classification is done in a phased approach, e.g. if Forest Area and subsequently Forest Type are mapped, independent reports have to be produced.
Completeness of Coverage (25)	State whether the coverage is limited to a subset, or portion of the final product.
Completeness of Classification (26)	State whether classification was constrained to a subset, or portion of the final product.

Completeness of Verification (27)	State whether verification applied to lineage, positional, or thematic accuracy is constrained to a subset, or portion of the final product.
Product (28)	Please delete / add additional product sections as necessary.
Lineage (29)	Definition (INSPIRE 2015): Lineage is "a statement on process history and/or overall quality of the spatial data set. Where appropriate it may include a statement whether the data set has been validated or quality assured, whether it is the official version (if multiple versions exist), and whether it has legal validity. The value domain of this element is free text."
Source(30)	Definition (INSPIRE, 2015): "This is the description of the organisation responsible for the establishment, management, maintenance or distribution of the resource. This description shall include: name of the organisation and contact email address."

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Earth Observation for Sustainable Development – Urban

Quality Assurance and Quality Control Sheets

These QA/QC Templates were prepared by GAF AG compliant with ISO 9001:2015 Quality Management System standards and can only be used by Partners in the current EO4SD-Urban Project.

Project Title:	EO4SD-Urban		
Project Leader:	GAF AG		
Service Provider:	GAF AG	Editor:	D. Angelova
Client:	GPSC, World Bank	Date:	13.11.2018
Product:	Urban Green Areas Product		

Overview of QC-Sheets and Processing Steps	***Sheet used***	***Sheet filled in***
Requirements		
0.1 Requirements	Yes	Yes
Specifications of Input Data		
1.1 List of EO Data	Yes	Yes
1.2 List of In-situ Data	Yes	Yes
1.3 List of Ancillary Data	Yes	Yes
Data Quality Checks		
2.1 EO Data Quality	Yes	Yes
2.2 In-situ Data Quality	Yes	Yes
2.3 Ancillary Data Quality	Yes	Yes
Pre-Processing of EO Data		
3.1 Geometric Correction	Yes	Yes
3.1.1 Data Fusion	Yes	Yes
3.2 Data Processing	Yes	Yes
Thematic Processing		
4.1 Classification	Yes	Yes
4.2 Intermediate Quality Control of Land Use Data	Yes	Yes
Accuracy Assessment		
5.1 Thematic Accuracy	Yes	Yes
5.2 Error Matrices	Yes	Yes
Delivery Checks / Delivery		
6.1 Completeness	Yes	Yes
6.2 Compliancy	Yes	Yes

Glossary (index numbers in the QA/QC tables refer to the glossary at the end of this document)

Further QC-relevant Documents:

Comments / Characteristics:

0.1 Requirements			
Product 1 (28)	Urban Green Areas 2005 and 2017		
Abstract			
Urban Green Areas information product contains spatial explicit information on green areas within the urban extent. Green areas include linear green features such as river alignments, hedges and trees, as well as public parks, private gardens, forested areas, etc. *Urban Green Areas & Change dataset is based on Very High Resolution (VHR) satellite imagery by means of automated classification processing techniques.*			
Service / Product Specifications			
Area Coverage			
Country:	**India**	A) Wall-to-wall: Bhopal city	
City:	**Bhopal**	Selected Sites: High density core	
Area km²	High density core: 316 km2	B) Sampling based: n/a	
Time Period - Update Frequency			
A) Baseline Year(s): 2005 and 2017		B) Update Frequency 2 points in time, no future update	
Comments: None			
Geographic Reference System			
EPSG: 32643. WGS 84 / UTM 43N			
Mapping Classes and Definitions			
Single date			
0	Non-urban green area		
1	Urban green area		
Change product			
0	Non-urban green area		
1	Permanent urban green area		
2	Loss of urban green area		
3	New urban green area		
254	No change analysis due to absence of historic VHR imagery or out of historic urban extent		
Cloud and Cloud Shadow Detection and Removal			
n/a			
Spatial Resolution			
1 m			
Minimum Mapping Unit (MMU)			
1 m²			
Data Type & Format			

