Earth Observation for
Sustainable Development

urban development
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Urban Development Project

Service Operations Report – Phnom Penh

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Summary

This document contains information about EO4SD-Urban service operations performed for providing to stakeholders the full geospatial dataset required over the Area of Interest of Phnom Penh located in Cambodia. The context as well as the product requirements and specifications are firstly detailed, before providing the relevant information about all steps of the service operations including the input data, the processing methods, the accuracy assessment and Quality Control procedures. Finally, the relevant analysis of mapping results is presented with explicit visual inputs.

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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 an 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

The report describes the methodological approach to produce geospatial products and results of urban analytics derived from the products as implemented as a part of the ESA funded EO4SD Urban project for Phnom Penh, Cambodia in collaboration with the World Bank. EO-based information support has been provided to the World Bank Urban GP's Advisory Services and Analytics (ASA) Programme **"Urban Development in Cambodia"** for the counterpart City Authorities in Phnom Penh.

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 and delivered:

- Settlement Extent and Imperviousness
- Urban Land Use / Land Cover
- Urban Extent
- Transport Infrastructure – Road Network
- Flood Hazard

This City Operations Report for Phnom Penh 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 the Annexe of this Report. There is also the provision of standard analytical work undertaken with the products, which can be further included as inputs into further urban development assessments, modelling and reports. The text of the Report is accompanied by several maps, charts and tables with statistics. Total built-up extent and level of imperviousness as of 2015 are estimated for the extended (peri-urban) area. LU/LC distribution and its structure relevant for years 2002/2003 and 2017 are provided for the core and peri-urban area of interest, as well as distribution and typology of road network and flood hazard.

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List of Abbreviations

ADB	Asian Development Bank
AOI	Area of Interest
CS	Client States
DEM	Digital Elevation Model
DLR	German Space Agency - Geospatial Service Provider, Germany
EDF	European Development Fund
EEA	European Environmental Agency
EGIS	Consulting Company for Environmental Impact Assessment and Urban Planning, France
EIB	European Investment Bank
EO	Earth Observation
EO4SD	Earth Observation for Sustainable Development
ESA	European Space Agency
EU	European Union
FAO	Food and Agriculture Organization
GAF	GAF AG, Geospatial Service Provider, Germany
GDB	ESRI Geodatabase
GEO	Group on Earth Observations
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
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
LCF	Land use / Land cover Change Flow
LIDAR	Light Detection and Ranging
LUCC	Land use / Land cover Change
LULC	Land use / Land cover
MDB	Multi-lateral Development Bank
MDG	Millennium Development Goal
MGCP	Multinational Geospatial Co-production Program
MMU	Minimum Mapping Unit
NDVI	Normalized Difference Vegetation Index
NEO	Geospatial Service Provider, The Netherlands
NGO	Non-Governmental Organisation
ODA	Official Development Assistance
OGC	Open Geospatial Consortium
OSP	Operational Service Providers
OSM	Open Street Map
PUMA	Web Based Platform for Urban Management and Analysis
QA	Quality Assurance

QC	Quality Control
R&D	Research and Development
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SC	Service Cluster
SDG	Sustainable Development Goal
S.L.	(Soil) Sealing Level ~ Imperviousness
SO	Service Operations
SP	Service Provider
SRTM	Shuttle Radar Topographic Mission
TEP	Thematic Exploitation Platform
TNA	Training Need Assessment
ToC	Table of Contents
UN	United Nations
UNDP	United Nations Development Programme
UUA	User Utility Assessment
VHR	Very High Resolution
WB	World Bank
WBG	World Bank Group

1 Introduction 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 leave and avoiding 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 Phnom Penh (Cambodia) within the EO4SD-Urban Project and as it had been delivered to the user in September 2017.

2.1 Stakeholders and Requirements

The project provided information support to the Advisory Services and Analytics (ASA) programme **“Urban Development in Cambodia”** in the form of a Rapid City Diagnostic report for Phnom Penh, Cambodia. Objective of the activity was to generate evidence to inform Cambodia government policy and programs for sustainable urbanization with a focus on Phnom Penh. The Royal Government of Cambodia has approached the World Bank for assistance on some of their key challenges related to urban development. Specifically, through the Ministry of Land Management, Urban Planning and Construction, they have requested help with sustainable urban planning and management (including financing), capacity building, and integrated urban investments during a World Bank mission in July 2016.

Requirements included primarily provision of information describing status and change of land use pattern and evolution of urban extent pattern over a period of multiple years.

Following table provides summary of products identified during user capacity and requirements assessment phase and reflected by user requirement specification in the D2 document.

Table 1: Summary of requirements.

Required Product Name (naming adopted from D3 specification)	Specific requirements (beyond standard product specification in D3)	Producer
Urban & Peri-Urban Land Use / Land Cover (LULC)	None	GISAT
Urban & Peri-Urban Land Use / Land Cover Change (LUCC)	None	GISAT
Transport Network	None	GISAT
Urban Extent	Provide urban extent development in the last 2 decades to identify main development areas and axes	DLR
Imperviousness	None	DLR
Flood History, Hazard & Risk	None	JR

2.2 Service Area Specification

The Service Area or Area of Interest (AOI):

- *Core Urban Area* which corresponds to the most populated area including the historic city centre
- *Peri-Urban Area* which covers the surroundings of the city.

This AOI geographical division has been set up for offering products specifically relevant for artificial areas only and which require the use of Very High Resolution satellite imagery (< 4 m spatial resolution, see chapter 3.1 for details).

Figure 1 shows the Core City (373 km^2) and the whole AOI (886 km^2) of Phnom Penh, Cambodia.

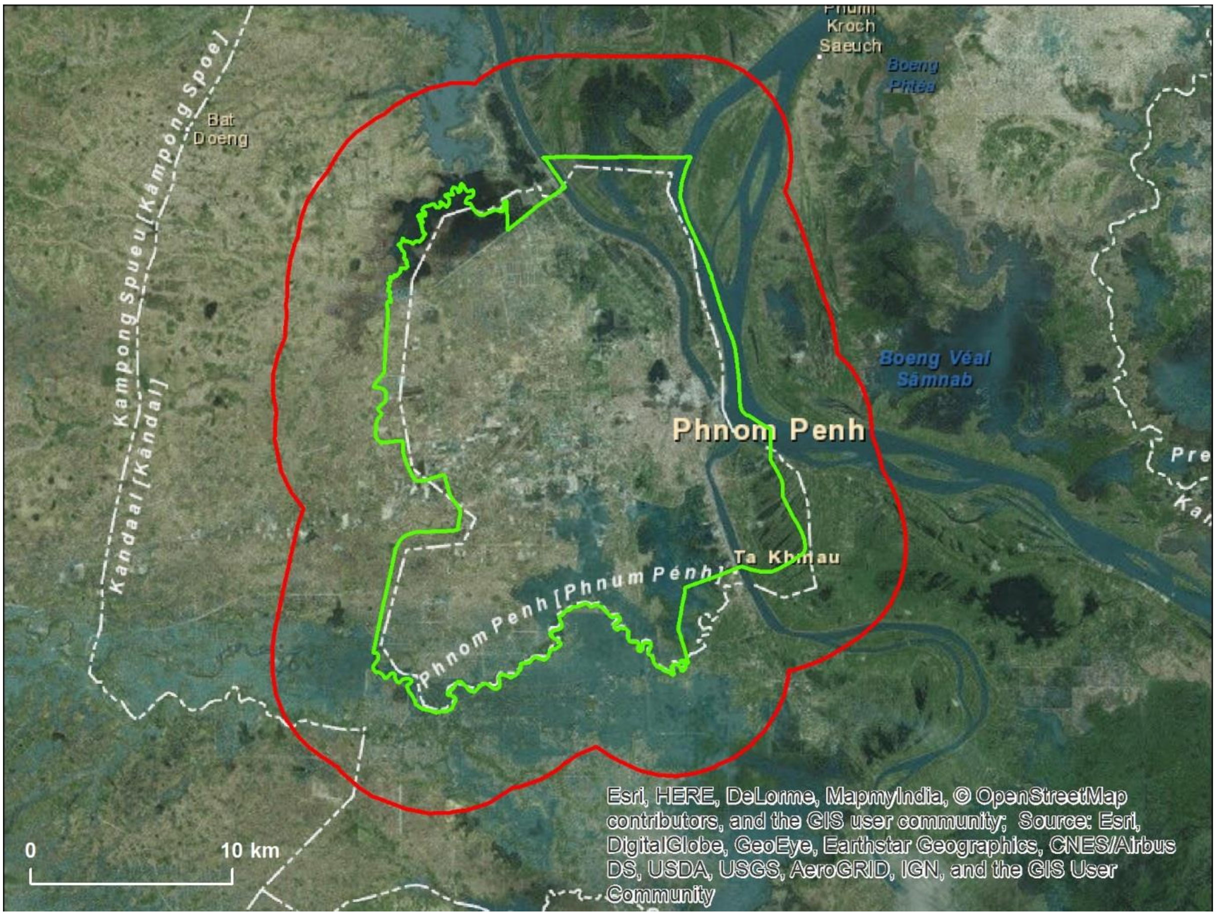


Figure 1: Phnom Penh, Cambodia – Core City (green), Service Area (red)

2.3 Product List and Product Specifications

The following table lists the products, which have been produced within the EO4SD-Urban project for the production site in Phnom Penh.

Table 2: Product list.

Product Name	Classes and Definitions	Resolution	
		Spatial (MMU, scale)	Temporal (revisit)
Urban & Peri-Urban Land Use / Land Cover (LULC)	11100 - Formal high density continuous residential (Sealing level > 80%) 11200 - Formal high density discontinuous residential (Sealing level: 50% - 80%) 11300 - Formal low density discontinuous residential (Sealing level: 10% - 50%) 12000 - Commercial and industrial units 12100 - Non-residential urban fabric 12200 - Roads and associated land 12300 – Airports 13000 - Construction sites 13200 – Land without current use 14100 - Urban greenery 14200 - Sport and leisure facilities 20000 - Agriculture 31000 - Trees 32000 – Other Natural and Semi-natural areas incl. wetlands 33000 - Bare land 50000 - Water bodies	Core Urban Area: 0.5 m (MMU – 0.25 ha) Peri-Urban Area: 10 m (MMU – 1 ha)	2002/2003 – 2017 14-year interval
Urban & Peri-Urban Land Use / Land Cover Change (LUCC)	<u>Land Cover Flows Level 1:</u> LCF1 – Urban Extension LCF2 – Urban Internal changes LCF3 – Agricultural development LCF4 – Natural and semi-natural internal changes LCF5 – Water bodies development LCF6 – Natural and semi-natural development	Core Urban Area: 0.5 m (MMU – 0.25 ha) Peri-Urban Area: 10 m (MMU – 1 ha)	2002/2003 – 2017 14-year interval
Urban Extent	<u>Single date</u> Urban / artificial area	Core- and peri-Urban Area: 1 ha (MMU)	2017
Imperviousness	0 - Non-impervious area 1-100 – Impervious area (1 to 100% imperviousness degree) 254 - Unclassifiable (no satellite image available or presence of clouds, shadows) 255 - Outside area of interest	30 m	2007 - 2017
Flood History, Hazard & Risk	<u>Product 1: Flood Extent</u> Water body Flooded area <u>Product 2: Flood Hazard</u> 0 - Water body	30 m	

	1-n - Number of flood occurrences in the past 10 years -999 - Remarkable historical flood (2000) Product 3: Flood Risk Flood risk level considering both flood hazard level (1-2-3) and land use damage cost level (A-B-C-D): Low risk (1A-1B-2A) Medium risk (1C-1D-2B-2C-3A-3B) High risk (2D-3C) Very high risk (3D)		

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 (LULC) nomenclature as well as class definitions. The approach taken was to use a standard remote sensing based LULC nomenclature and then adapt it to the user's LU requirements. Thus the remote-sensing based LULC classes in the urban context can be grouped into 5 Level 1 classes, which are Artificial areas, Natural/ Semi Natural, Agricultural, Wetland, 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. A depiction of the way the levels and classes are structured is presented as follows:

Table 3: LULC nomenclature

LULC Level I	LULC Level II	LULC Level III
Artificial surfaces	Urban Fabric	Continuous Urban Fabric (Sealing Layer-SL > 80%)
		Discontinuous Dense Urban Fabric (S.L. 50% - 80%)
		Discontinuous Low Density Urban Fabric (S.L. 10% - 50%)
	Industrial, commercial, public, military, private and transport unit	Industrial and commercial units
		Non-residential urban fabric
		Road and rail network and associated land (Open Street Map)
		Airport areas
	Urban greenery	Urban green
		Sport and leisure facilities
	Construction and other sites	Construction sites
		Land without current use
Non-artificial surface	Agriculture land	
	Forest	

	Natural and semi-natural land including wetlands	
	Bare land	
	Water bodies	

(Reference: Urban Atlas, 2012)

It should be noted that the Level 1 classes were used as the basis for classification of the Peri-urban areas using the High Resolution (HR) data such as Landsat or Sentinel. However, for the Core Urban 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 adapted to the User requirements based on existing Master Plans for cities and/or direct advise from the User on critical classes required. The final LULC nomenclature had to be endorsed by the user before productions started.

2.5 Land Use/Land Cover Change Nomenclature

Land Use/Land Cover Changes are presenting as LULC flows (LCF). These flows represent grouped individual changes into logical blocks.

Table 4: LCF nomenclature

LCF level 1	LCF level 2	Description
LCF10: Urban extension	LCF11: Urban extension: extension of residential urban fabric	Formation of new residential urban fabric over non-artificial land over non-artificial land
	LCF12: Urban extension: extension of commercial & industrial units	Formation of new commercial & industrial fabric over non-artificial land
	LCF13: Urban extension: extension of transportation units	Formation of new transportation units over non-artificial land
	LCF14: Urban extension: extension of non-residential urban fabric	Formation of new non-residential urban fabric over non-artificial land over non-artificial land
	LCF15: Urban extension: extension of urban greenery	Formation of new urban greenery areas over non-artificial land
	LCF16: Urban extension: extension of construction sites	Formation of new construction sites over non-artificial land
LCF20: Urban internal changes	LCF21: Internal urban development: formation and densification of residential urban fabric	Internal conversion between artificial surfaces, formation and densification of residential urban fabric over other urban classes
	LCF22: Internal urban development: formation of commercial & industrial units	Internal conversion between artificial surfaces, formation of commercial and industrial units over other urban classes
	LCF23: Internal urban development: formation of transportation units	Internal conversion between artificial surfaces, formation of transportation units over other urban classes
	LCF24: Internal urban development: formation of non-residential urban fabric	Internal conversion between artificial surfaces, formation of non-residential urban fabric over other urban classes
	LCF25: Internal urban development: formation of urban greenery	Internal conversion between artificial surfaces, formation of urban greenery over other urban classes
	LCF26: Internal urban development: formation of construction sites	Internal conversion between artificial surfaces, formation of construction sites over other urban classes

LCF30: Agriculture development	LCF31: Agriculture uptake	Conversion of various types of natural and semi-natural land into agricultural land
	LCF32: Agriculture abandonment	Abandonment of agricultural land in favor of various types of natural and semi-natural land
	LCF33: Agriculture development: consumption of urban fabric	Conversion of various types of urban fabric into agricultural land
LCF40: Natural and semi-natural internal changes	LCF40: Natural and semi-natural areas internal changes	Internal conversion between various natural and semi-natural classes
LCF50: Riverbed and water bodies development	LCF51: Riverbed development: Extension of agriculture	Conversion of water body into agriculture (related mostly to riverbed development)
	LCF52: Riverbed development: consumption of agriculture	Conversion of agriculture into water body (related mostly to riverbed development)
	LCF53: Riverbed development: extension of natural and semi-natural areas	Conversion of water body into natural and semi-natural land (related mostly to riverbed development)
	LCF54: Riverbed development: consumption of natural and semi-natural areas	Conversion natural and semi-natural land into water body (related mostly to riverbed development)
	LCF55: Riverbed development: consumption of urban fabric	Conversion of various types of urban fabric into water body
LCF60: Natural and semi-natural development	LCF61: Trees development: consumption of urban fabric	Conversion of various types of urban fabric into trees
	LCF62: Natural areas development: consumption of urban fabric	Conversion of various types of urban fabric into natural areas
	LCF63: Vacant land development: consumption of urban fabric	Conversion of various types of urban fabric into vacant land
	LCF64: Bare land development: consumption of urban fabric	Conversion of various types of urban fabric into bare land

2.6 Nomenclatures of other products

Nomenclatures of flood products are described in the Annex 1.

2.7 Terms of Access:

Product dissemination has mainly done via online secured FTP solution.

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 Quality Control procedures.

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 and Radar EO Data

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

More specifically, the following images have been downloaded, processed and used:

- Landsat-5: 1 scene acquired on 30/11/2003 for the peri-urban historic mapping of LULC
- Sentinel-2: 1 scene acquired on 01/01/2017 for the peri-urban current mapping of LULC
- Landsat-8: 280 scenes from 2017 for detection of urban extent and imperviousness within peri-urban area
- Sentinel-1: 35 scenes from period 05/12/2015 – 21/02/2017 for flood detection

For Flood risk analysis there are two types of data available for this purpose: optical and Radar data. Available HR optical data from the sensors Landsat 5, Landsat 7, Landsat 8, ASTER, and Sentinel-2 covering the period from 2000 to 2017 was downloaded and analyzed with regard to regional and/or local flooding.

Radar data from the current European Space Agency (ESA) Sentinel-1 data is acquired constantly and it is free of charge. The spatial resolution of this data is approximately 10 m. In order to go further back in time (2002 – 2012), ERS/ENVISAT data could be used. Currently, these datasets are commercially available, but for the future, there are concrete actions of ESA to make this data available also free of charge during 2018. Sentinel-1 Radar Data covering the period from 2015-12-05 to 2017-02-21 (35 datasets) was downloaded and processed with regard to water extent.

Very High Resolution Optical EO Data

The VHR data for the core urban 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 agreemen**ts 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:

- QuickBird: 2 scenes acquired on 13/10/2002 and 03/02/2003
- Pleiades: 2 scenes acquired on 03/01/2017 and 12/02/2017

Ancillary Data

- **DEM:** Terrain heights for the Ortho-Image production were taken from the standard 1 arcsec SRTM DEM (SRTM = Shuttle Radar Topography Mission), providing a ground spatial resolution of 30m x 30m. The SRTM data meet the absolute horizontal and vertical accuracies of 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence)

- **OSM:** Thematic vector data available through Open Street Map portal were mainly related to road network. These data have been downloaded and refined by visual interpretation for creating a full and consistent road network as solid basis before producing the baseline LULC mapping.

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 has 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 Applied 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.

[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

However, in complex LULC products with many classes, this usually results in a large number of strata (one stratum per LULC 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 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 (see **Chyba! Nenalezen zdroj odkazů.**). In the second stage ll 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 5) that did not received samples in the first run, additionally 215 samples were randomly drawn across all these classes.

Table 5: **Number of sampling points for the EO4SD-Urban mapping classes after applying sampling design for year 2017.**

Class Name	Class ID	No. of Samplin g Points	Km² coverage
Residential	1000	205	80.2
Industrial and Commercial	1200	50	31.11
Non-residential	1210	35	11.98
Transportation	1220	15	4.59
Airport	1230	10	3.32
Construction	1300	30	13.88
Land without current use	1320	55	49.62
Urban greenery, sport and leisure facilities	1400	25	4.7
Agriculture	2000	30	91.66
Forest	3100	15	0.96
Natural and semi-natural areas	3200	30	26.55
Bare land	3300	30	1.06
Water	5000	10	53.6

3.3.2 The Applied 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.

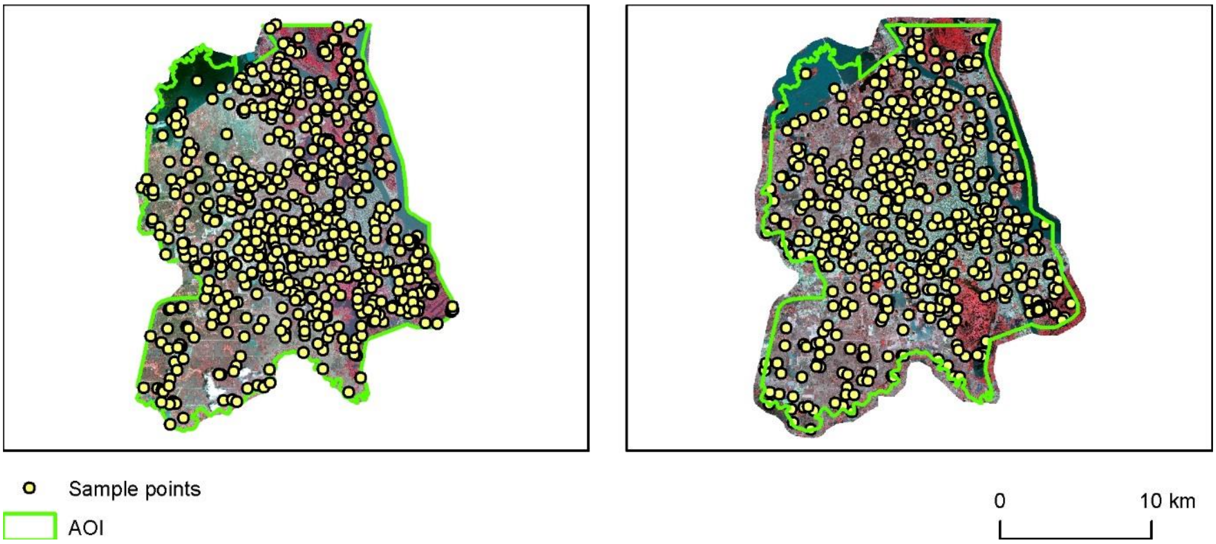


Figure 2: VHR data of the city of Phnom Penh for year 2002/2003 (left) and 2017 (right) overlaid with randomly distributed sample points for accuracy assessment.

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 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).

3.3.3 The Applied Analysis Design

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

[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.).

matrices (see Annex 2). 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 is +/- 1.96*σ.

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 baseline Land Use/Land Cover product for Phnom Penh has an overall mapping accuracy of 89 %. The specific class accuracies are given in Annex 2.

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;
- eometric 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

[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.

After each intermediate processing step a QC/QA was performed to evaluate products appropriateness for the subsequent processing (see Figure 3).

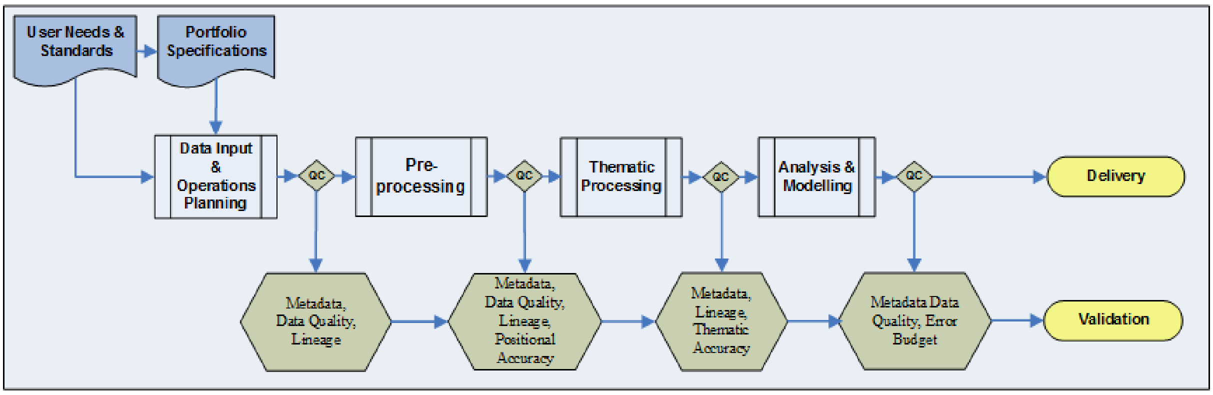


Figure 3: Quality Control process for EO4SD-Urban product generation. At each intermediate processing step output properties are compared against pre-defined requirements.

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 Overview of accuracy assessment per product

Table 6: **Overview of accuracy assessment per product**

Product	Overall Accuracy
Land Use / Land Cover	90 %
Land Use / Land Cover Change	86 %
Urban Green Areas	85 %
Flood History and Flood Hazard	88.9 % - 95.8 %

3.6 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 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, including the following sub-sections:

- Urban Global Products – Urban Extent and Imperviousness
- Urban Extent – Status and Trends
- Urban & Peri-Urban Land Use / Land Cover - Status and Trends
- Urban Green areas – Status and Trends
- Transportation network
- Flood Risk

4.1 Urban Global Products

The 2014-2015 Global Urban Products - Settlement Extent and Imperviousness Level products are generated by exploiting multi-temporal Sentinel-1 (S1) radar and Landsat-8 optical data intersecting the investigated Area of Interest (AOI) in the period 2014-2015. These products based on land cover definition are supposed to provide means to cost-effective screening and global benchmarking of city extent between multiple cities thanks to availability of high resolution satellite data and their comparability. Hot-spots identified using the Global Urban Products can be then further explored and analysed in detail using tailored products from the EO4SD portfolio.

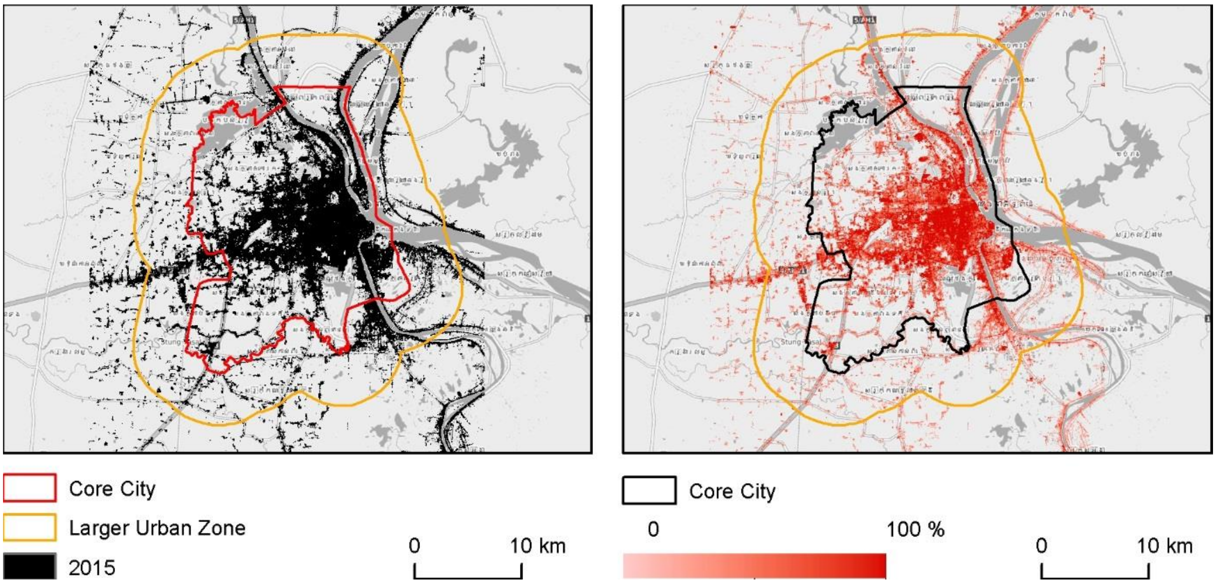


Figure 4: Global Urban Extent Status (left) and Level of Imperviousness (right) – 2015

Figure 4 shows very high level of urbanization and imperviousness within the city center and around the main transportation axis.

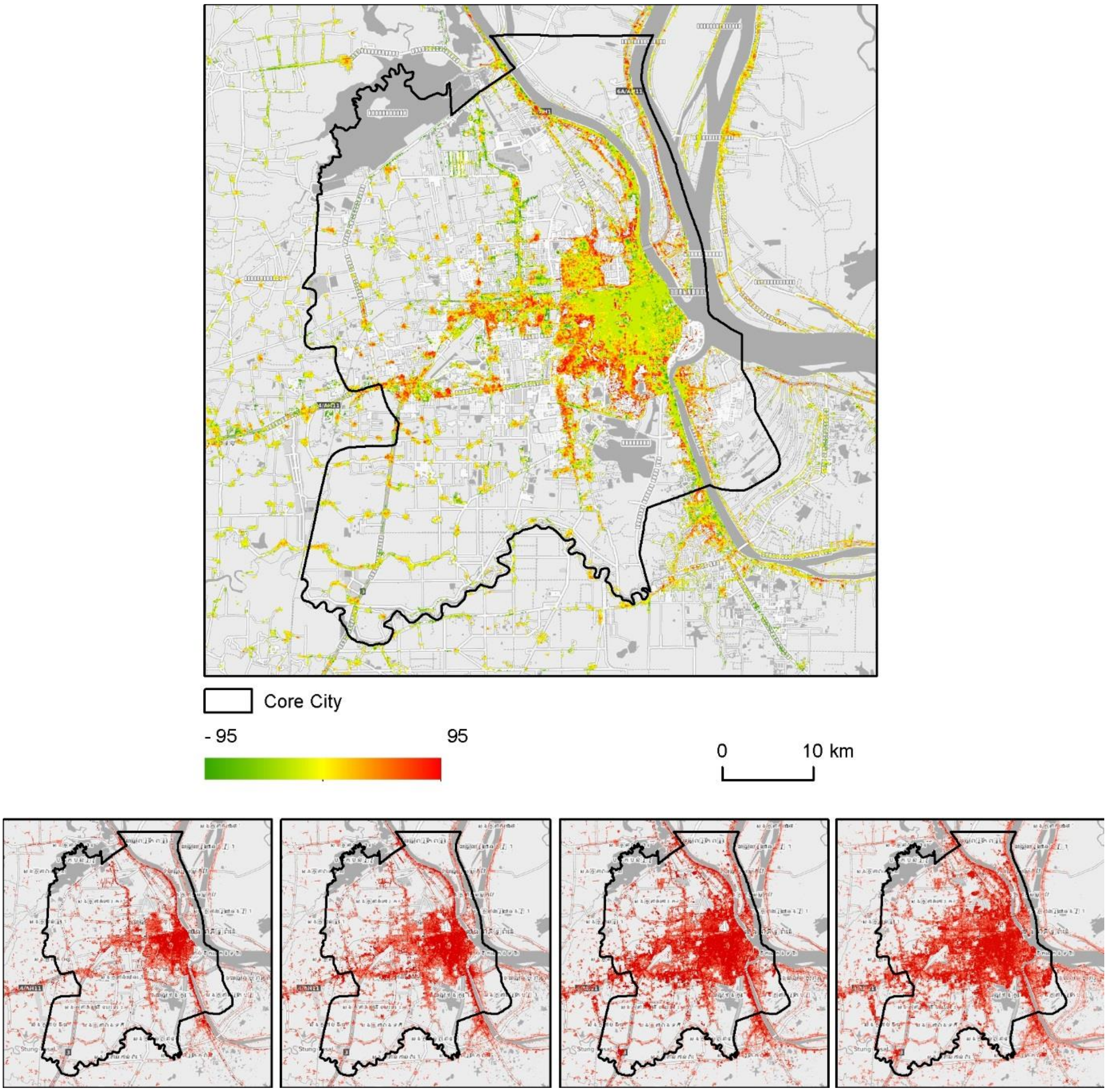


Figure 5: Difference of Imperviousness between 1990 - 2015 (above) and Level of Imperviousness (bottom form left 1990, 2000, 2010, 2015)

Figure 5 shows the development of Imperviousness between years 1990 and 2015. It shows both the extension of urban fabric and the densification of areas on the edge of core city. Core city itself remaining without significant changes.

4.2 Urban Extent – Status and Trends

The assessment of the urban extent of cities over time provides information on the changes in the urban development in terms of built-up area expansion/reduction. Urban Extent product delivered within EO4SD-Urban project has been directly extracted from the baseline LULC information product by aggregating classes to artificial and non-artificial areas. In contrast to information presented in Figure 4 which is more related to land cover showing predominantly built-up and sealed areas, urban extent status and growth presented in Figure 6 is based on land use nomenclature, i.e. the urban extent mask contains also artificial classes like construction sites. No further analysis based on morphology or functional urban area concept has been applied, but the data products can provide a solid basis for such analyses. Figure 6 below shows the overall extent of artificial areas and the location of urban expansion.

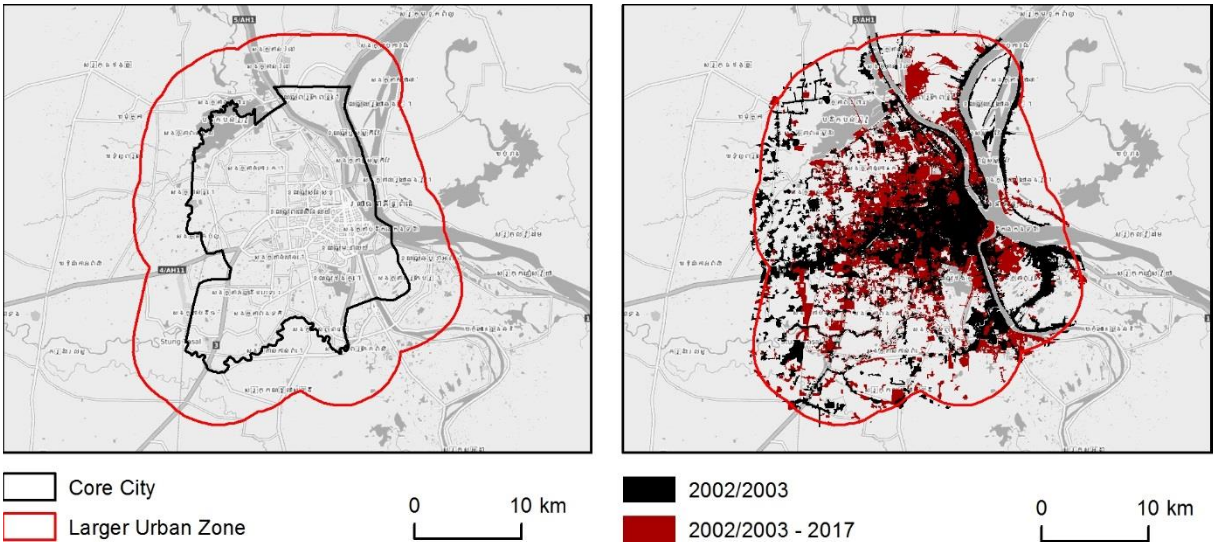


Figure 6: Urban Extent Status and Growth - Spatial Distribution.

Figure 6 shows that the urban growth is mainly located on the west bank of Mekong River. There is quite rapid expansion of urban fabric to north and south from core city.

Figure 7 shows the growth of urban area between years 2003 and 2017. The graph on the left displays the proportion of the total area divided into three classes: *Urban Extent 2003* which represent the urban area in 2003, *Urban Extent Growth 2003-2017* which shows the growth of urban area between these years, and *Non-urbanised* area which is the area in 2017 covered by non-urban classes. On the right side the same is shown in km^2. The graph is displayed for the whole area of Phnom Penh (overall), and then separately for the area of the Core City and for the Larger Urban Zone.

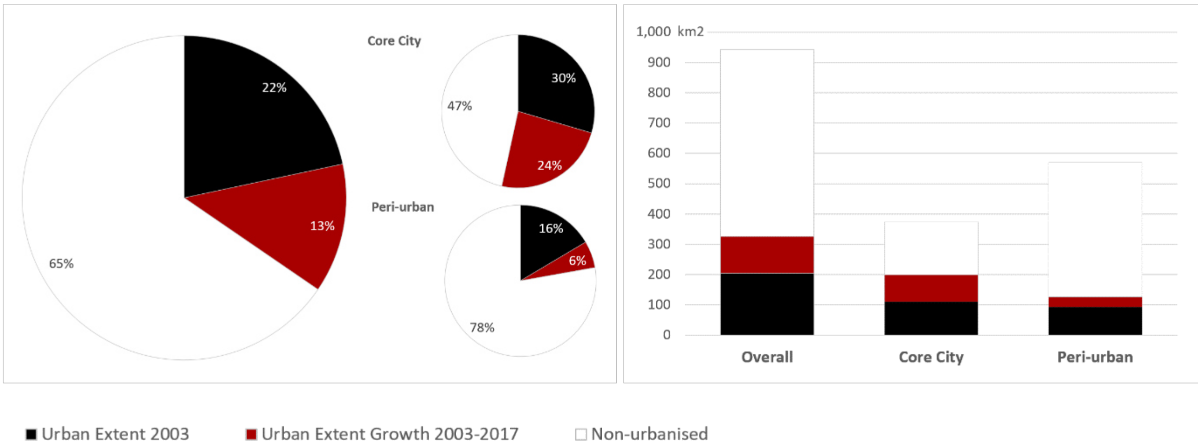


Figure 7: Urban Extent Status and Growth: Overall, in Core City, and in Larger Urban Zone- in % (left) and in km2 (right).

As seen on the graphs above the Urban extent growth over the period of 14 years presents 13 % of the overall area of Phnom Penh, 24 % in the Core City area and 6 % the Larger Urban Zone. Whilst in 2003 urban area represented 22 % of the whole area, in 2017 urban area occupies 35 % which is just over 1/3 of the area. In 2017 the urban area in the Core City represents 54 % of the area, whilst in the Larger Urban Zone it represents just under a quarter of the area (22 %).

Figure 8 displays the situation regarding urban extent in 2003 and the urban extent growth between years 2003 and 2017 for each of the Phnom Penh's township. Townships are divided to those situated in the Core city (on the left of the graph) and to those in the Larger urban zone (on the right of the graph). *Urban extent 2003* shows the % of overall township area covered by urban classes in 2003. *Urban extent growth 2003-2017* displays the % of area which in 2003 belonged to non-urban classes but which was urbanised and by 2017 it belongs to urban area. *The non-urbanised* area shows the proportion of the whole township area which is not covered by urban classes in 2017.