Raster data in GEOTIFF		
Bit Depth		
8 bit for *.tif raster files		
Class Coding		
Class Code	*Class Name*	*RGB Code*
Single date		
0	Non-urban green area	255/245/235
1	Urban green area	56/168/0
Change product		
0	Non-urban green area	255/245/235
1	Permanent urban green area	56/168/0
2	Loss of urban green area	255/100/100
3	New urban green area	152/230/0
254	No change analysis due to absence of historic VHR imagery or out of historic urban extent	255/255/255
Metadata		
Provided as INSPIRE conformant *xml data set, covering at least the mandatory elements. ISO standard 19115 "Metadata" and ISO 19139 "XML Scheme Implementation"		
Service / Product Quality		
Thematic Accuracy		
Overall Accuracy: >80%		
Positional Accuracy		
3 m (CE90)		
Delivery Procedure		
Service Provision		
Online via FTP		
Delivery Date		
End of November 2018.		

1.1 List of EO Data

Sensor (8)	QB-2, WV-4	Incoming Date	Acquisition Date	Proc. Level	Path / Row	AOI - City / Region / Country	Spatial Res.	No. of Bands	Cloud Cover (Data Provider)	Projection / Spheroid (16)	Data Format (3)	Bit Depth (5)	Header / Metadata (2)
File Name [e.g yymmdd; tbd…]													
WV-4													
1.	17SEP24053406-M2AS_058163933010_01_P001	16.07.2018	24.09.2017	LV2A	P001	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	0%	UTM zone 43N	.tiff	16 Bit	.xml
2.	17SEP24053341-M2AS-058163933010_01_P002	16.07.2018	24.09.2017	LV2A	P002	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	4.0e-03%	UTM zone 43N	.tiff	16 Bit	.xml
3.	17SEP24053353-M2AS_R1C1-058163933010_01_P003	16.07.2018	24.09.2017	LV2A	P003	Bhopal, IND	MUL: 2m; PAN: 0.5m	4	1.0e-03%	UTM zone 43N	.tiff	16 Bit	.xml
Quickbird-2													
4.	05NOV25054424-M2AS-058160620010_01_P001	16.07.2018	25.11.2005	LV2A	P001	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml
5.	05OCT07054718-M2AS-058160620010_01_P002	16.07.2018	07.10.2005	LV2A	P002	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml
6.	05SEP01054530-M2AS-058160620010_01_P003	16.07.2018	01.09.2005	LV2A	P003	Bhopal, IND	MUL: 2m; PAN: 0.6m	4	0%	UTM zone 43N	GeoTIFF	16 Bit	.imd, .rpb, .til, xml

1.2 List of In-situ Data

Dataset 1 (14)	Incoming Date	Acquisition Date	AOI - City / Region / Country	Data Type (4)	Projection / Spheroid (16)	No. of Sample Plots	Sampling Design (22)	Positional Accuracy (11)	Purpose (9)
No In-situ Data Used									

1.3 List of Ancillary Data

Dataset 1 [14]	LULC	Date of Receipt from Client	Metadata [2]	Reference Mapping Date / Date of Creation	Geographic Area/- City / Region / Country	Area Coverage	Data Type [4]	Data Format [3]	Projection / Spheroid [16]	Positional Accuracy [11]	No. of Classes	Thematic Accuracy	Availability of Class Definitions
EO4SD-Urban Land Use/Land Cover Baseline Product		2018-10-15	Yes (INSPIRE)	2005 and 2017	Bhopal (core urban area)	100%	Vector	*.shp	EPSG: 32643. WGS 84/ UTM 43N	< 3 m	19	94.57%	Yes
Lineage[29]:	/												
Source [30]:	GAF AG												