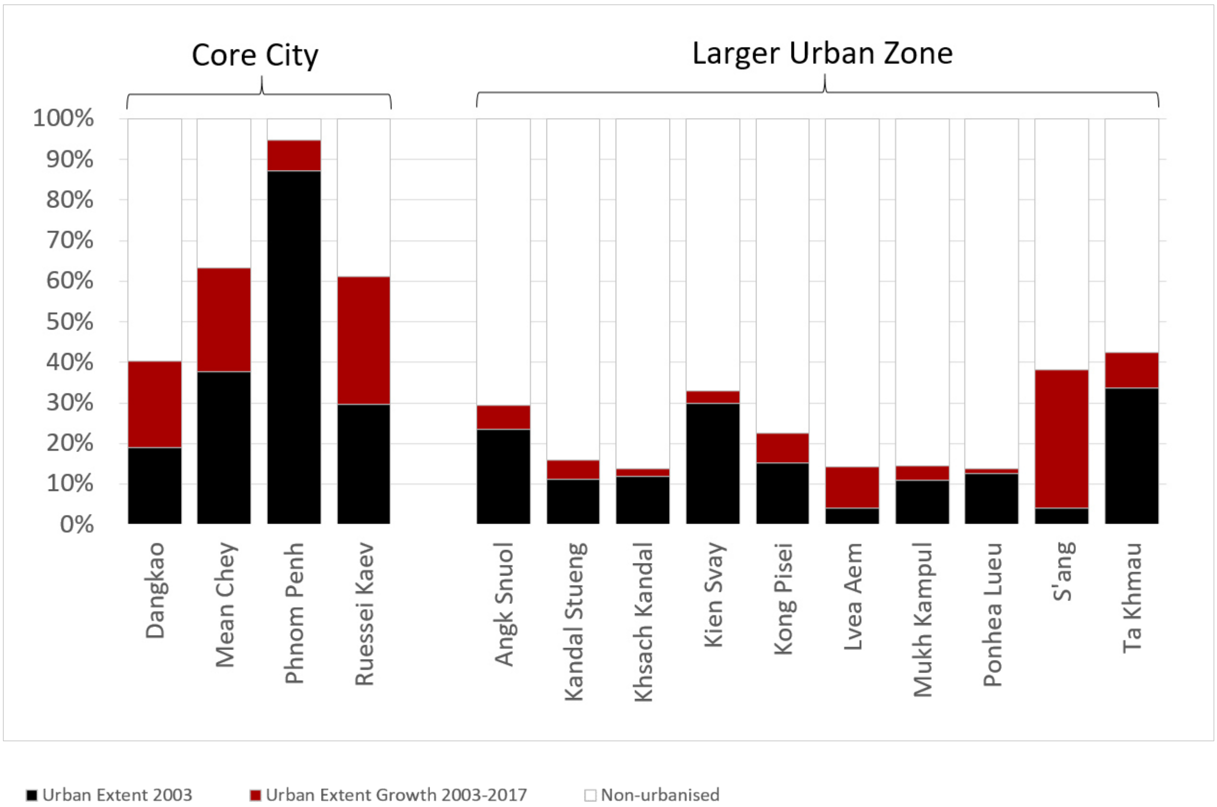


Figure 8: Urban Extent in 2002/2003 and Urban Extent Growth 2002/2003-2017 in % per district.

The red colour displays the proportion of each of the township areas' which was urbanised between 2003 and 2017. The graph shows the proportions, not the overall figures. The largest urban extent growth proportionate to the area of the township was recorded in the S'ang township where this area represents 34 %. However, the overall largest urban extent growth between 2003 and 2017 (considering the area in km^2) was recorded in Dangkao township where this area covers 40.3 km^2. The largest non-urbanised area in 2017 is in the also in the Dangkao township where this area represents111.7 km^2. If looking into the proportion of the township area then the largest non-urbanised area can be found in the Ponhea Lueu township where it covers 786.3 % of the area.

Figure 9 shows share of urbanized areas per districts and growth intensity of urban areas.

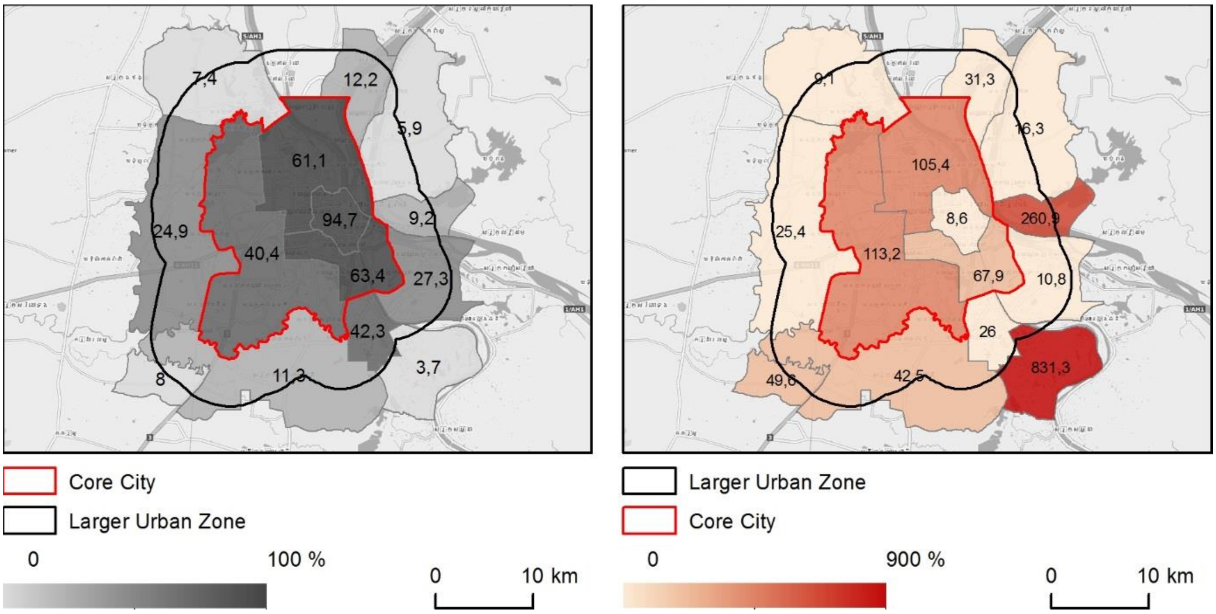


Figure 9: Urban Extent 2017 (% urbanized area of total area; left) and Urban Extent Growth Intensity 2002/2003-2017 (% increase comparing to initial 2002/2003 area; right) per districts – spatial distribution.

Figure 9 on the left map displays the distribution of urbanized area in districts. Only the very Core City (Phnom Penh) is highly urbanized, other districts in core area are medium urbanized, but they are subject of urban development, which can be seen in the right map. Districts in Peri-Urban areas are mainly agricultural or under water, and the urban development is not so radical.

4.3 Land Cover Land Use - Status and Trends

Core city of Phnom Penh is a highly urbanized area with rapid development. Surroundings of Core City is occupied by construction sites which consume agriculture lands a water bodies in neighborhood of Core city.

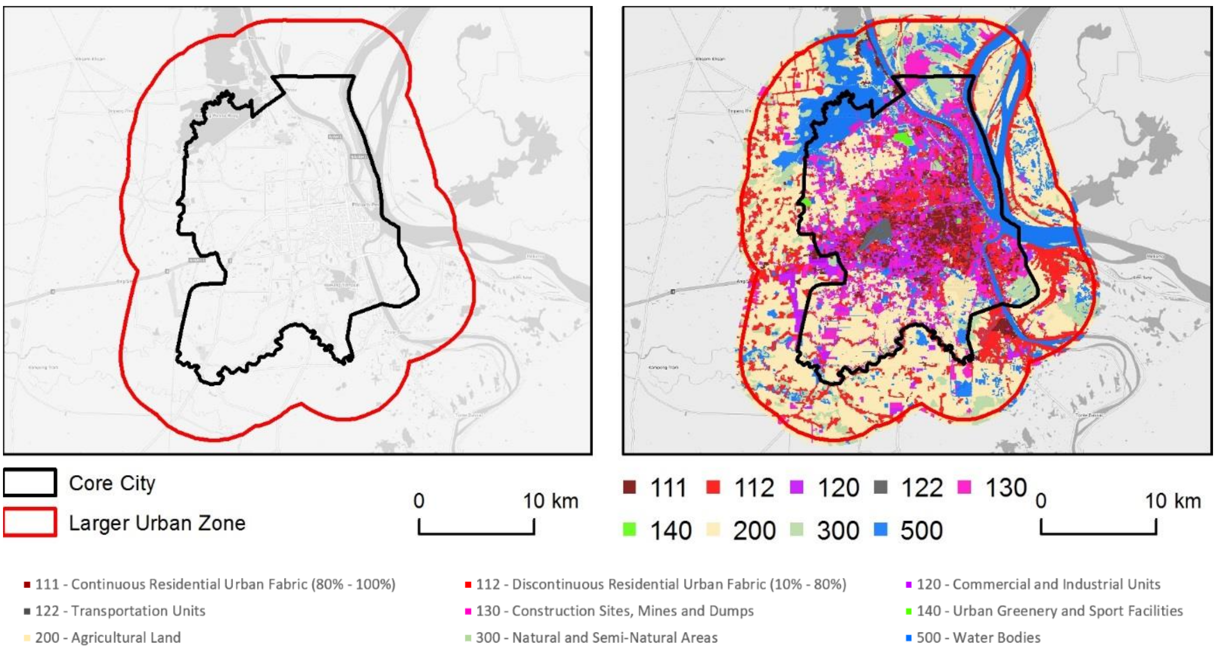


Figure 10: Detailed Land Cover Land Use 2017 - Spatial Distribution.

Figure 11 shows how the area of Phnom Penh is distributed between the main Land Cover Land Use classes, both proportionally (on the left) and in actual area extent (on the right). In both cases this is presented for the whole area of Phnom Penh (overall) and then individually for the Core City area and for the Larger Urban Zone.

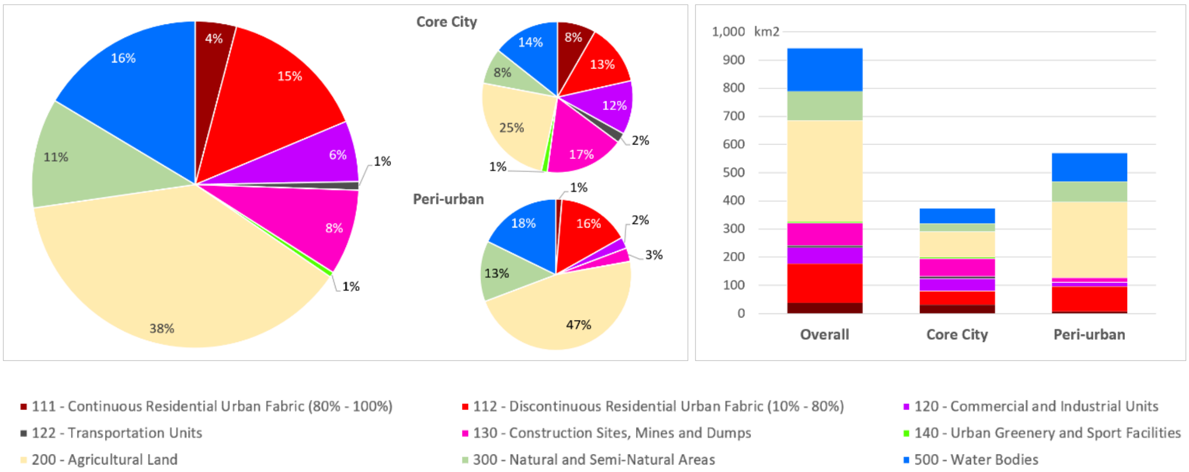


Figure 11: Detailed Land Cover Land Use 2017 structure - overall, in Core City and in Larger Urban Zone in % (left) and km^2 (right).

The largest portion of the overall area of Phnom Penh is taken by Agricultural land (38 %). The second largest portion (16 %) is covered by the Water bodies area. In the Core City area the largest part is taken by the Agricultural land area which represents 25 % of the Core City area, i.e. a quarter of the area. The Continuous residential urban fabric (80% - 100% sealing level) area covers 8 %. In Larger Urban Zone the most common class is also Agricultural land (47 %), whilst Continuous residential urban fabric (80% - 100% sealing level) area only covers 1 %. The overall proportion of all urban classes is 35 % in the whole area of Phnom Penh, 53 % in Core City and 22 % in the Larger Urban Zone.

Figure 12 displays the proportion of each Land Cover Land Use class in each township. Townships are divided to those situated in the Core city (on the left of the graph) and to those in the Larger urban zone (on the right of the graph).

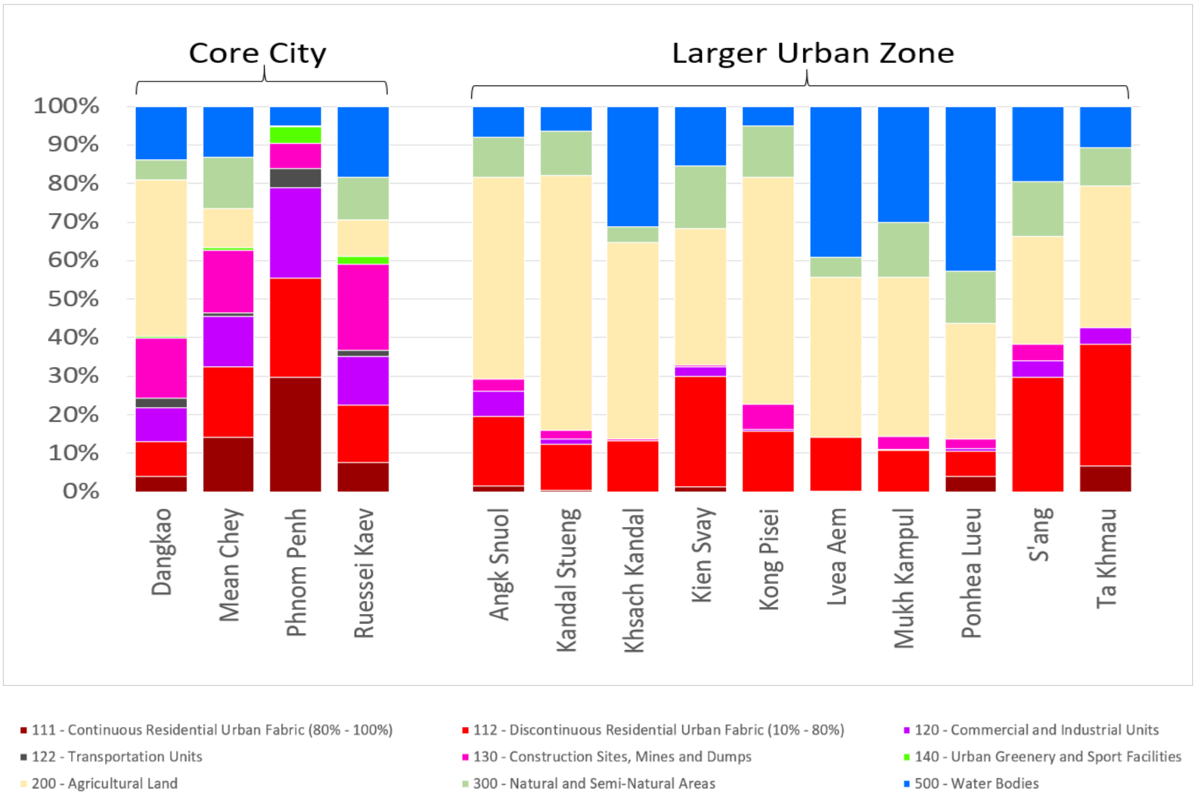


Figure 12: Detailed Land Cover Land Use 2017 structure in % per districts.

Based on the proportion of the township area the township where Continuous residential urban fabric (80% - 100% sealing level) area covers the largest proportion is Phnom Penh where this area represents 30 % of the township area. Ruessei Kaev is the township where Continuous residential urban fabric (80% - 100% sealing level) class covers the largest area: 8.1 km^2.

When merging all the urban classes together the largest proportion of township area covered by urban classes can be found in Phnom Penh township, i.e. 90 % of the township area. When looking at the actual area covered by the urban classes Dangkao represents the township where the area covered by urban classes is the largest, i.e. 74.8 km^2.

Kandal Stueng is both the township where the highest proportion and the largest area of the township area is covered by Agricultural land: 66 %, i.e. 80.4 km^2.

The next table displays the overall statistics of the Land Cover Land Use classes in Phnom Penh. It shows the area covered by each of the main classes in 2003 and in 2017 (both in km^2 and %). It also displays the total area which was changed from one class to another between years 2003 and 2017 in %. The last column shows the annual average change within each class in %.

Table 7: Overall LU/LC Statistics.

LU/LC Classes	2003 Area		2017 Area		Changed Area	Annual Change
	km^2	%	km^2	%	%	%
Urban	204.31	21.66	326.00	34.55	59.56	4.25
Agricultural	398.02	42.19	359.99	38.16	-9.55	-0.68
Natural-Semi Natural	150.81	15.98	102.61	10.88	-31.96	-2.28
Water	190.34	20.17	154.88	16.42	-18.63	-1.33

As foreseen the actual largest changed area was recorded within the Urban classes where the area in 2003 was 204.31 km^2 and in 2017 it is 326 km^2. The change represents a changed area of 59.56 %, i.e. 4.25 % per year on average.

A negative change was recorded within Agricultural, Natural and Water classes meaning reduction in the area in 2017 compared to the original state in 2003.

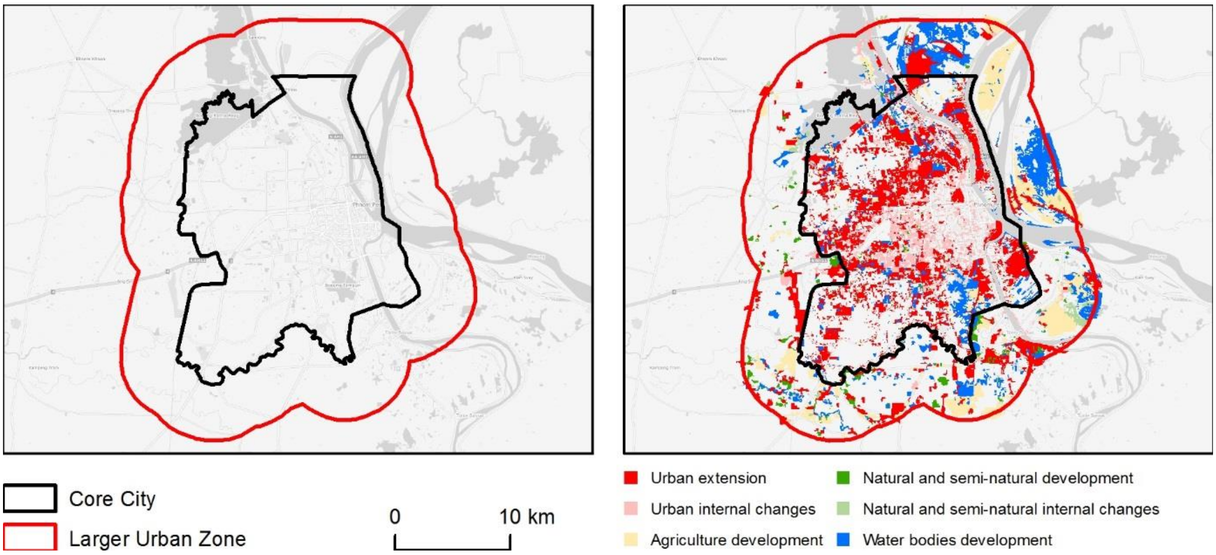


Figure 13: Land Cover Land Use Change Types 2002/2003-2017 - Spatial Distribution.

Rapid development in Phnom Penh is shown in Figure 13. Portion of Urban expansion is high, mainly in north and south. Also water bodies' development points to drainage surroundings of Core city for future construction activities.

Figure 14 displays the change types between years 2003 and 2017. On the left the change types are shown proportionally in %, whereas on the right the actual area of the changes is displayed. In both cases the statistics is shown for the overall area of Phnom Penh, and then separately for the Core City area and for the Larger Urban Zone.

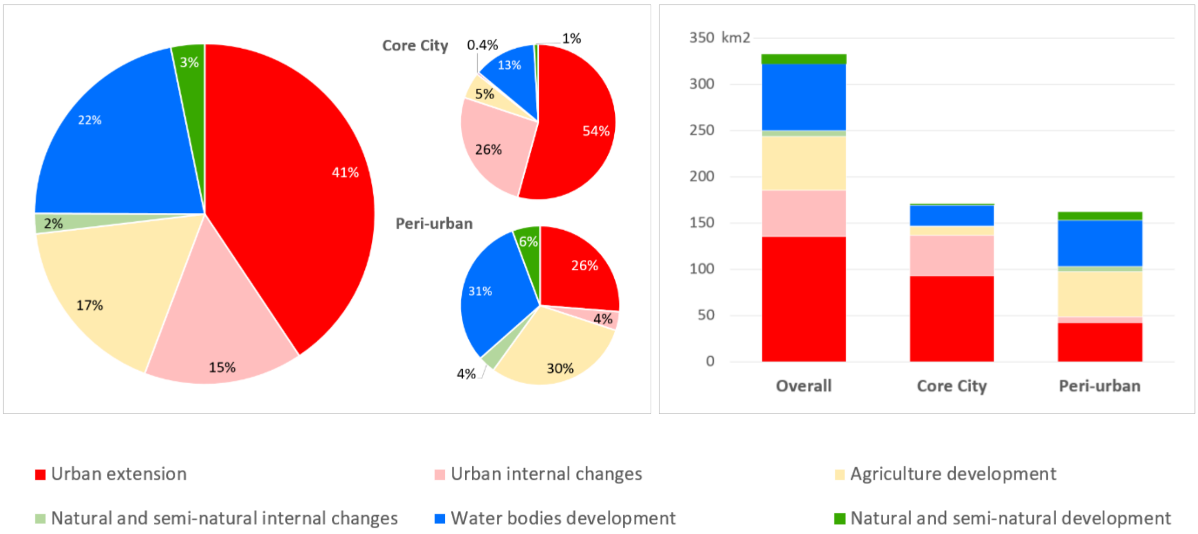


Figure 14: Land Cover Land Use Change Types 2002/2003-2017 - overall, in Core City and in Larger Urban Zone in % (left) and km^2 (right).

Proportionally the largest change type considering the whole area of Phnom Penh is the *Urban extension* which represents 41 % (135.3 km^2), followed by the *Water bodies development* representing 22 % (72.4 km^2) of all changes. Urban extension together with the Urban internal changes represent 56 % (185.6 km^2) of all changes in Phnom Penh between 2003 and 2017.

Within the Core City the most common change type is the *Urban extension* which represents 54 % of all changes in the Core City (92.7 km^2). Together with the *Urban internal changes* these two change types represent 80 % of all changes in the Core City (136.9 km^2).

The situation is different in the Larger Urban Zone where the most common change type is the *Water bodies development* which represents 31 % of all changes (50.0 km^2). *Urban extension* and U*rban internal changes* change types together represent 30 % of all the changes in the Larger Urban Zone area (48.7 km^2).

The next figure shows the change types proportionately within each township. Townships are divided to those situated in the Core city (on the left of the graph) and to those in the Larger urban zone (on the right of the graph).

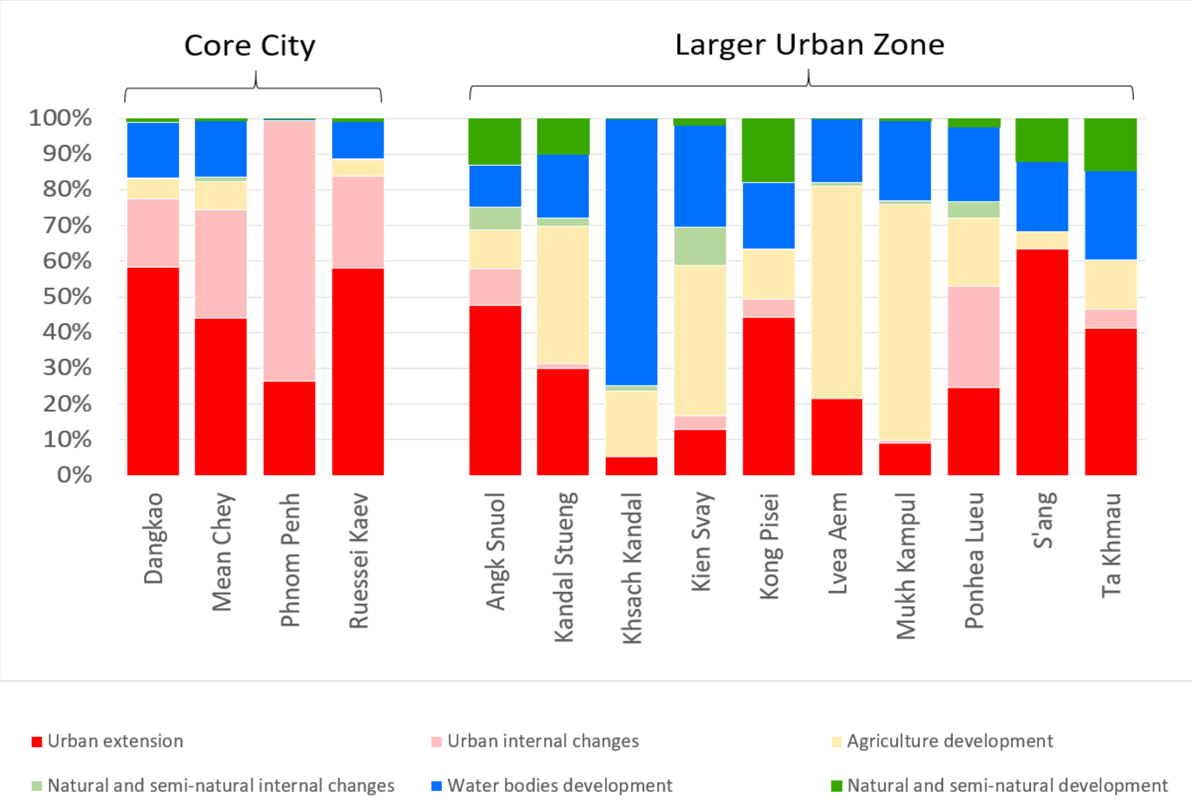


Figure 15: Land Cover Land Use Changes Types 2002/2003-2017 structure in % per district.

The actual largest changed area classified as *Urban extension* change type occurred in Dangkeo township where this type of change represents 42.0 km^2. Proportionally the largest *Urban extension* happened in S'ang township where *Urban extension* represents 63 % of all the changes.

The proportionally largest *Urban internal changes* change type happened in Phnom Penh township representing 73 %. Ruessei Kaev is the township where the largest *Urban internal changes* occurred and these cover an area of 15.5 km^2.

As for *Agriculture development* the proportionally largest changes happened in Mukh Kampul township representing 66 %. However, Kandal Stueng is the township where the largest *Agricultural development* occurred representing 13.6 km^2.

Next figure shows another point of view on changes in Core city of Phnom Penh. Figure on left represents difference of sealed areas between 2003-2017. Figure on the right on other hand shows share of LCF1 (Urban Extension) per Urban Fabric (2003) per ward.

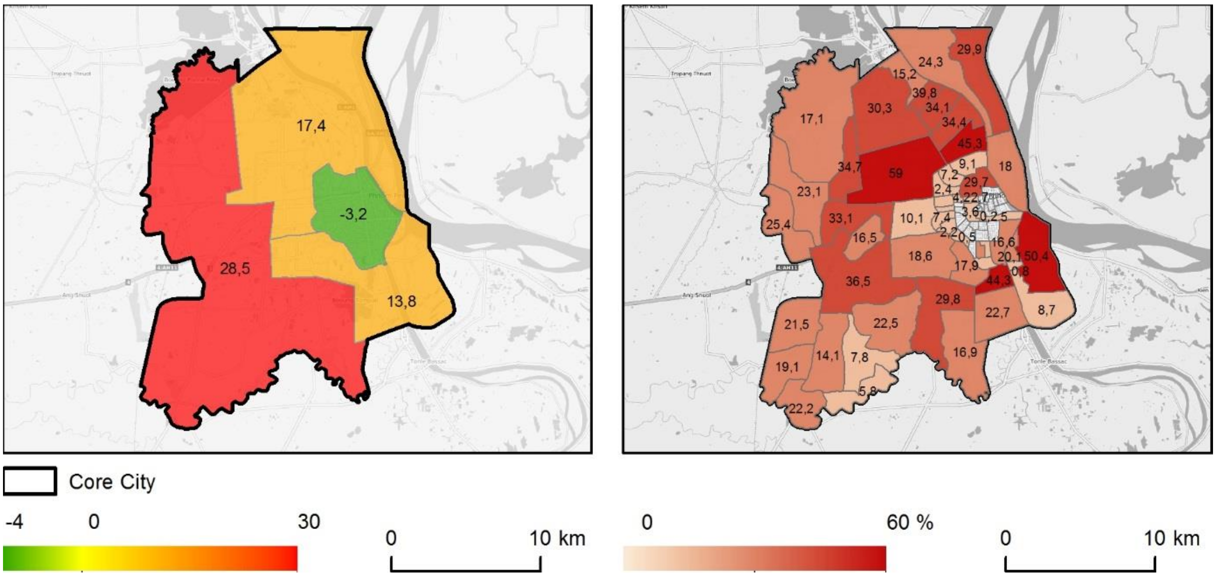


Figure 16: Urban Densification change type intensity (left) and Share of LCF1 per Urban Fabric 2003 per ward (right) 2003-2017 (in %) - Spatial Distribution

Figure 16 shows different views on development in Phnom Penh Core City. According to the left figure the core city is quite stable regarding densification. Densification process is located in surroundings of core city and to the west is the process more significant.

Right figure presents more detailed view on urban expansion. Also from this figure is clear that the city center is already highly urbanized and another development is not possible. Urban extension is located in the fringe around the city center.

Figure 17 displays the proportionate consumption (on the left) and formation (on the right) within classes between 2003 and 2017. Both consumption and formation is shown for the overall Phnom Penh area, and individually for the Core City area and for the Larger Urban Zone.

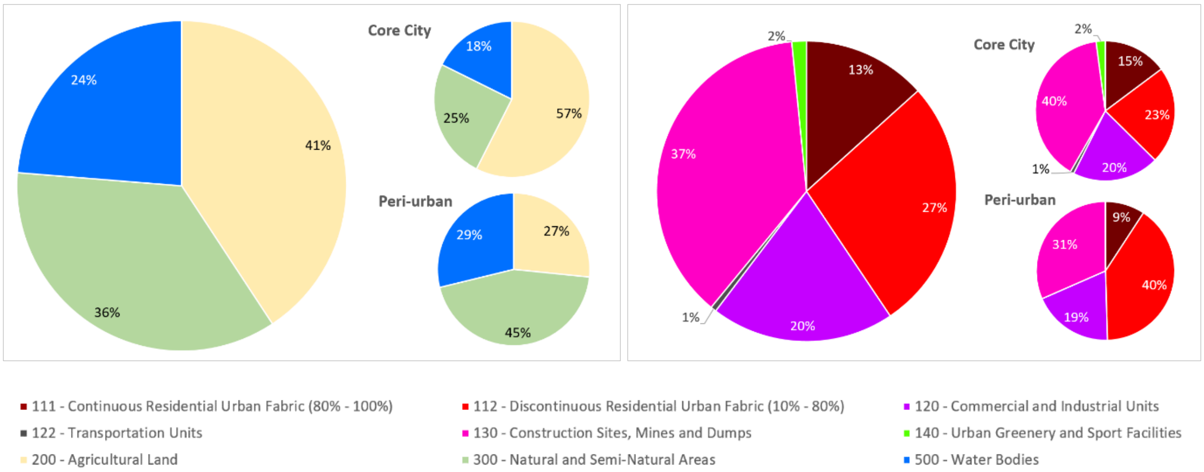


Figure 17: Consumption (left) and Formation structure (right) for Land Cover Land Use changes LCF1 (Urban extension) 2002/2003-2017 - overall, in Core City and in Larger Urban Zone in %.

The largest consumption occurred within the *Agricultural Land*, representing 41 % of the overall Phnom Penh area, 57 % within the Core City and 27 % in the Larger Urban Zone. Other consumption processes occurred in the *Natural and Semi-natural areas* and within the *Water bodies*, these representing 36 % and 24 % of consumption within the overall area respectively, 25 % and 18 % respectively in the Core City area, and 45 % and 29 % respectively within the Larger Urban Zone area.

As expected the proportionately largest formation process in all areas is presented by the *Construction sites, Mines and Dumps class,* representing 37 % in the overall Phnom Penh area, 40 % in the Core City and 31 % in the Larger Urban Zone area.

4.4 Urban Green Areas and Open Spaces

The section is giving insight into statistics about distribution of green areas within the city, their connectivity and accessibility. Statistics are provided aggregated at ward level or using urban fabric blocks (polygons delimited by bounding linear features – mostly roads).

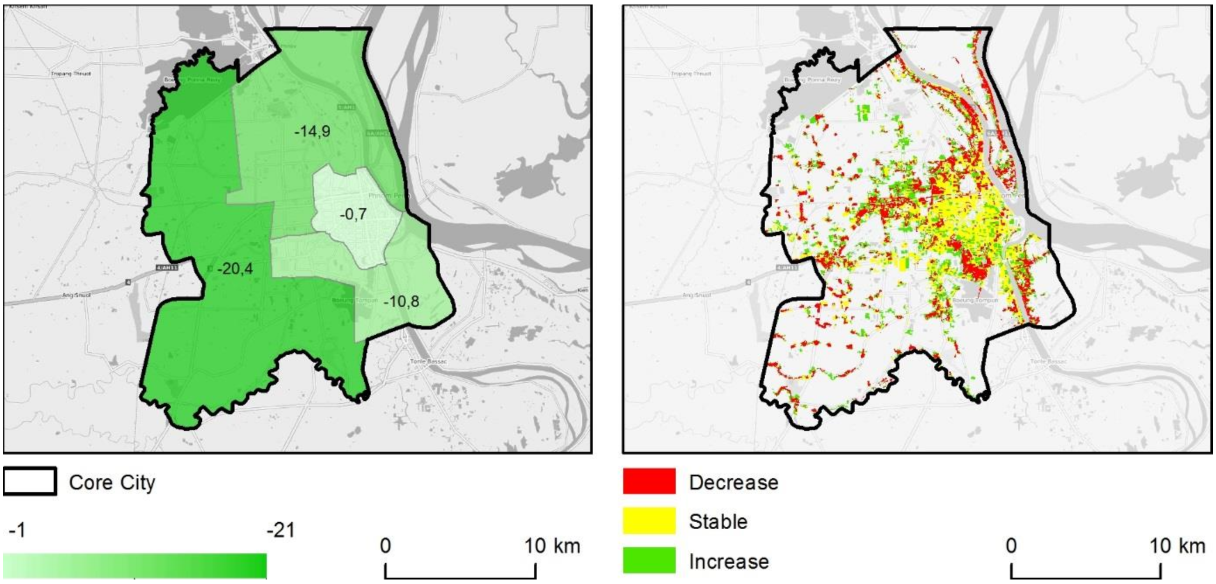


Figure 18: Development of Green Areas change type intensity (left) and Change of green patterns per urban fabric block (2003 – 2017)

Left Figure present change of Greenness index (automatic detection) between years 2003 and 2017 aggregated per district. In all districts there is a reduction of green areas corresponding with urban extension.

In the right Figure there is more detail inside into green areas development. This development is calculated per urban fabric block. Where the relative difference between years 2003 and 2017 per urban fabric block is between ± 5%, this block is considered as Stable in portion of green areas.

4.5 Transportation network - Status

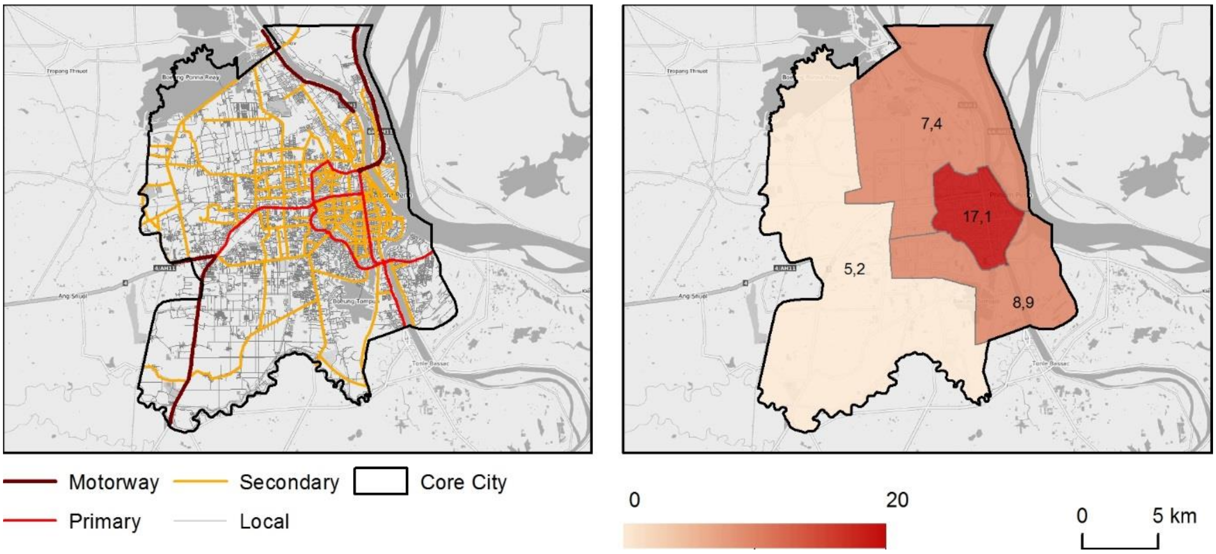


Figure 19: Current status of transportation network (left) and Length of transportation per ward (km/km²)

Figure 19 shows the transportation network in Core City of Phnom Penh. These two figures could give an inside into network density and spatial distribution. Right figure presents length of all roads in kilometers per square kilometer of district area. The density is decreasing with distance from core city.

4.6 Flood Risk

Flood Hazard and Risk Mapping is a vital component for appropriate land use planning in flood-prone areas. First of all, Flood Hazard and Risk Maps are designed to increase awareness of the likelihood of flooding among the public, local authorities and other organisations.

Specific flood regimes and underlying causes for the flooding events in the area of interest have to be analysed carefully, as these can be very different in different cities. For the Phnom Penh area generally two types of floods are typical and have to be taken into account accordingly:

a) long-term seasonal floods (Tonle Sap and Mekong River floods)

According to the Mekong River Commission, for the Lower Mekong River Basin the seasonal Flood covers the period between June and October (November). Heavy rainfall is connected to the Southwest Monsoon activity, low pressure troughs, and storm and typhoon appearances in the South China Sea. However, spatial variation of rainfall normally is high. The high precipitation situations move from the upper to the lower reaches of the basin as a function of time.

b) short-term flash floods after heavy thunderstorms in urban area

According to local reports and press releases, these floods are often connected with problems with the drainage system. Phnom Penh's drainage system is not yet adequate to cope with heavy rain. Rubbish is often blocking the drains, and debris and trash clog the outlets. During a typical rainstorm, water rises a few feet.