2.1 EO Data Quality

Sensor[8]	QB-2, WV-4	Backup	Readability (1)	Check Header / Metadata (2)	Band Specifications			Projection / Spheroid (16)	Scene Location	Completeness of Additional Data	Data Format (3)	Bit Depth (5)	Cloud Cover (internal check)	Radiometry	Topography	Dropped Lines / Artefacts (7)	Acceptance Status	Comments
	File Name [e.g yymmdd; tbd...]				No. of Bands	Band Registration	Spectral/Spatial Resolution											
WV-4																		
1.	17SEP24053406-M2AS_R1C1-058163933010_01_P001	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
2.	17SEP24053341-M2AS-058163933010_01_P002	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
3.	17SEP24053353-M2AS_R1C1-058163933010_01_P003	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
Quickbird-2																		
4.	05NOV25054424-M2AS-058160620010_01_P001	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
5.	05OCT07054718-M2AS-058160620010_01_P002	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none
6.	05SEP01054530-M2AS-058160620010_01_P003	Y - Q	Y - V Q	Y - V Q	Y - V Q	Y - V Q	Y - Q	Y - V	Y - V	Y - V Q	Y - Q	Y - Q	Y - V Q	Y - V Q	Y - V	N - V Q	Yes	none

2.2 In-situ Data Quality

Dataset 1 (14)	Field Data	Backup	Readability (1)	Check Header / Metadata (2)	Extent	Projection / Spheroid (16)	Spatial Resolution	Data Format (3)	Bit Depth (5)	Location	Completeness	Geom. Misalignment	Plausibility	Dropped Lines / Artefacts (7)	Acceptance Status	Comments
File Name [e.g yymmdd; tbd...]																
No in-situ data used																

2.3 Ancillary Data Quality

Dataset 1 (14) LULC / File Name [e.g yymmdd; tbd...]	Readability (1)	Check Header /Metadata (2)	Data Coverage Matches Service Area (%)	Projection / Spheroid , EPSG(16)	Spatial Resolution and unit (e.g. m, km)	Data Format (3)	Bit Depth (5)	Completeness (Vector: Attribute Table; Raster: Thematic Values)	Geom. Misalignment	Dropped Lines / Artefacts (EO data only)(7)	Utility for Current Project
EO4SD-Urban LULC Product	☒ Yes ☐ No	☒ Complete (INSPIRE/ISO19119) ☐ Incomplete ☐ not available	☒ Yes ☐ No ☐ Unknown If no: xxx%	☒ Correct ☐ Incorrect ☐ Unknown EPSG: 32643	n.a.	*.shp	n.a.	☒ Complete ☐Incomplete	☒ No ☐ Yes ☐ Unknown If yes: XX m	☒ No ☐ Yes ☐ n.a. If yes: xxx %	☐ None ☐ Partial ☒ Full
Comments:	/										

3.1 Geometric Correction

Sensor [8]	QB-2, WV-4												
No.	File Name [e.g yymmdd; tbd…]	Processing Date	AOI City / Region / Country	Projection / Spheroid [16]	No. & RMS (m) of GCPs [17]	No. & RMS (m) of TPs [18]	No. & RMS (m) of CPs [19]	Digital Elevation Model (DEM)	Model / Algorithm [13]	Resampling Method [20]	Validation Reports	Acceptance Status	Output File Name [e.g yymmdd; tbd…]
WV-4													
1.	17SEP24053406-M2AS_058163933010_01_P001	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x0.92; y1.39	18; RMSE x0.56; y0.29	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053406-PMS_058163933010_01_P001_toa
2.	17SEP24053341-M2AS-058163933010_01_P002	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x0.95; y1.59	9; RMSE x0.17; y0.22	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053341-PMS-058163933010_01_P002_toa
3.	17SEP24053353-M2AS_058163933010_01_P003	20.07.2018	Bhopal IND	UTM 43N/WGS	4; RMSE x1.98; y1.39	31; RMSE x0.27; y0.32	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o17SEP24053353-PMS_058163933010_01_P003_toa
Quickbird-2													
4.	05NOV25054424-M2AS-058160620010_01_P001	20.07.2018	Bhopal IND	UTM 43N/WGS	5; RMSE x1.99; y1.65	31; RMSE x0.60; y0.70	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05NOV25054424-PMS-058160620010_01_P001_toa
5.	05OCT07054718-M2AS-058160620010_01_P002	20.07.2018	Bhopal IND	UTM 43N/WGS	1; RMSE x1.11; y0.83	10; RMSE x1.05; y0.99	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05OCT07054718-PMS-058160620010_01_P002_toa
6.	05SEP01054530-M2AS-058160620010_01_P003	20.07.2018	Bhopal IND	UTM 43N/WGS	0; RMSE xNaN; yNaN	9; RMSE x0.15; y0.26	N/A	SRTM 30	0 order polynom	CC	Yes	Yes	o05SEP01054530-PMS-058160620010_01_P003_toa

3.1.1 Data Fusion

Dataset 1 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053406-M2AS_058163933010_01_P001		17SEP24053406-P2AS_058163933010_01_P001		17SEP24053406-PMS_058163933010_01_P001_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	2m	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 2 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053341-M2AS-058163933010_01_P002		17SEP24053341-P2AS-058163933010_01_P002		17SEP24053341-PMS-058163933010_01_P002_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 3 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	17SEP24053353-M2AS_058163933010_01_P003		17SEP24053353-P2AS_058163933010_01_P003		17SEP24053353-PMS_058163933010_01_P003_toa			none
Sensor	WorldView-4		WorldView-4		WorldView-4			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.5m	Pan	0.5m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 4 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05NOV25054424-M2AS-058160620010_01_P001		05NOV25054424-P2AS-058160620010_01_P001		05NOV25054424-PMS-058160620010_01_P001_toa		Yes	none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u		

Dataset 5 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05OCT07054718-M2AS-058160620010_01_P002		05OCT07054718-P2AS-058160620010_01_P002		05OCT07054718-PMS-058160620010_01_P002_toa		Yes	none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u		

Dataset 6 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	05SEP01054530-M2AS-058160620010_01_P003		05SEP01054530-P2AS-058160620010_01_P003		05SEP01054530-PMS-058160620010_01_P003_toa		Yes	none
Sensor	Quickbird-2		Quickbird-2		Quickbird-2			
Method	PCI / Pansharp2		PCI / Pansharp2		PCI / Pansharp2			
Spatial Resolution /(MS/Pan)	2m	MS	0.6m	Pan	0.6m	MS		
Band Combination	BGR NIR		PAN		BGR NIR			
Data Format (3) & Bit Depth (5)	*.tif	16 Bit u	*.tif	16 Bit u	*.tif	16 Bit u		

3.2 Data Processing

Sensor [8]	QB-2, WV-4	Processing Date	Atmospheric Correction		Radiometric Processing [15]		Topographic Normalisation		OTHER Calculation:		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd...]		processed	Software / Method	processed	Software / Method	processed	Software / Method	processed	Software / Method			
WV-4													
1.	17SEP24053406-M2AS_058163933010_01_P001	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
2.	17SEP24053341-M2AS-058163933010_01_P002	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
3.	17SEP24053353-M2AS_058163933010_01_P003	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
Quickbird-2													
4.	05NOV25054424-M2AS-058160620010_01_P001	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
5.	05OCT07054718-M2AS-058160620010_01_P002	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none
6.	05SEP01054530-M2AS-058160620010_01_P003	17.07.2018	No	N/A	No	N/A	No	N/A	Yes	GAFmap / TOA	Yes	No	none