Filling the lakes which acted as important water storage basins in and around the city is a further major cause of flooding. The lakes used to play an important role in reducing storm runoff for the surrounding areas. Over the last decade, six lakes in Phnom Penh have been filled for land development after being leased to development companies by the Cambodian government (Shelby 2012).

4.6.1 Product description and accuracy assessment

There are three final layers in this product: (1) the raw data on past flood extents as derived from EO data and ancillary data (flood history), (2) the Flood Hazard map which summarizes past flood events and thus gives information about the likelihood of future events, and (3) the Flood Risk map combining this data with information on urban and peri-urban land use and its damage potential in case of flooding.

The accuracy assessment of the water extent classification was done based on stratified random sampling. The following equation is applied to determine the number of points required for an accepted standard error of the error of commission per class:

$$n_c = \frac{p_c (1-p_c)}{\sigma_c^2}, \quad c = 1,\ldots,L$$

n_c number of SSUs for category c
p_c estimated error rate for category c
σ_c accepted standard error of the error of commission for category c
L number of categories

The following values were applied: $p_c=0.1$, $\sigma_c=0.05$, $L=2$ (Water or No Water)
- => $n_c = 36$

In Phnom Penh, the validation was based on the visual comparison of 72 points (randomly distributed) of each satellite image and the respective classification result since no independent reference data were available.

Overall accuracies for the classification range from 88.9% to 95.8%.

The Flood Hazard map (subset see Figure 20) displays flood hazard information (delivered in vector format). This data is based on the occurrence of floods of the past 6 years. It takes into account both the hazard from seasonal Monsoon floods as well as from short-term local floods after heavy rainstorms in urban areas. The classification in three qualitative hazard levels is expert-based under consideration of reported frequencies of floods.

Since no independent reference data are available no accuracy assessment is possible. The plausibility of the results nevertheless was evaluated on basis of local reports and press releases.

The Flood Risk Map (subset see Figure 21) displays flood risk information (delivered in vector format) This data is based on the occurrence of floods of the past 6 years combined with information of the land use map provided by GISAT of this project area. It takes into account both the hazard level and potential damages, based on different land uses. The damages are assessed on 4 aspects: economic, social, physical and flood duration.

Since this product is a direct derivation and combination of the Hazard Classification and the land use Classification its plausibility can be rated high when the mentioned input datasets are rated as being plausible and reliable.

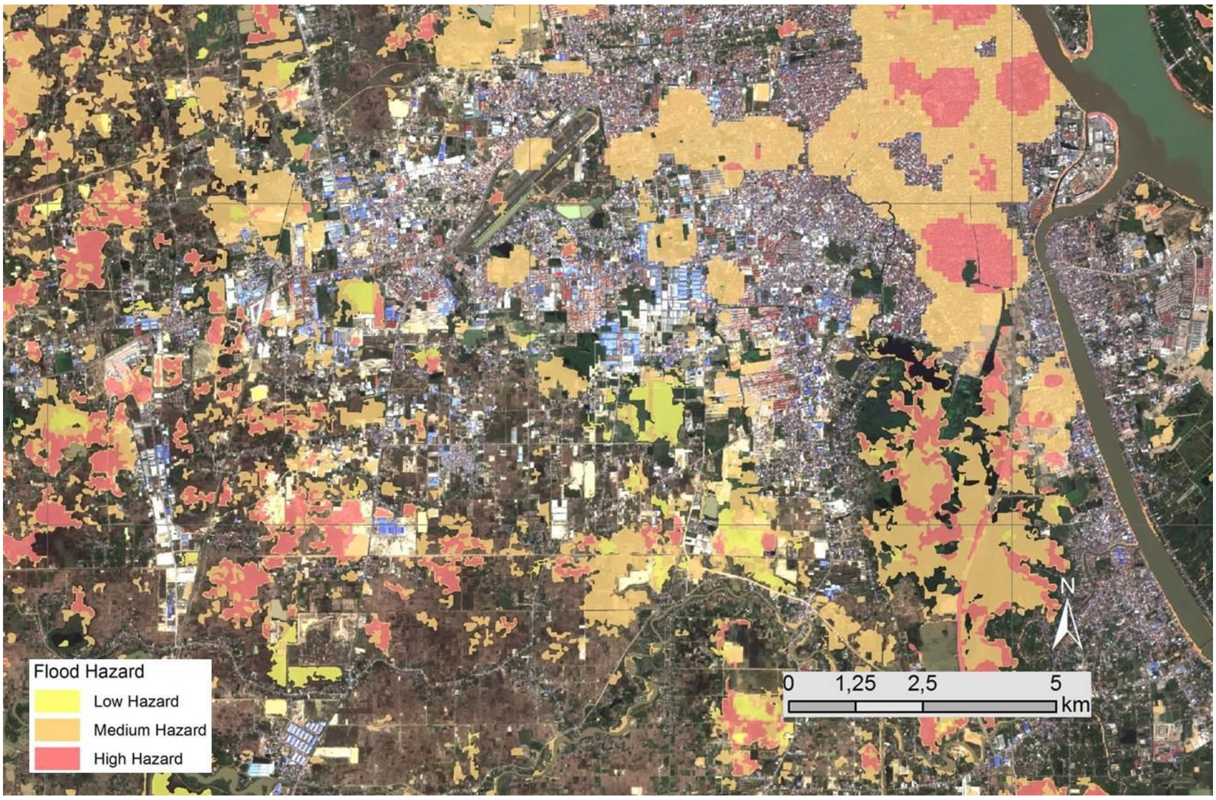


Figure 20: Subset of Flood Hazard Map of Phnom Penh (Downtown area) (Image: Sentinel-2 20170101)

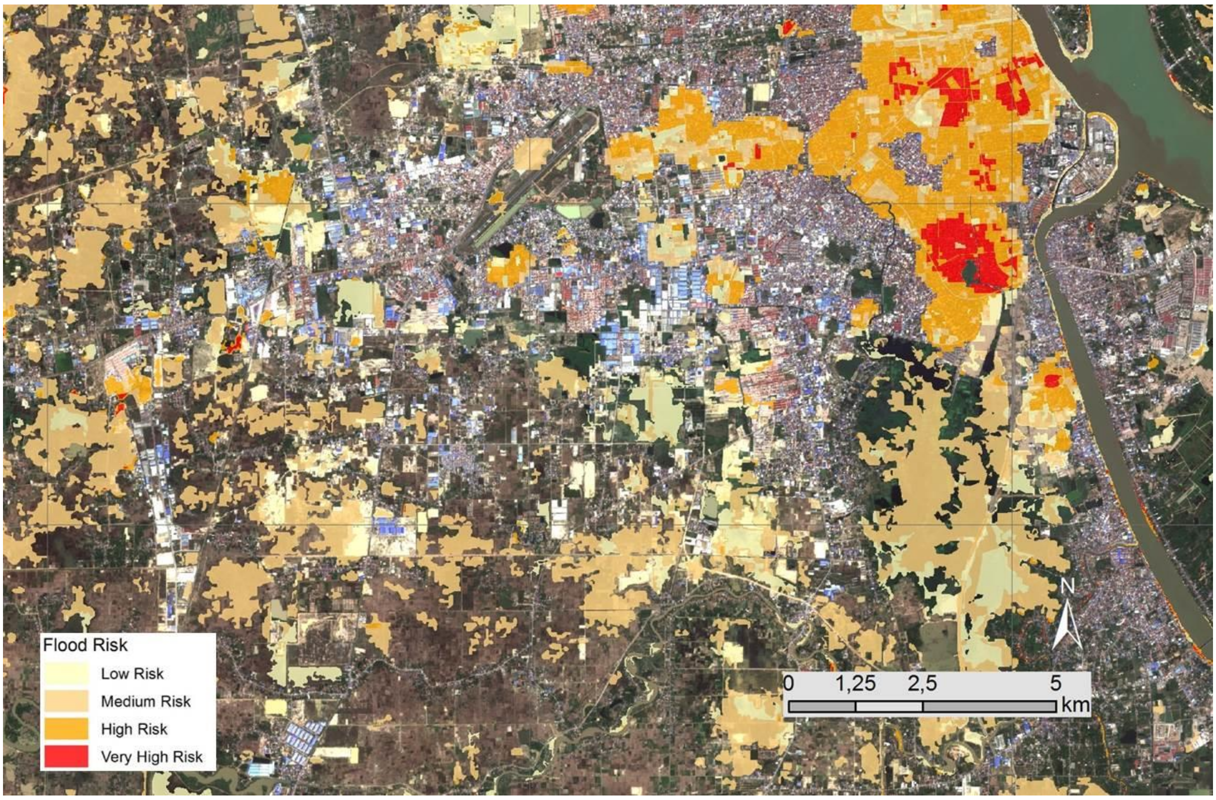


Figure 21: Subset of Flood Risk Map of Phnom Penh (Downtown area) (Image: Sentinel-2 20170101)

4.6.2 Results

With regard to the total calculated flood hazard zones it can be observed that the expansion of such zones is very similar in Phnom Penh Core City and in the peri-urban region: approx. 22,5% in the Core City and 23,7% in the peri-urban region are classified as flood prone. Also the distribution of medium and high hazard zones is similar with a higher percentage of high hazard zones in the peri-urban region (Figure 22).

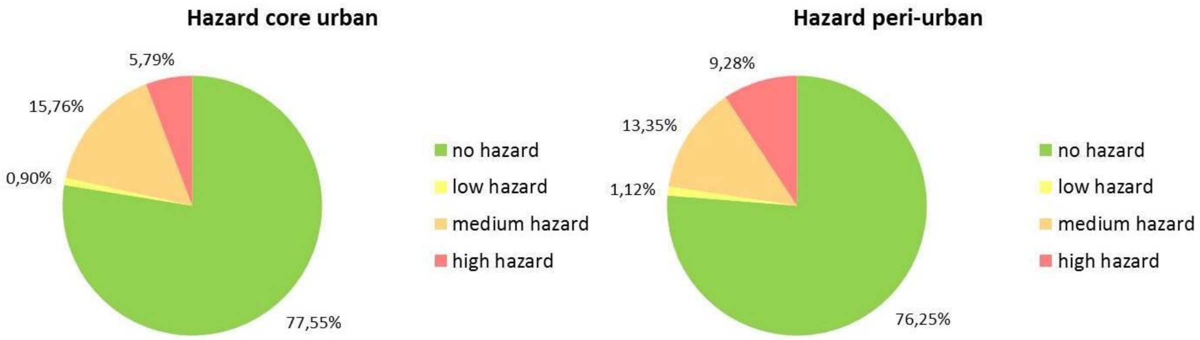


Figure 22: Proportion of flood hazard zones in Phnom Penh Core City (left) and in peri-urban region (right)

As the expansion of flood risk zones is equal to that of hazard zones this results in a similar picture with regard to the risk zones. Because of the higher exposition of urban land use the high and very high risk categories (accumulated) occur disproportionately high in the Core City (approx. 5,7% vs. 1% in the peri-urban region, Figure 23).

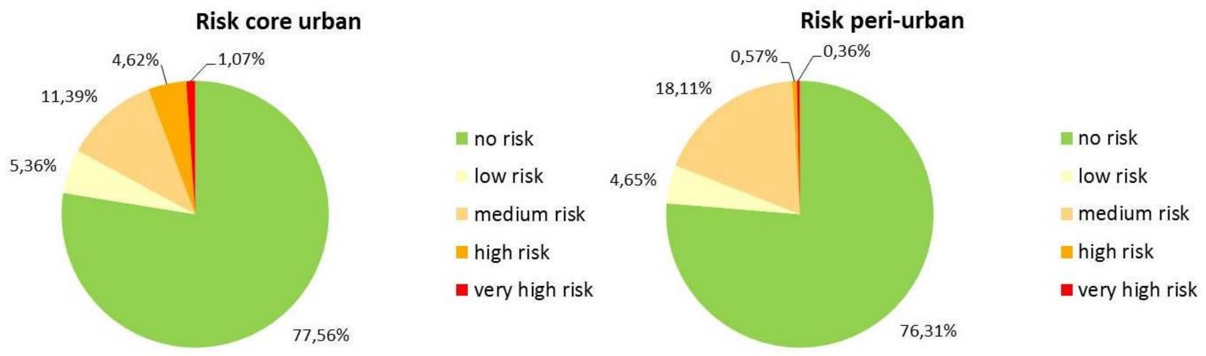


Figure 23: Proportion of flood risk zones in Phnom Penh Core City (left) and in peri-urban region (right)

With regard to flood risk zones in single districts it can be observed that the expansion of such zones is by far highest in Phnom Penh urban district (almost 50% of the total area being classified as high and very high risk zones, Figure 25). This is on the one hand a consequence of numerous medium and high hazard zones in this district (Figure 20), most of them explained by the occurrence of urban (flash) floods. On the other hand, a high concentration of land use with high damage potential (Commercial and Industrial Units, Residential and Non-residential urban fabric) can be observed in this district. The other three urban districts show similar risk levels with Ruessei Kaev being stronger exposed due to its position close to Tonle Sap and Mekong River (Figure 24 and Figure 25).

In the peri-urban region, the Khsach Kandal, Lvea Aem, Mukh Kampul and Ponhea Lueu districts, all of them situated at the Tonle Sap and Mekong River banks, are most concerned by floods. Approx. 50% of the area is classified as flood risk zones (most of it ranked in the medium risk class) in these four districts (Figure 24 and Figure 26).

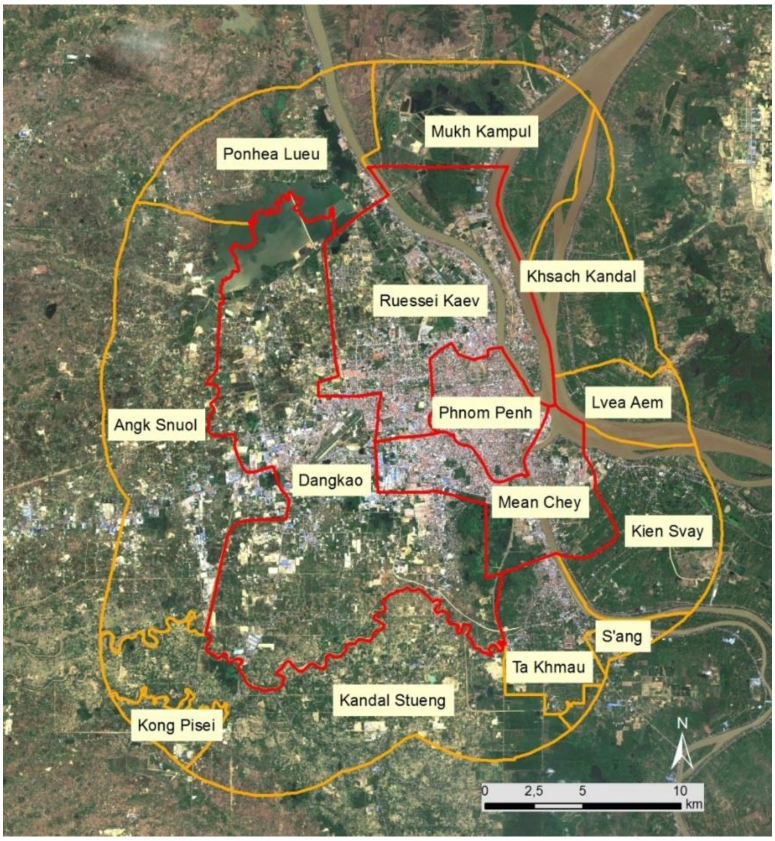


Figure 24: Geographic position of Phnom Penh urban (red) and peri-urban (orange) districts (Image: Sentinel 2 20170101)

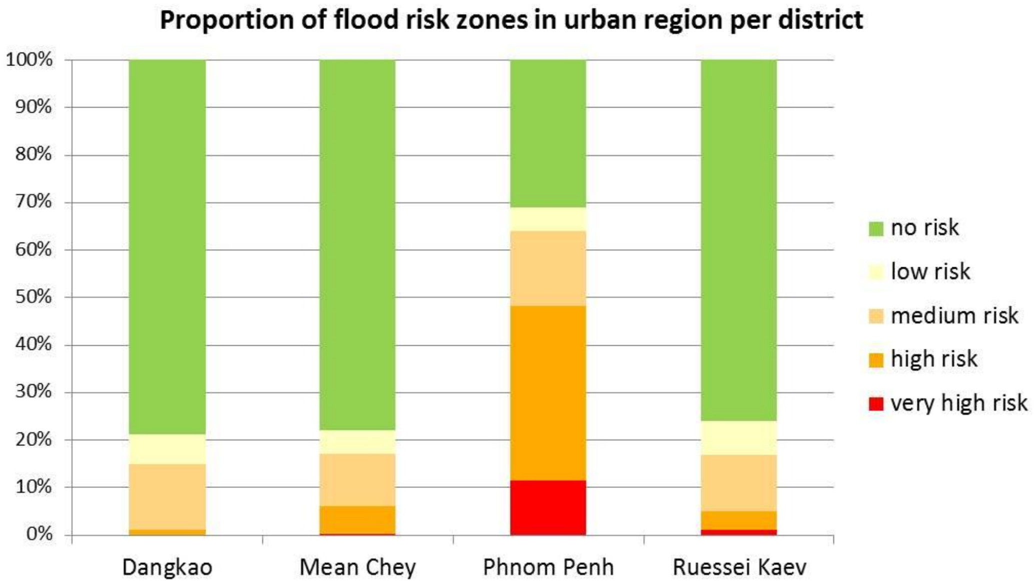


Figure 25: Proportion of flood risk zones in Phnom Penh Core City per district

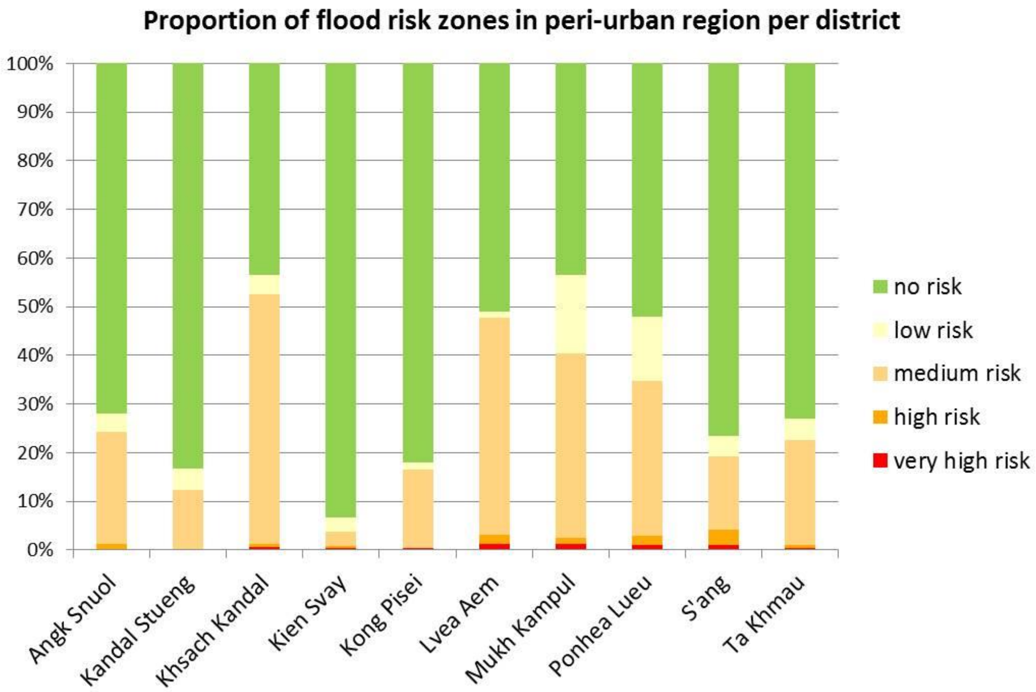


Figure 26: Proportion of flood risk zones in Phnom Penh peri-urban region per district

The following land use / land cover categories and groups of land use categories were analyzed more detailed both in the urban and in the peri-urban area regarding their position in hazardous regions:

- Residential urban fabric
- Transportation units: airport, railway, arterial lines, collector lines
- Commercial and industrial units, non-residential urban fabric
- Construction sites, mines and dumps
- Agricultural land
- Urban Greenery, Cemeteries and Sports facilities
- Semi-natural and natural area

The analysis of residential and public urban fabric shows that a total of approx. 23% of such land use is situated in the calculated medium and high hazard zones in the urban region (Figure 27).