4.1 Classification

Sensors (8)	WV-4, QB	Processing Date	Cloud Masking		Thematic Classification		Manual Enhancement		Border Matching		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd…]		processed	Software/ Method	processed	Software/ Method	processed	Software/ Method	processed	Software/ Method			
1.	17SEP24053406-M2AS_058163933010_01_P001 17SEP24053341-M2AS-058163933010_01_P002 17SEP24053353-M2AS_058163933010_01_P003	14.09.2018	No	No clouds	Y	Geomatica 2017/supervised classification	Y	Geomatica 2017/Visual interpretation	Y	QGIS / Manual check with CIR image at the background	Y	Y	None
2.	05NOV25054424-M2AS-058160620010_01_P001 05OCT07054718-M2AS-058160620010_01_P002 05SEP01054530-M2AS-058160620010_01_P003	14.09.2018	No	No clouds	Y	Geomatica 2017/supervised classification	Y	Geomatica 2017/Visual interpretation	Y	QGIS / Manual check with CIR image at the background	Y	Y	None

5.1 Thematic Accuracy

No.	Product Name	Processing Date	Area Coverage	No. of Classes	Reference Data	Sample Size	Sampling Unit (21)	Sampling Design (22)	Sample Exclusion Criteria (23)	Thematic Accuracy (24)	Acceptance Status	Comment
1.	Urban Green Areas 2005	22.10.2018	Bhopal (316 km²)	2	VHR EO Data	215 per strata (Level 1 classes)	Point	Stratified random sampling	None, all used	88.37%	**Yes**	None
2.	Urban Green Areas 2017	08.11.2018	Bhopal (316 km²)	2	VHR EO Data	215 per strata (Level 1 classes)	Point	Stratified random sampling	None, all used	86.98%	**Yes**	None

5.2 Error Matrices

Urban Green Area 2017	Reference Data		Totals
	0 - Non-Urban Green Area	1 - Urban Green Area	
0 - Non-Urban Green Area	**136**	27	163
1 - Urban Green Area	1	**51**	52
Totals	137	78	**215**

Accuracy Statistics	z=	1.96
95% Confidence Interval:	82.25%	91.71%

Overall Accuracy: 86.98%

Class Name	Producer's Accuracy	User's Accuracy
0 - Non-Urban Green Area	99.27%	83.44%
1 - Urban Green Area	65.38%	98.08%

Urban Green Area 2005	Reference Data		Totals
	0 - Non-Urban Green Area	1 - Urban Green Area	
0 - Non-Urban Green Area	**107**	15	122
1 - Urban Green Area	10	**83**	93
Totals	117	98	**215**

Accuracy Statistics	z=	1.96
95% Confidence Interval:	83.85%	92.89%

Overall Accuracy: 88.37%

Class Name	Producer's Accuracy	User's Accuracy
0 - Non-Urban Green Area	91.45%	87.70%
1 - Urban Green Area	84.69%	89.25%

6.1 Completeness									
INPUT DATA									
No.	Item	AOI Coverage [km²]	Area Coverage [km²]	Completeness of Coverage (25)	No. of Scenes	Scenes used in Production	Completeness of Verification (27)	Metadata	Comments
1.	VHR EO Data	Bhopal	316 km2	100%	6	6	100%	Yes	none
No.	Product (28)	AOI Coverage [km²]	Product Coverage [km²]	Completeness of Coverage (25)	Completeness of Classification (26)	Unclassifiable Area [%]	Completeness of Verification (27)	Metadata	Comments
1.	Urban Green Areas and change 2005 & 2017	Bhopal	316 km²	100%	100%	N/A	100%	Yes	none

6.2 Compliancy					
Product 1 (28)	Urban Green Areas 2005 and 2017				
Abstract					
Urban Green Areas information product contains spatial explicit information on green areas within the urban extent. Green areas include linear green features such as river alignments, hedges and trees, as well as public parks, private gardens, forested areas, etc. *Urban Green Areas & Change dataset is based on Very High Resolution (VHR) satellite imagery by means of automated classification processing techniques.*					
Service / Product Specifications					
Area Coverage					
Requirements		**Achieved Specifications**		**Compliancy**	**Comments**
Country 1:	India	Country 1:	India	100%	
A) Wall-to-wall: Bhopal city High Density Core Area (316 km2)		A) Wall-to-wall: Bhopal city High Density Core Area (316 km2)		100%	
*Area of Interest: Bhopal **316 km², defined** by the national user.*					
B) Sampling based: N/A		B) Sampling based: N/A			
Time Period - Update Frequency					
Requirements		**Achieved Specifications**		**Compliancy**	**Comments**
Baseline Year(s): 2005 (+/- 1 years) 2015 (+/- 1 years)		Baseline Year(s): **2005** **2017**		Yes	EO data used differs from specified Baseline Years, within accepted range
B) Update Frequency No update		B) Update Frequency No update		-	-
Geographic Reference System					
Requirements		**Achieved Specifications**		**Compliancy**	**Comments**
WGS84 / UTM zone 43N		WGS84 / UTM zone 43N		Yes	None

Mapping Classes and Definitions				
Requirements		**Achieved Specifications**		**Compliancy**
Single date				
0	Non-urban green area	0	Non-urban green area	YES
1	Urban green area	1	Urban green area	YES
Change product				
0	Non-urban green area	0	Non-urban green area	YES
1	Permanent urban green area	1	Permanent urban green area	YES
2	Loss of urban green area	2	Loss of urban green area	YES
3	New urban green area	3	New urban green area	YES
254	No data available due to absence of historic VHR imagery	254	No data available due to absence of historic VHR imagery	YES

Cloud and Shadow Detection and Removal			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
NA	NA	---	—
Spatial Resolution			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
1 m	1 m	Yes	None
Minimum Mapping Unit (MMU)			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
1 m²	1 m²	YES	None
Data Type			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Raster data	Raster data	YES	None
Bit Depth			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
N/A	8 bit	YES	None
Data Format			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
GEOTIFF	GEOTIFF	YES	None

Class Coding		
Requirements	**Achieved Specifications**	**Compliancy**
NA	NA	---

Metadata			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
ISO standard 19115 "Metadata" and ISO 19139 "XML Scheme Implementation"	ISO standard 19115 "Metadata" and ISO 19139 "XML Scheme Implementation"	YES	None
Service / Product Quality			
Thematic Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Overall Accuracy: >80%	>80%	YES	None
Positional Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
3 m (CE90)	3 m (CE90)	YES	None
Delivery Procedure			
Service Provision			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
online via FTP	online via FTP	Yes	None

Delivery Date			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
End of November 2018	End of November 2018	Yes	None

Glossary

Quality Checks		
Prefix	*Suffix*	*Explanation*
Y (Yes)	- V	*Visually checked*
N (No)	- Q	*Quantitatively/qualitatively checked*
N/A	- V Q	*Visually and quantitatively/qualitatively checked*
	- N/A	*Not applicable*

Readability (1)	Check readability of all required input data. Can the data be stored again?
Header / Metadata (2)	Check Image Header Information and/or Metadata for completeness / distinctive features.
Data Format (3)	For digital data, please give file format (e.g. *.tiff, *.shp).
Data Type (4)	Please specify the type of the data (e.g. raster, vector or analogue).
Bit Depth (5)	Please give pixel depth and sign of raster data (e.g. 8 bit unsigned integer).
Dynamic Range (6)	Check dynamic range of all image bands. Visual check of dynamic range should be accompanied by histograms and statistics.
Dropped Lines & Artefacts (7)	Check Image for dropped lines and other artefacts. If such occurs, please give description of extent and influence in the Comments section.
Sensor 1, 2, ... (8)	Please delete / add additional sensor sections as necessary.
Purpose (9)	The purpose and use of the given auxiliary or reference data should be stated: ORHTOrectification, GEOmetric correction, REFerence, VERification source, POSitional ACCuracy assessment, THEmatic ACCuracy assessment.
Sampling Methodology (10)	Methodology of in situ or reference/auxiliary data sampling scheme should be outlined. In case of sample plots, also state how the plot positions have been determined (e.g. from GPS measurements, topographic maps, terrestrial triangulation, EO data, etc.) and how the sampling grid was established.
Positional Accuracy (11)	Positional accuracy of collected in situ data should be given. For reference/auxiliary data it MUST be given. If unknown, the data's use must be explained. For DEM or other data with 3D information please specify both vertical and horizontal Positional Accuracy. For analogue data (e.g. maps) try to give approximate accuracy related to mapping scale.
Completeness (12)	Data should be checked for spatial/temporal/content gaps.
Model / Algorithm (13)	Give the name of the software and its version. Specify the software module/algorithm used for: a) geometric correction, e.g., Polynomial and its degree, Rational Functions, Thin Plate Spline, etc. b) classification, e.g., ISODATA, Maximum Likelihood, Neural Networks, etc.
Dataset 1, 2, ... (14)	Please delete / add additional dataset sections as necessary.
Radiometric Processing (15)	State whether (and which) radiometric processing was applied (e.g., contrast enhancement, histogram matching, bundle block adjustment, radiometric normalisation, filtering, etc.).