In the peri-urban region this percentage is significantly lower with a total of 5,7% of the area situated in the calculated medium and high hazard zones.

For this land use class almost no low hazard zones are shown in both the urban and the peri-urban region.

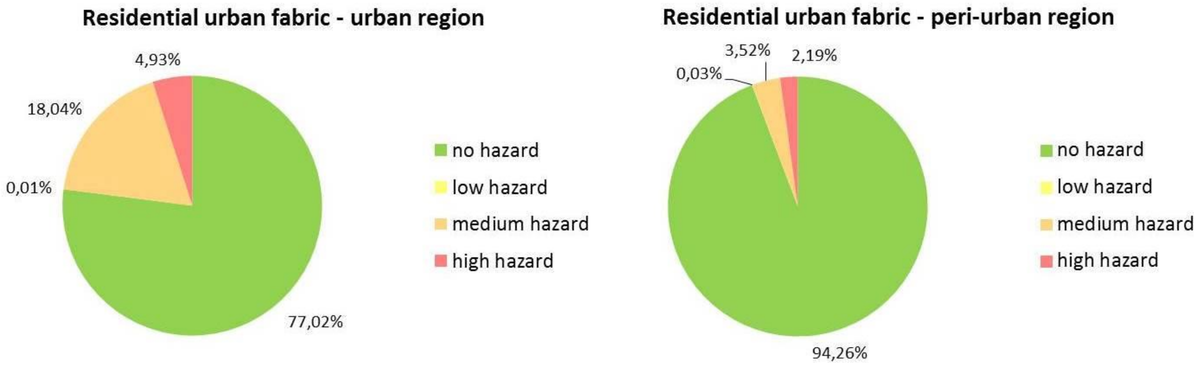


Figure 27: Proportion of residential urban fabric in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City (left) and in peri-urban region (right)

Focusing on the risk aspect, the applied methodology implies that no low risk zones can exist in this land use class (Annex 1, Table 8 and Table 9). Figure 28 displays the proportions of residential and public urban fabric in the medium, high, and very high risk zones. As expected, the proportions of the high and very high risk zones are significantly higher in the Core City.

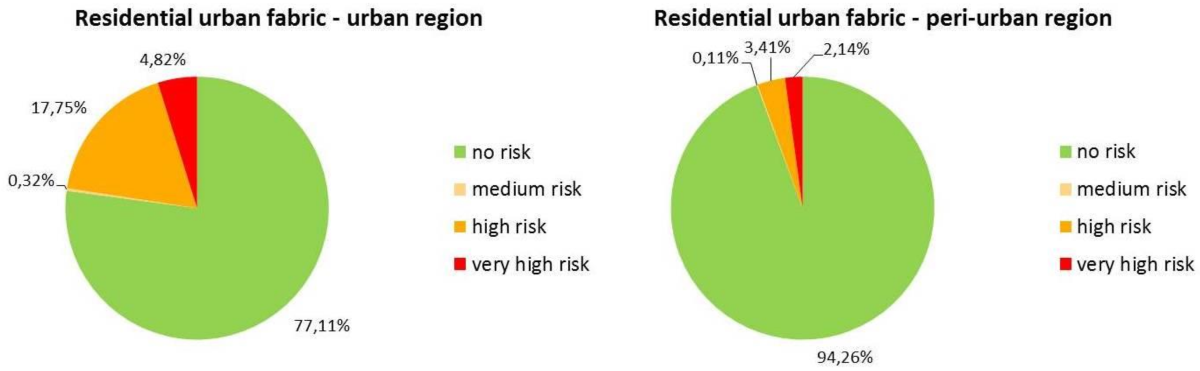


Figure 28: Proportion of residential urban fabric in flood risk areas (very high/high/medium/no risk) in Phnom Penh Core City (left) and in peri-urban region (right)

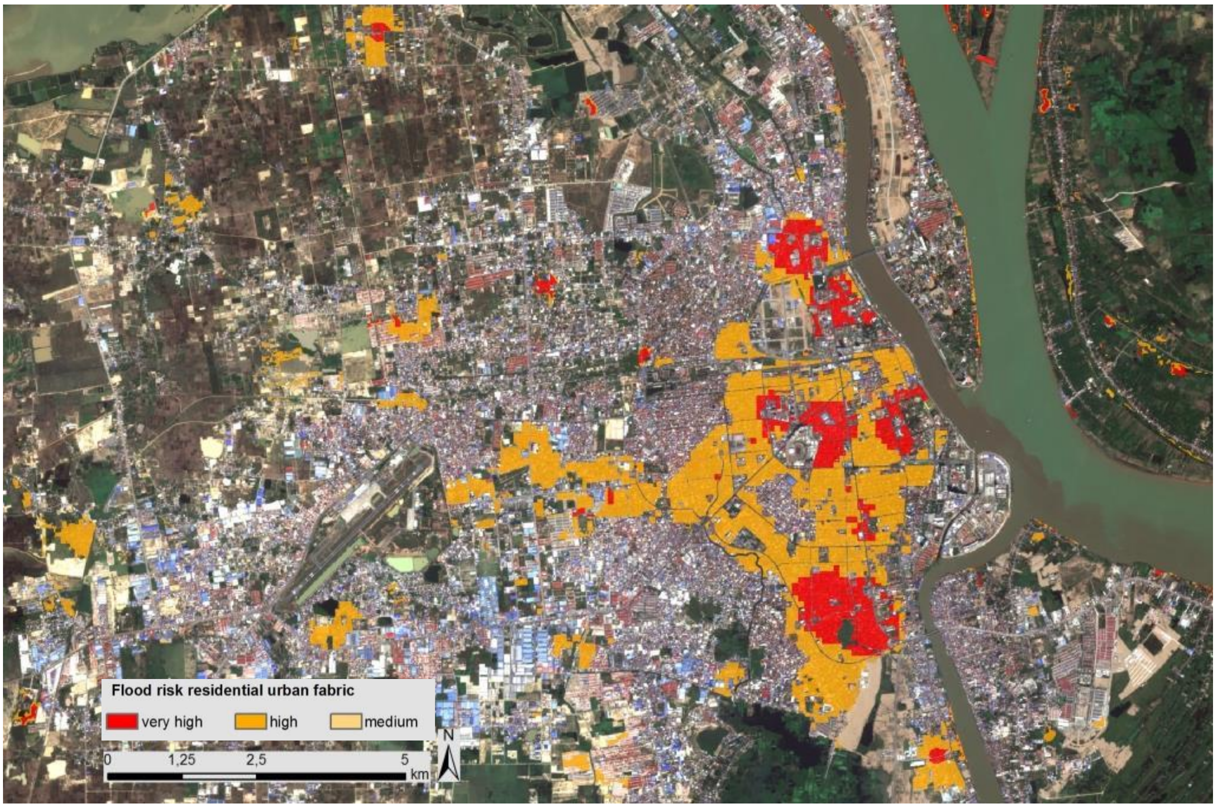


Figure 29: Map of Residential Urban Fabric combined with Flood Risk Zoning in the centre of Phnom Penh (Image: Sentinel-2 20170101)

For the analysis of high-ranking infrastructure (airport, railway, arterial lines, collector lines) only land use / land cover data from the core urban region is available. More than 23% of the high-ranking infrastructure can be found in zones with medium or high flood hazard (Figure 30).

Regarding the risk classification, these proportions are very similar with most of the involved transportation units to be found in the medium risk class (Figure 31).

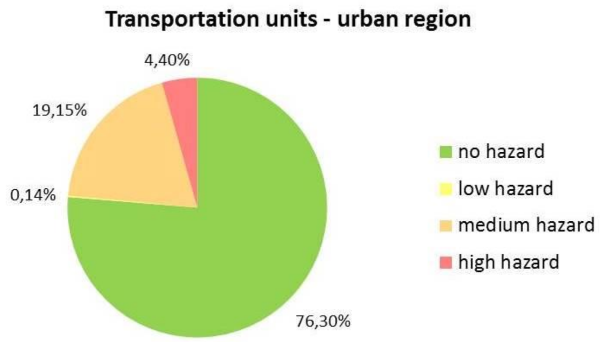


Figure 30: Proportion of high-ranking infrastructure in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City

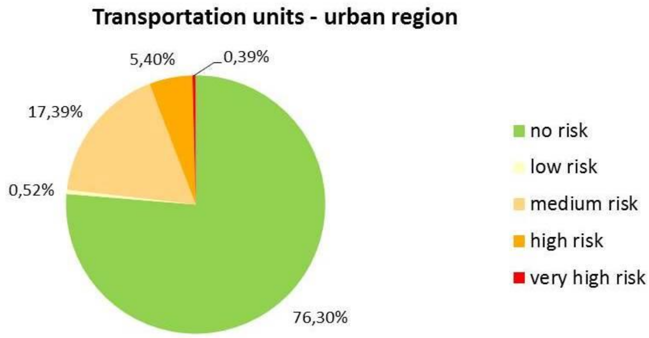
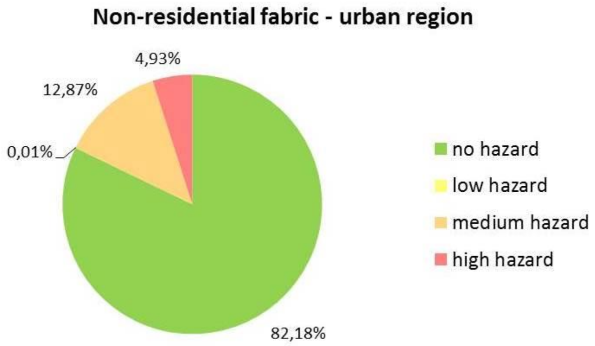


Figure 31: Proportion of high-ranking infrastructure in flood risk areas (very high/high/medium/low/no risk) in Phnom Penh Core City

For the non-residential urban fabric, including commercial and industrial units, the percentages of this land use class are relatively similar in Phnom Penh Core city and in the peri-urban region: approx. 18% and 15% respectively are situated in flood prone zones with most of it to be found in the medium hazard as well as in the medium risk class (Figure 32 and Figure 33).



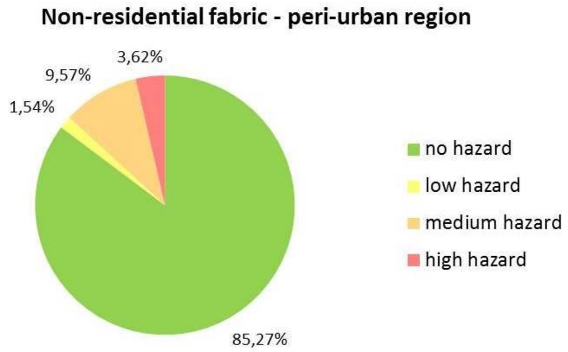
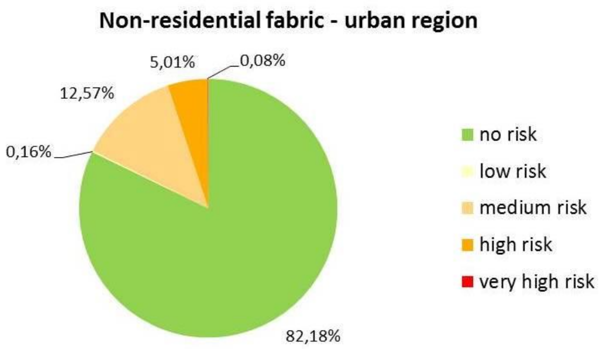


Figure 32: Proportion of non-residential urban fabric in flood hazard areas (high/medium/low/no hazard) in Phnom Penh Core City (left) and in peri-urban region (right)



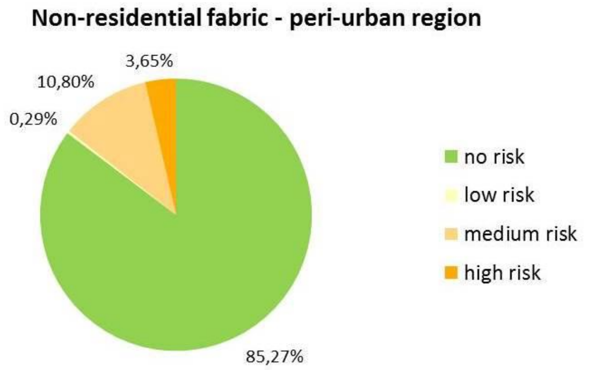


Figure 33: Proportion of non-residential urban fabric in flood risk areas (very high/high/medium/low/no risk) in Phnom Penh Core City (left) and in peri-urban region (right)

The results of the hazard analysis of the land use categories “Construction sites, mines and dumps”, “Agricultural land”, “Urban Greenery, Cemeteries and Sports facilities”, and “Semi-natural and natural area” are displayed in Figure 34 to Figure 37.

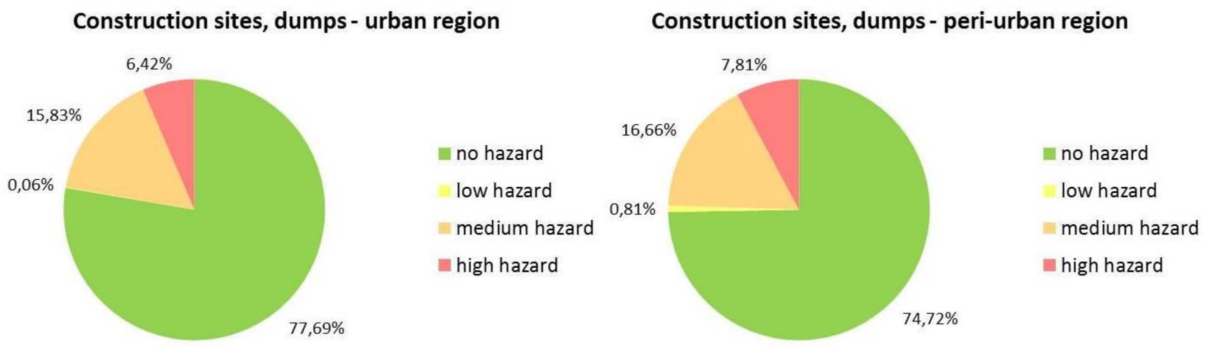


Figure 34: Proportion of construction sites, mines and dumps in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City (left) and in peri-urban region (right)

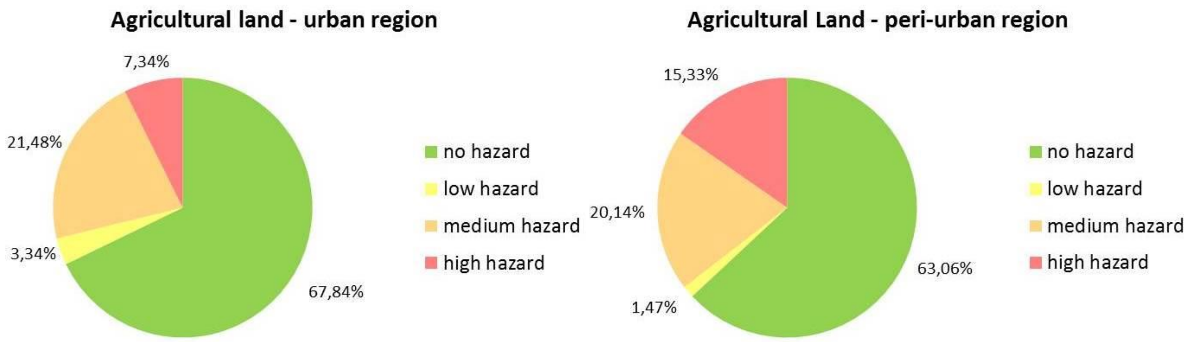


Figure 35: Proportion of agricultural land in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City (left) and in peri-urban region (right)

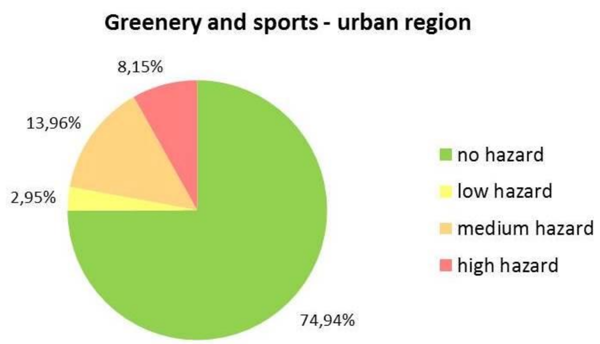


Figure 36: Proportion of urban greenery, cemeteries and sports facilities in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City

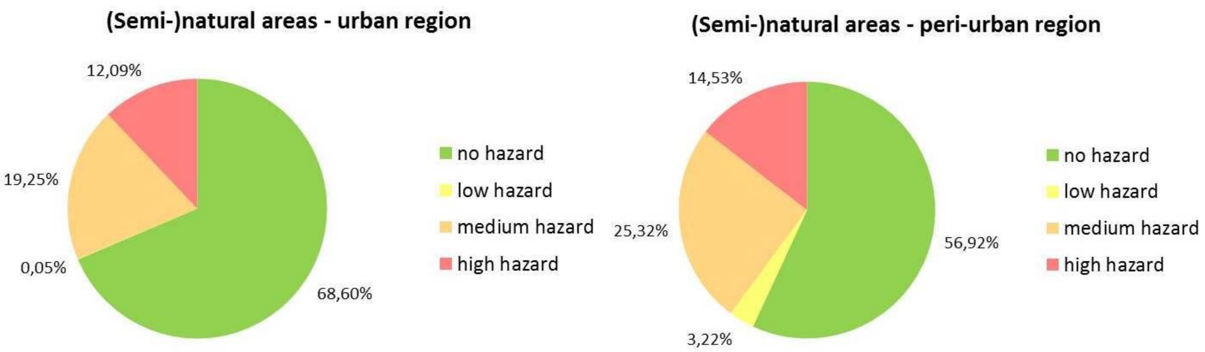


Figure 37: Proportion of natural and semi-natural areas in flood prone areas (high/medium/low/no hazard) in Phnom Penh Core City (left) and in peri-urban region (right)

References:

Dasgupta, S., Asif, Z., Subhendu, R., Mainul, H., Sarwar, J. & Ainun, N. (2015): Urban Flooding of Greater Dhaka in a Changing Climate: Building Local Resilience to Disaster Risk. Directions in Development. Washington, DC: World Bank. doi:10.1596/978-1-4648-0710-7. License: Creative Commons Attribution CC BY 3.0 IGO

Feyisa, L.G., Meilby, H., Fensholt, R. & Proud, S.R. (2014): Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery.- Remote Sens. Environ, 140 (2014), pp. 23-35.

Mekong River Commission (2009-2015): Seasonal Flood Situation Reports for the Lower Mekong River Basin.

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Annex 1 – Processing Methods for EO4SD-Urban Products

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Summary of Processing Methods

Urban and Peri-Urban Land Use/Land Cover and Change

The input data include Very High Resolution (VHR) and High Resolution (HR) satellite imagery from different sensors acquired at different times for covering both Core Urban and Peri-Urban Areas. The data are pre-processed to ensure a high level of geometric and radiometric quality (ortho-rectification, radiometric calibration, pan-sharpening).

Core Urban Area of AOI is covered by VHR satellite imagery to ensure the ability to extract LULC information within the artificial areas at Level 3-4 of the nomenclature. The complexity when dealing with VHR images comes from the internal variability of the information for a single land-use. For instance, urban area is represented by a high number of heterogeneous pixel values hampering the use of automated pixel-based classification techniques.

Nevertheless, it is possible from VHR images 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 peri-urban rural classes. However, within urban areas, land use information is often difficult to extract 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) needs 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 to extract the LULC/LULCC information from VHR EO data.

Although LULC information at the most detailed level (3-4) within artificial areas is extracted by means of visual interpretation, it is also relevant to mention that the distinction between the different classes defined for residential urban fabric units is performed using an automated approach based on the additional Imperviousness product (dedicated section about the processing method in this annex). Indeed, the average value of Imperviousness Degree (IMD) or Soil Sealing (SL) per urban fabric unit well characterizes the density of built-up area and allows to associate each residential unit to the relevant classes well defined in the LULC nomenclature.

Peri-Urban Area of AOI is covered by HR satellite imagery only. As Level-1 nomenclature is applied, it is quite easy to get the LULC information using automated pixel-based classification algorithm outside the urban mask extracted by visual interpretation beforehand.

Manual enhancement is the final post-processing step of the production framework. It aims to validate the detected thematic classes and refine the geometry of polygon features if necessary, especially for ensuring that the correct MMU has been respected. Finally, a thorough completeness and logical consistency check is applied to ensure the topological integrity and coherence of the product which is delivered in vector format. That makes easier its integration in GIS and for subsequent analysis.

Change detection - Four important aspects must 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 surface extent of the change and (4) assessing the spatial pattern of the change.

Apart from visual comparison, the change detection layer can be based on automated image-to-image classification approach given that the same sensor is used for both reference dates. An original and efficient image processing chain is promoted consisting in the comparison of images acquired at two different dates providing multi-labelled changes. The approach mainly relies on texture analysis, which has the benefits to deal easily with heterogeneous data and VHR images.

Summary of Processing Methods

Urban Extent and Change

For each reference date, the product is directly and easily derived from the baseline LULC dataset by extracting and merging all polygon features from the classes related to artificial areas (1xxxx).

Change information layer is basically derived from the geometric intersection of the historic and current Urban Extent layers by means of GIS operation. This resulting product finally provides information about permanent artificial areas, converted ones to another land use category and new ones. Quality control and accuracy assessment tasks have been performed through the LULC product generation.

Summary of Processing Methods

Urban Imperviousness and Change

The Imperviousness product is intended to represent the impervious surfaces because of urban development, layers of completely or partly impermeable artificial material (asphalt, concrete, etc.) and infrastructure construction. Therefore, the Imperviousness Degree (IMD) or Soil Sealing (SL) information can be produced relatively easily based on the Urban Extent derived from the baseline LULC information product and the linear model between impervious areas and vegetation presence that can be determined and characterized from Landsat or Sentinel-2 NDVI time series.

More precisely, the raster product is generated at 10m - 30m spatial resolution by properly exploiting Landsat-4/5/7/8 or Sentinel-2 multitemporal imagery acquired over the study area within a given time interval of interest in which no relevant changes are expected to occur (typically a time period of 1-2 years allows to get very accurate results). Each acquired EO data is pre-processed (ortho-rectification, radiometric calibration, pansharpening, cloud-masking). Then, the Normalized Difference Vegetation Index (NDVI) is extracted for each image within the urban mask (corresponding to Urban Extent product). NDVI is inversely correlated with the amount of impervious areas, i.e. the higher the NDVI is, the higher the expected presence of vegetation, hence the lower the corresponding imperviousness degree. The core idea is to compute per each pixel its temporal maximum which depicts the status at the peak of the phenological cycle.

It is worth noting that for different pixels in the study area, different number of scenes might be available. However, in the hypothesis of sufficient minimum number of acquisitions unavailable for computing consistent statistics, this does not represent an issue. Indeed, in this framework, it is also possible to get spatially consistent datasets useful for the desired analyses, even when investigating large territories. Areas associated with different levels of impervious surfaces are then extracted by visual interpretation from data sources with higher spatial resolution (e.g. VHR imagery, Google Earth imagery). OSM layers or information derived from in-situ campaigns are other auxiliary data sources which can also be used for this purpose. At the end, reference data are extracted in various parts of the study region and then rasterized and aggregated at the spatial resolution of input EO data.

A support vector regression SVR module is then used for properly correlating the resulting training information with the temporal maximum NDVI to finally derive the Percentage of Impervious Surface (PIS) or Imperviousness Degree (IMD) for the entire AOI. Specifically, 8bit integer values from the raster product range from 0 (no impervious surface in the given pixel) to 100 (completely impervious surface in the given pixel).

Summary of Processing Methods

Flood History and Risk

<u>Historic flood extent mapping</u>

Flood extent mapping based on EO data heavily depends on available datasets as well as on types of floods in focus. Whereas there is a good chance to identify large-scale river and coastal floods, normally no information regarding short-term local floods (flash-floods) can be obtained from EO data due to short duration and/or cloud cover. In some cases short-term local floods can be recorded and localized based on reports (e.g. in social media) and press releases but such inventory never will meet the claim of being complete.

The relevant optical datasets were corrected atmospherically applying the Dark Object Subtraction (DOS) approach. For defining the water extent in coastal areas the water cover was classified by applying the Automated Water Extraction Index $AWEI_{nsh}$ (Feyisa et al. 2014) which makes use of the reflectance values of Green, Near Infrared and Shortwave Infrared spectral bands of the Landsat 5, Landsat 7, Landsat 8, ASTER and Sentinel-2 sensors. The $AWEI_{nsh}$ is an index formulated to effectively eliminate non-water pixels, including dark built surfaces in areas with urban background.

Regarding the occurrence of short-term local floods (flash-floods) point data of reported and localized urban floods (2012 – 2017) were buffered with 200 m to roughly estimate potential flooding hotspots.

<u>Flood hazard mapping</u>

Water extents representing seasonal Monsoon floods of Mekong and Tonle Sap River are based on data from Landsat 5 (acquired on 05/11/2000, 21/10/2006, 16/08/2011), Landsat 8 (acquired on 24/10/2013, 12/11/2014, 30/10/2015, both provided by the US Geological Survey), Sentinel-1 (24/10/2016) and Sentinel-2 (acquired on 20/08/2015 both provided by the European Space Agency).

However, as the development of the city is extremely dynamic (e.g. filling of lakes and swamps using the areas for buildings and other development) “old” data (e.g. floods 2000 and even 2011) do not represent the current situation at all.

Thus, the most recent data had to be analysed only: in the period from 2013 to 2017, two classes of seasonal Monsoon floods can be distinguished:

a. average seasonal flood: this class is characterized by the floods 2014 (LS8; 20141112), 2015 (LS8; 20151030), 2016 (S1; 20161024). Areas which were flooded during one of these average events, were classified as high hazard zones.

b. remarkable seasonal flood: this class is presented by the extent of the 2013 seasonal flood (LS8; 20131024) which was the last above average flood event (nevertheless, according to data of the Mekong River Commission, in Phnom Penh the water level still was below alarm level). Areas which were flooded by this event only, were classified as medium hazard zones.

Areas with high frequencies and densities of urban (flash) floods were merged based on a point aggregation approach.

The flood hazard map is taking into account all available data sources (EO based water extents, Seasonal Flood Situation Reports and Water Level data of the Mekong River Commission, Flooding Reports and Map in the local network “Urban Voice Cambodia”, Press Releases) aiming at covering all types of floods and thus all areas which are potentially endangered by flooding. The combined hazard classification in three qualitative hazard levels is expert-based under consideration of observed and reported frequencies of floods.

<u>Flood risk mapping</u>

Risk is defined as a combination of probability and consequences. A detailed and uniform land-use map is an important prerequisite to perform flood risk calculations, since it determines what is damaged in case of flooding. The original land use/land cover map as provided by GISAT was recoded to pre-defined categories (as given in Table 8) to ensure consistent results.

The exposition is classified following an approach developed by NEO (based on: Dasgupta et al. 2015) integrating economic costs, social damage, physical damage and flood duration. Four land use damage levels (A, B, C, D) are defined based on this estimation.

Table 8: **Land use/Land cover classes and reclassification to pre-defined damage levels**

Classes	Damage				Total	Level
	Economic Costs 0-2	Social Damage 0-2	Physical Damage 0-2	Flood Duration 0-2		
Agricultural Land	1,5	0,5	0	1	3	B
Commercial and Industrial Units, Non-residential urban fabric	2	1	1	1	5	C
Construction Sites, Mines and Dumps	1	0,5	0	0	1,5	A
Natural and semi-natural areas	0,5	0	0	0	0,5	A
Residential urban fabric	1,5	1,5	2	1,5	6,5	D
Transportation units	1,5	1	2	1,5	6	C
Urban Greenery, Cemeteries and Sports facilities	0,5	0,5	0,5	1	2,5	B
Water Bodies	0	0	0	0	0	A

The Flood Risk matrix is generated based on above code and flood hazard classified into three hazard levels. The flood risk level is classified in four qualitative classes based on the combination of flood hazard and land use damage as shown in Table 9.

Table 9: **Flood hazard and risk classification**

		Damage cost on land use			
		A	B	C	D
Flood Hazard	1 (low)	1A	1B	1C	1D
	2 (medium)	2A	2B	2C	2D
	3 (high)	3A	3B	3C	3D

Flood Risk classification	
Low Risk	1A 1B 2A
Medium Risk	1C 1D 2B 2C 2D 3A 3B
High Risk	2D 3C
Very high Risk	3D

Annex 2 – 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 9001:2008 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:	GISAT, s.r.o.	Editor:	Václav Stonáček
Client:	WB	Date:	15.9.2017

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	No
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	No
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
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 2002/2003 and 2017

Abstract

The Land Use/Land Cover product contains spatial explicit information on different land use and land cover in both Core and Peri-Urban areas of the city of Phnom Penh (Cambodia) for the years of 2002/2003 and 2017. The Core area has detailed LU/LC nomenclature whereas the Peri-Urban area LU/LC nomenclature is at an aggregated Level. The input data for the Core area was the Very High Resolution data (Pleiades for 2017, Quickbird-2 for 2002/2003) and the input data for the Peri-Urban area was Sentinel (2017) and Landsat (2003) data. The LU/LC product is the Baseline Product from which various derived products (such as Green Areas and Informal Settlements) are produced.

Service / Product Specifications

Area Coverage		
Country:	Bangladesh	
City:	Dhaka	
Area km²	Core Urban:	373 km²
	Peri-Urban:	886 km²

Time Period - Update Frequency	
A) Baseline Year(s): 2002/2003, 2017	B) Update Frequency 2 time horizons, no future update
Comments:.	

Geographic Reference System
EPSG: 32648. UTM 48N / WGS84

Mapping Classes and Definitions	
Formal high density continuous residential (Sealing level > 80%)	Urban fabric where formal housing (in the form of individual houses or apartment blocks) dominates. Formal houses expected to be organized in a relatively regular spatial pattern with clearly visible roads. 0 %-20 % of the urban fabric consists of non-sealed or vegetated surface.
Formal high density discontinuous residential (Sealing level: 50% - 80%)	Urban fabric where formal housing (in the form of individual houses or apartment blocks) dominates. Formal houses expected to be organized in a relatively regular spatial pattern with clearly visible roads. 20 %-50 % of the urban fabric consists of non-sealed or vegetated surface.
Formal low density discontinu (Sealing level: 10% - 50%)	Urban fabric consist of individual houses with little evidence of apartment blocks. Plot size are relatively large compare to formal high density residential. 50 % - 90 % of the urban fabric consists of non-sealed or vegetated surfaces.
Commercial and industrial units	Factories, warehouses, kilns, shopping malls and all associated facilities and land includes medium to large scale compound units.
Non-residential urban fabric	Governmental, Medical, Religious, Military, Educational areas including associated areas.
Roads and associated land	Motorways, primary and secondary roads.
Airports	Administrative area of airports, mostly fenced. Included are all airports installations: runways, buildings and associated land.
Construction sites	Areas with on-going building/infrastructure construction activity or areas obviously prepared for construction.
Land without current use	Vacant land for which there is no evidence of on-going building/infrastructure construction activity.
Urban greenery, sport and leisure facilities	Urban green area, recreational use as gardens, zoos, parks including sport and leisure facilities, sport fields.
Agriculture	Cultivated areas non-irrigated or permanently irrigated including rice fields. Arable land (annual crops), permanent crops, orchards.

Trees	High woody vegetation in natural forests including bushes and shrubs at the fringe of the forest.	
Other Natural and Semi-natural areas incl. wetlands	Shrubs and/or herbaceous vegetation incl. transitional woodland and wetlands.	
Bare land	Natural areas where there is no or very little evidence of vegetation and does not serve as construction site.	
Water bodies	Visible water surface areas.	
Cloud and Cloud Shadow Detection and Removal		
EO data without clouds or shadows.		
Spatial Resolution		
n.a. (Product provided as Shapefile)		
Minimum Mapping Unit (MMU)		
Minimum Mapping Unit is 0.25 ha for Core City, 0.5 ha for Peri-urban areas.		
Data Type & Format		
Vector files (ESRI File Geodatabase, Shapefile), Maps (JPEG, TIFF, PDF, KMZ)		
Bit Depth		
N/A		
Class Coding		
Class Code	*Class Name*	*RGB Code*
11100	Formal high density continuous residential (Sealing level > 80%)	(RGB: 115-0-0)
11200	Formal high density discontinuous residential (Sealing level: 50% - 80%)	(RGB: 255-0-0)
11300	Formal low density discontinuous residential (Sealing level: 10% - 50%)	(RGB: 255-190-190)
12000	Commercial and industrial units	(RGB: 197-0-255)
12100	Non-residential urban fabric	(RGB: 232-190-255)
12200	Roads and associated land	(RGB: 78-78-78)
12300	Airports	(RGB: 205-102-102)
13000	Construction sites	(RGB: 255-0-197)
13200	Land without current use	(RGB: 190-232-255)
14000	Urban greenery, sport and leisure facilities	(RGB: 85-255-0)
20000	Agriculture	(RGB: 255-235-175)
31000	Forest	(RGB: 38-115-0)
32000	Other Natural and Semi-natural areas incl. wetlands	(RGB: 180-215-158)
33000	Bare land	(RGB: 204-204-204)
50000	Water bodies	(RGB: 0-112-255)
Metadata		
Provided as INSPIRE conformant *.xml data set, covering at least the mandatory elements.		
Service / Product Quality		
Thematic Accuracy		
Overall Accuracy: 91,1 %		
Positional Accuracy		
RMSE < 30 m.		
Delivery Procedure		
Service Provision		
Online via FTP		
Delivery Date		

End of June 2017		
0.1 Requirements		
Product 2 [(28)]	Urban Land Use/ Land Cover Change 202/2003 - 2017	
Abstract		
The Land Use/Land Cover Change product contains spatial explicit information on different land use and land cover change in both Core and Peri-Urban areas of the city of Phnom Penh between the years of 2002/2003 and 2017. The Core area has detailed LU/LC nomenclature whereas the Peri-Urban area LU/LC nomenclature is at an aggregated Level. The input data for the Core area was the Very High Resolution data (Pleiades for 2017, Quickbird-2 for 2002/2003) and the input data for the Peri-Urban area was Sentinel (2017) and Landsat (2003) data. The LU/LC product is the Baseline Product from which various derived products (such as Green Areas and Informal Settlements) are produced.		
Service / Product Specifications		
Area Coverage		
Country:	Bangladesh	
City:	Dhaka	
Area km²	Core Urban:	373 km²
	Peri-Urban:	886 km²
Time Period - Update Frequency		
A) Baseline Year(s): 2002/2003, 2017	B) Update Frequency 2 time horizons, no future update	
Comments:.		
Geographic Reference System		
EPSG: 32648. UTM 48N / WGS84		
Mapping Classes and Definitions		
Urban extension: extension of residential urban fabric	Formation of new residential urban fabric over non-artificial land over non-artificial land	
Urban extension: extension of commercial & industrial units	Formation of new commercial & industrial fabric over non-artificial land	
Urban extension: extension of non-residential urban fabric	Formation of new non-residential urban fabric over non-artificial land over non-artificial land	
Urban extension: extension of construction sites	Formation of new construction sites over non-artificial land	
Internal urban development	Internal conversion between artificial surfaces.	
Agriculture abandonment	Abandonment of agricultural land in favor of various types of natural and semi-natural land	
Natural areas development: consumption of urban fabric	Conversion of various types of urban fabric into natural areas	
Water bodies development: consumption of agriculture	Conversion of agriculture into water body (related mostly to riverbed development)	
Other changes	Other changes	
Cloud and Cloud Shadow Detection and Removal		
EO data without clouds or shadows.		
Spatial Resolution		
n.a. (Product provided as Shapefile)		

Minimum Mapping Unit (MMU)		
Minimum Mapping Unit is 0.25 ha for Core City, 0.5 ha for Peri-urban areas.		
Data Type & Format		
Vector files (ESRI File Geodatabase, Shapefile), Maps (JPEG, TIFF, PDF, KMZ)		
Bit Depth		
N/A		
Class Coding		
Class Code	*Class Name*	*RGB Code*
LCF11	Urban extension: extension of residential urban fabric	(RGB: 255-0-0)
LCF12	Urban extension: extension of commercial & industrial units	(RGB: 197-0-255)
LCF14	Urban extension: extension of non-residential urban fabric	(RGB: 232-190-255)
LCF16	Urban extension: extension of construction sites	(RGB: 255-0-197)
LCF20	Internal urban development	(RGB: 255-127-127)
LCF32	Agriculture abandonment	(RGB: 255-235-175)
LCF62	Natural areas development: consumption of urban fabric	(RGB: 180-215-158)
LCF52	Water bodies development: consumption of agriculture	(RGB: 0-112-255)
XXX	Other changes	(RGB: 156-156-156)
Provided as INSPIRE conformant *.xml data set, covering at least the mandatory elements.		
Service / Product Quality		
Thematic Accuracy		
Overall Accuracy: 86,6%		
Positional Accuracy		
RMSE < 30 m.		
Delivery Procedure		
Service Provision		
Online via FTP		
Delivery Date		
End of June 2017		