Projection; Spheroid / Ellipsoid (16)	Always specify completely, i.e. at minimum the Projection (+Zone, if applicable), Spheroid / Ellipsoid, Map Datum. Give additional information if necessary to unambiguously define the reference system.
Ground Control Points (GCPs) (17)	Give the number, distribution and RMS of used Ground Control Points (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of GCPs should be attached as a snapshot, or described in the Comments section.
Tie Points (TPs) (18)	In case of mosaicking, give the number of used Tie Points and their total RMS (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of TPs should be attached as a snapshot, or described in the Comments section.
Check Points (CPs) (19)	The real measure of positional accuracy and the only measure which should be examined as to its Acceptable Range. Give the independent Check Points' total RMS (as average per scene) as obtained from the Geometric Correction, in meters [m]. Optionally, also RMSx and RMSy may be given. Distribution of CP's should be attached as a snapshot, or described in the Comments section.
Resampling Method (20)	Specify, if / which resampling algorithm has been used (e.g. NN=Nearest Neighbour, BIL=Bilinear Interpolation, CC=Cubic Convolution).
Sampling unit (21)	Specify sampling unit of Accuracy Assessment as POINT, FRAME, POLYGON and how it is treated (e.g. pixel center, polygon centre, etc.).
Sampling Design (22)	SYST=Systematic, RAND=Random, STRAT=Stratified, SBCLASS=Stratified by class, SBAREA=Stratified by area
Sample exclusion criteria (23)	Describe which criteria you apply for sampling point selection resp. exclusion of certain points. For example, if the point is too close to a class boundary (less than 1 pixel), it is excluded. If the selected sample point is not representative of the class , it is excluded. For these reasons, it is recommended to oversample by 10% to compensate for sample point exclusion.
Thematic Accuracy (24)	Provide a detailed description of the Accuracy Assessment results in the form of error matrices showing commission and omission errors, user's , producer's and overall accuracies and other measures of Thematic Accuracy, as the confidence level (usually fixed at 95%) and the respective confidence interval, at least for the overall accuracy. If classification is done in a phased approach, e.g. if Forest Area and subsequently Forest Type are mapped, independent reports have to be produced.
Completeness of Coverage (25)	State whether the coverage is limited to a subset, or portion of the final product.
Completeness of Classification (26)	State whether classification was constrained to a subset, or portion of the final product.
Completeness of Verification (27)	State whether verification applied to lineage, positional, or thematic accuracy is

	constrained to a subset, or portion of the final product.
Product (28)	Please delete / add additional product sections as necessary.
Lineage (29)	Definition (INSPIRE 2015): Lineage is “a statement on process history and/or overall quality of the spatial data set. Where appropriate it may include a statement whether the data set has been validated or quality assured, whether it is the official version (if multiple versions exist), and whether it has legal validity. The value domain of this element is free text.”
Source(30)	Definition (INSPIRE, 2015): “This is the description of the organisation responsible for the establishment, management, maintenance or distribution of the resource. This description shall include: name of the organisation and contact email address.”