1.1 List of EO Data

Sensors[8]	QuickBird. Pleiades, Landsat5, Sentinel-2	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													
QuickBird													
2.	02OCT13032902-M2AS-056359384010_01_P002	03.04.2017	13.10.2002	LV2A	N/A	Phnom Penh	MUL:2.4 m PAN: 0.6 m	4	0%	UTM48N / WGS84	*.tif	16 Bit u	*.IMD / *.XML
3.	03FEB03033300-M2AS-056359384010_01_P001	03.04.2017	03.02.2003	LV2A	N/A	Phnom Penh	MUL:2.4 m PAN: 0.6 m	4	0%	UTM48N / WGS84	*.tif	16 Bit u	*.IMD / *.XML
Pleiades													
4.	PHR1B_MS_201702120326100_SEN_2226846101-002	23.03.2017	12.02.2017	Primary	N/A	Phnom Penh	MUL:2 m PAN: 0.5 m	4	0%	UTM48N / WGS84	*.tif	16 Bit u	*.XML
5.	PHR1B_MS_201701030334090_SEN_2226847101-002	23.03.2017	03.01.2017	Primary	N/A	Phnom Penh	MUL:2 m PAN: 0.5 m	4	0%	UTM48N / WGS84	*.tif	16 Bit u	*.XML
Landsat-5													
6.	LT05_L1TP_126052_20031130_20161204_01_T1	15.03.2017	30.11.2003	L1TP	126 / 52	Phnom Penh	30 m	7	0%	UTM48N / WGS84	*.tif	8 Bit u	*MTL.txt
Sentinel-2													
7.	S2A_MSIL1C_20170101T032132_N0204_R118_T48PVT	14.03.2017	01.01.2017	L1C	T48/ PVT	Phnom Penh	10 m	4	0%	UTM48N / WGS84	*.jp2	16 Bit u	*.safe / *.xml

1.2 List of In-situ Data

N/A

1.3 List of Ancillary Data

Dataset 1 (14)	DEM	Incoming Date	Acquisition Date	AOI - City / Region / Country	Data Type (4)	Data Format (3)	Projection / Spheroid (16)	Positional Accuracy (11)	No. of Classes	Area Coverage	Header / Metadata (2)
SRTM1arcsec		23.03.2017	11.02.2000	Phnom Penh /Myanmar	Raster	*.tif	WGS84	Horizontal: CE90 <20m Vertical: CE90 <16m	N/A	100%	*.mta
Lineage:		*The Shuttle Radar Topography Mission (SRTM) was flown aboard the space shuttle Endeavour on February 11 - 22, 2000. The National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) participated in an international project to acquire radar data which were used to create detailed topographic maps. SRTM data are intended for scientific use with a Geographic Information System (GIS) or other special application software. Endeavour orbited Earth 16 times each day during the 11-day mission completing 176 orbits. SRTM successfully collected radar data over 80% of the Earth's land surface between 60° north and 56° south latitude with data points posted every 1 arc-second (approximately 30 meters).*									
Source:		USGS Earth Explorer https://earthexplorer.usgs.gov/									

Dataset 2 (14)	OSM	Incoming Date	Acquisition Date	AOI - City / Region / Country	Data Type (4)	Data Format (3)	Projection / Spheroid (16)	Positional Accuracy (11)	No. of Classes	Area Coverage	Header / Metadata (2)
OSM roads/railways		10.03.2017	N/A	Phnom Penh /Myanmar	Vector	*.shp	UTM48N / WGS84	N/A	N/A	100%	N/A
Lineage:		*Up-to-date data extracts from the OpenStreetMap project. OSM data is crowded source data with contribution from volunteers and freely available.*									

Source:	Htttp://www.download.geofabrik.de

2.1 EO Data Quality

Sensors [8]: QuickBird, Pleiades, Landsat5, Sentinel-2

	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
QuickBird																		
1.	02OCT13032902-M2AS-056359384010_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
2.	03FEB03033300-M2AS-056359384010_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
Pleiades																		
3.	PHR1B_MS_201702120326100_SEN_2226846101-002	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.	PHR1B_MS_201701030334090_SEN_2226847101-002	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
Landsat5																		
5.	LT05_L1TP_126052_20031130_20161204_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
Sentinel-2																		
6.	S2A_MSIL1C_20170101T032132_N0204_R118_T48PVT	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

N/A

2.3 Ancillary Data Quality

Dataset 1 [14]	DEM	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																
SRTM1arcsec		Y - Q	Y - V Q	Y – V Q	Y – V Q	Y - V Q	Y - Q	Y - Q	Y - Q	Y - V	Y - V	N - V	Y - V	N - V	Yes	none

Dataset 2 [14]	OSM	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																
OSM roads/railways		Y - Q	Y - Q	N/A	Y - V Q	Y – V Q	N/A	Y - Q	N/A	Y - V Q	Y - V	N - V	Y - V	N - V	Yes	none

3.1 Geometric Correction

Sensors [8]	QuickBird, Pleiades, Landsat5, Sentinel-2	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...]
No.	File Name [e.g yymmdd; tbd...]												
QuickBird													
1.	02OCT13032902-M2AS-056359384010_01_P002	30.04.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	17; X RMSE:0,98;Y RMSE: 0,44	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	002OCT13032902-M2AS-056359384010_01_P002
2.	03FEB03033300-M2AS-056359384010_01_P001	30.04.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	17; X RMSE:0,98;Y RMSE: 0,44	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	003FEB03033300-M2AS-056359384010_01_P001
3.	02OCT13032902-P2AS-056359384010_01_P002	30.04.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	17; X RMSE:0,87;Y RMSE: 1,32	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	002OCT13032902-P2AS-056359384010_01_P002
4.	03FEB03033300-P2AS-056359384010_01_P001	30.04.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	17; X RMSE:0,87;Y RMSE: 1,32	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	003FEB03033300-P2AS-056359384010_01_P001
Pleiades													
5.	PHR1B_MS_201702120326100_SEN_2226846101-002	28.03.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	16; X RMSE:0,58;Y	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	0PHR1B_MS_201702120326100_SEN_2226846101-002

					RMSE: 0,59								
6.	PHR1B_P_201702120326100_SEN_2226846101-002	28.03.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	15; X RMSE:0,13;Y RMSE: 0,23	N/A	N/A	SRTM30	polynomic; 1st order	CUB	Yes	Yes	oPHR1B_P_201702120326100_SEN_2226846101-002
Landsat5													
9.	LT05_L1TP_126052_20031130_20161204_01_T1	22.03.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	LT05_L1TP_137043_20061221_20161118_01_T1
Sentinel-2													
10.	S2A_MSIL1C_20170101T032132_N0204_R118_T48PVT	22.03.2017	Phnom Penh /Myanmar	UTM48 N / WGS84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	S2A_MSIL1C_20170201T043011_N0204_R133_T45QZG_20170201T043825

3.1.1 Data Fusion

Dataset 1 [14]	Input A		Input B		Output		Acceptance Status	Comments
Filename	EO4SD_PhnomPenh_QB_20021013_MS		EO4SD_PhnomPenh_QB_20021013_PAN		EO4SD_PhnomPenh_QB_20021013_PS2Y			
Sensor	QuickBird		QuickBird		QuickBird			
Method	PANSHARP2 (PCI)		PANSHARP2 (PCI)		PANSHARP2 (PCI)			
Spatial Resolution / (MS/Pan)	2,4m	MS	0,6m	Pan	0,6m	PS		
Band Combination	R,G,B,Nir		PAN		R,G,B,Nir			
Data Format [3] & Bit Depth [5]	*.img	16 Bit u	*.img	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 2 [14]	Input A		Input B		Output		Acceptance Status	Comments
Filename	EO4SD_PhnomPenh_QB_20030203_MS		EO4SD_PhnomPenh_QB_20030203_PAN		EO4SD_PhnomPenh_QB_20030203_PS2Y			
Sensor	QuickBird		QuickBird		QuickBird			
Method	PANSHARP2 (PCI)		PANSHARP2 (PCI)		PANSHARP2 (PCI)			
Spatial Resolution / (MS/Pan)	2,4m	MS	0,6m	Pan	0,6m	PS		
Band Combination	R,G,B,Nir		PAN		R,G,B,Nir			
Data Format [3] & Bit Depth [5]	*.img	16 Bit u	*.img	16 Bit u	*.tif	16 Bit u	Yes	

Dataset 3 [14]	Input A		Input B		Output		Acceptance Status	Comments
Filename	EO4SD_PhnomPenh_PLE_20170212_MS		EO4SD_PhnomPenh_PLE_20170212_PAN		EO4SD_PhnomPenh_PLE_20170212_PS2Y			
Sensor	Pleiades		Pleiades		Pleiades			
Method	PANSHARP2 (PCI)		PANSHARP2 (PCI)		PANSHARP2 (PCI)			
Spatial Resolution / (MS/Pan)	2m	MS	0,5m	2m	MS	0,5m		
Band Combination	R,G,B,Nir		PAN		R,G,B,Nir			

Data Format (3) & Bit Depth (5)	*.img	16 Bit u	*.img	*.img	16 Bit u	*.img	Yes	

Dataset 4 (14)	Input A		Input B		Output		Acceptance Status	Comments
Filename	EO4SD_PhnomPenh_PLE_20170103_MS		EO4SD_PhnomPenh_PLE_20170103_PAN		EO4SD_PhnomPenh_PLE_20170103_PS2Y			
Sensor	Pleiades		Pleiades		Pleiades			
Method	PANSHARP2 (PCI)		PANSHARP2 (PCI)		PANSHARP2 (PCI)			
Spatial Resolution / (MS/Pan)	2m	MS	0,5m	Pan	0,5m	PS		
Band Combination	R,G,B,Nir		PAN		R,G,B,Nir			
Data Format (3) & Bit Depth (5)	*.img	16 Bit u	*.img	16 Bit u	*.tif	16 Bit u	Yes	

3.2 Data Processing

Sensors (8)	QuickBird. Pleiades, Landsat5, Sentinel-2		Atmospheric Correction		Radiometric Processing (15)		Topographic Normalisation		OTHER Calculation:		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd...]	Processing Date	processed	Software / Method	processed	Software / Method	processed	Software / Method	processed	Software / Method			
QuickBird													
1.	03FEB03033300-M2AS-056359384010_01_P001	13.04.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none
2.	02OCT13032902-P2AS-056359384010_01_P002	30.04.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none
Pleiades													

3.	PHR1B_MS_201702120326100_SEN_2226846101-002	28.03.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none
4.	PHR1B_P_201702120326100_SEN_2226846101-002	28.03.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none
Landsat5													
5.	LT05_L1TP_126052_20031130_20161204_01_T1	22.03.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none
Sentinel-2													
6.	S2A_MSIL1C_20170101T032132_N0204_R118_T48PVT	22.03.2017	N	N/A	N	N/A	N	N/A	**N**	N/A	Yes	Yes	none

4.1 Classification

Sensor 1 (8)	QuickBird	Processing Date	Cloud Masking		Thematic Classification		Manual Enhancement		Mosaicking		Acceptance Status	Backup	Comment
No.	File Name [e.g yymmdd; tbd...]		processed	Software / Method	processed	Software / Method	processed	Software / Method	processed	Software / Method			
QuickBird													
1.	03FEB03033300-M2AS-056359384010_01_P001 02OCT13032902-P2AS-056359384010_01_P002	28.08.2017	N	N/A	Y	eCognition/semi-automatic approach	Y	Webim/GISAT proprietary solution	N	N/A	Y	Y	
Pleiades													
2.	PHR1B_MS_201702120326100_SEN_2226846101-002 PHR1B_P_201702120326100_SEN_2226846101-002	14.08.2017	N	N/A	Y	eCognition/semi-automatic approach	Y	Webim/GISAT proprietary solution	N	N/A	Y	Y	
Landsat5													
3.	LT05_L1TP_126052_20031130_20161204_01_T1	30.08.2017	N	N/A	Y	eCognition/semi-automatic approach	Y	Webim/GISAT proprietary solution	N	N/A	Y	Y	
Sentinel-2													
4.	S2A_MSIL1C_20170101T032132_N0204_R118_T48PVT	30.08.2017	N	N/A	Y	eCognition/semi-automatic approach	Y	Webim/GISAT proprietary solution	N	N/A	Y	Y	

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.	LULC 2002/2003	5.9.2017	Phnom Penh – core city	11	QuickBird	520 points	POINT	Stratified random sampling	None	86,6%	**Yes**	
2.	LULC 2017	5.9.2017	Phnom Penh – core city	11	Pleiades	535 points	POINT	Stratified random sampling	None	91,1%	**Yes**	

5.2 Error Matrices

Class Name (columns = Mapped Class; Rows = Ground Truth) LandUse/Land Cover 2003		Urban fabric	Commercial and Industrial	Transportation	Construct ion sites	Urban Greenery	Agriculture	Forest	Natural areas	Bare land	Water		User Accuracy and Confidence Interval at 95% Confidence Level
	Clas s ID	110	120	122	130	140	200	310	320	330	500	Totals	
Urban fabric	110	**124**	0	1	3	0	0	1	1	0	0	**130**	95.4 % ± 1.6
Comm. and Industrial	120	5	**40**	0	5	0	0	0	1	0	0	**51**	**78.4 %** ± 3.2
Transportation	122	1	0	**14**	0	0	0	0	0	0	0	**15**	93.3 % ± 1.9
Construction sites	130	0	2	0	68	0	1	0	0	0	0	**71**	95.8 % ± 1.6
Urban Greenery	140	0	0	0	0	**11**	0	0	0	0	0	**11**	**100 % n.a.**
Agriculture	200	6	0	0	21	0	**151**	0	8	0	1	**187**	80.7 % ± 3.1
Forest	310	0	0	0	0	0	0	**3**	3	0	0	**6**	50 % ± 3.9
Natural areas	320	2	0	0	7	0	8	2	**90**	0	1	**110**	81.8 % ± 3
Bare land	330	0	0	0	0	0	0	0	0	**9**	0	**9**	100 % n.a.
Water	500	1	0	0	0	0	2	0	2	1	**44**	**50**	88 % ± 2.5
Totals		**139**	**42**	**15**	**104**	**11**	**165**	**6**	**105**	**10**	**46**	**640**	
Producer Accuracy and Confidence Interval at 95% Confidence Level		89.2 % ±2.4	95.2 % ± 1.6	93.3 % ± 1.9	65.4 % ± 3.7	100 % n.a.	93.2 % ± 1.9	50 % ± 3.9	85.7 % ± 2.7	90 % ± 2.3	95.7 % ± 1.6	**Overall Accuracy: 86.6%** Confidence Interval 83.92% - 89.2%	

5.2 Error Matrices

Class Name (columns = Mapped Class; Rows = Ground Truth) LandUse/Land Cover 2017		Urban fabric	Commercial and Industrial	Transportation	Construction sites	Urban Greenery	Agriculture	Forest	Natural areas	Bare land	Water		User Accuracy and Confidence Interval at 95% Confidence Level
	Class ID	110	120	122	130	140	200	310	320	330	500	Totals	
Urban fabric	110	**192**	0	0	1	0	0	1	0	0	0	**194**	99 % ± 0.9
Comm. and Industrial	120	10	**80**	0	0	5	0	0	0	0	0	**95**	84.2 % ± 3.1
Transportation	122	0	0	**25**	0	0	0	0	0	0	0	**25**	100 % n.a.
Construction sites	130	1	3	0	**76**	3	1	0	0	3	0	**87**	87.4 % ± 2.8
Urban Greenery	140	0	1	0	0	**16**	0	0	0	0	0	**17**	94.1 % ± 2
Agriculture	200	1	1	0	1	0	**28**	0	0	0	0	**31**	90.3 % ± 2.5
Forest	310	0	0	0	1	0	0	**13**	3	0	0	**17**	76.5 % ± 3.6
Natural areas	320	0	0	0	6	0	1	1	**27**	1	1	**37**	73 % 3.7
Bare land	330	0	0	0	0	0	0	0	0	**26**	0	**26**	100 % n.a.
Water	500	1	0	0	0	1	0	0	0	0	**9**	**11**	81.8 % ± 3.3
Totals		**205**	**85**	**25**	**85**	**25**	**30**	**15**	**30**	**30**	**10**	**540**	
Producer Accuracy and Confidence Interval at 95% Confidence Level		93.7 % ± 2.1	94.1 % ± 2	100 % n.a.	89.4 % ± 2.6	64 % ± 4	93.3 % ± 2.1	86.7 % ± 2.9	90 % ± 2.5	86.7 % ± 2.9	90 % ± 2.5	**Overall Accuracy: 91.1%** Confidence Interval 88.7 % - 93.5 %	

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	886 km²	886 km²	100%	2	2	100%	Yes	none
2.	VHR EO Data		373 km²	100%	4	4	100%	Yes	none
4.	Ancillary Data		N/A	N/A	N/A	N/A	N/A	Yes	none
PRODUCTS									
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.	LULC 2006	886 km²	886 km²	100%	100%	N/A	100%	Yes	none
2.	LULC 2016		886 km²	100%	100%	N/A	100%	Yes	none

6.2 Compliancy

Product 1 [(28)]	EO4SD_PHNOM_PENH_LULC_2002/2003_2017

Abstract

The Land Use/Land Cover product contains spatial explicit information on different land use and land cover in both Core and Peri-Urban areas of the city of Phnom Penh (Cambodia) for the years of 2002/2003 and 2017. The Core area has detailed LU/LC nomenclature whereas the Peri-Urban area LU/LC nomenclature is at an aggregated Level. The input data for the Core area was the Very High Resolution data (Pleiades for 2017, Quickbird-2 for 2002/2003) and the input data for the Peri-Urban area was Sentinel (2017) and Landsat (2003) data. The LU/LC product is the Baseline Product from which various derived products (such as Green Areas and Informal Settlements) are produced.

Service / Product Specifications

Area Coverage

Requirements		**Achieved Specifications**		**Compliancy**	**Comments**
Country 1:	Cambodia	Country 1:	Cambodia	100 %	
Country 2:	N/A	Country 2:	N/A		
Country 3:	N/A	Country 3:	N/A		
Country 4:	N/A	Country 4:	N/A		
A) Wall-to-wall: Sub-national, Phnom Penh		A) Wall-to-wall: Sub-national, Phnom Penh		100 %	
Area of approx. 710 km², defined by the user.					
B) Sampling based: N/A		B) Sampling based: N/A			

Time Period - Update Frequency

Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Baseline Year(s): **2000** **2015**	Baseline Year(s): **2002/2003** **2017**	Yes	EO data differs from requirements because of availability of VHR EO data.
B) Update Frequency N/A	B) Update Frequency N/A		

Geographic Reference System

Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
EPSG: 32648. WGS84 / UTM 48N	EPSG: 32648. WGS84 / UTM 48N	Yes	-

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

Requirements	**Achieved Specifications**	**Compliancy**
N/A	All classes were agreed by the user.	Yes

Cloud and Shadow Detection and Removal

Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Cloud free.	Cloud free scenes used.	Yes	-

Spatial Resolution			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
VHR for core	VHR for core	Yes	-
Minimum Mapping Unit (MMU)			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
0.25 ha for Core City, 0.5 ha for Peri-urban	0.25 ha for Core City, 0.5 ha for Peri-urban	Yes	-
Data Type			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
GIS-ready format	ESRI Shapefile / Geodatabase	Yes	-
Bit Depth			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Not specified	N/A	N/A	-
Data Format			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
*.shp ESRI Shapefile (open cross-platform format)	ESRI Shapefile	Yes	-
Class Coding			
Requirements	**Achieved Specifications**	**Compliancy**	
N/A	N/A		
Metadata			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
INSPIRE compliant	ISO/Inspire compliant	Yes	-
Service / Product Quality			
Thematic Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Overall Accuracy: 85%	86,6% - 91,1%	Yes	-
Positional Accuracy			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
RMSE < 2 m	RMSE < 2 m	Yes	

			Calculated from adjustment to OSM roads. Technical difficulties to co-registrate and find appropriate GCP/TPs due to extremely high amount of changes in the area
Delivery Procedure			
Service Provision			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Not specified	FTP	Yes	
Delivery Date			
Requirements	**Achieved Specifications**	**Compliancy**	**Comments**
Not specified	Sep 15th 2017	Yes	Interim products delivered earlier on demand

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.