
# Urban Mobility Plan Development in Chisinau, Moldova

Work Order Report

Supporting:
United Nations Development Programme (UNDP)

Reference: EOC0001_WOR_V1

Date: 2019 July 17

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# REFERENCE DOCUMENTS

| | |
|---|---|
| [RD-1] | ESA Request for Proposal: EOC0001_RFP_v01 |
| [RD-2] | Technical Proposal: EOC0001_PRO_C_T_V1 by GeoVille Gmbh and SIRS |
| [RD-3] | Financial Proposal: EOC0001_PRO_C_F_V1 by GeoVille Gmbh and SIRS |

# ABOUT THIS DOCUMENT

This document is the final Work Order Report of the ESA (European Space Agency) EO Clinic project EOC0001 Urban Mobility Plan Development in Chisinau, Moldova. This publication was prepared in the framework of the EO Clinic (Earth Observation Clinic, see below), in partnership between ESA, the United Nations Development Programme (UNDP) Moldova Office, and a team of service providers contracted by ESA: GeoVille GmbH (Austria) and SIRS (France).

This Work Order Report (WOR) is structured as in the following:

- **Section 1** describes the context of the UNDP activities on Urban Mobility Plan Development in Chisinau, Moldova, the project objectives and requested EO products and services.
- **Section 2** highlights the applied work logic and responsibilities among the EO Clinic service providers
- **Section 3** describes the services, their specifications, methods and outcomes.
- **Section 4** presents an evaluation of the data availability and suitability in support of the EO products and services under the perspective of a potential roll-out

# ABOUT THE EO CLINIC

The EO Clinic (Earth Observation Clinic) is an ESA initiative to create a rapid-response mechanism for small-scale and exploratory uses of satellite EO information in support of a wide range of International Development projects and activities. The EO Clinic consists of "on-call" technically pre-qualified teams of EO service suppliers and satellite remote sensing experts in ESA member states. These teams are ready to demonstrate the utility of satellite data for the development sector, using their wide range of geospatial data skills and experience with a large variety of satellite data types.

The support teams are ready to meet the short delivery timescales often required by the development sector, targeting a maximum of 3 months from request to solution.

The EO Clinic is also an opportunity to explore more innovative EO products related to developing or improving methodologies for deriving socio-economic and environmental parameters and indicators.

The EO Clinic was launched in March 2019 and is open to support requests by key development banks and agencies during the 2 years project duration.

# AUTHORS

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# ACKNOWLEDGEMENTS


- The following colleagues provided valuable inputs, insights and evaluation feedback on the work performed: Dumitru Vasilescu (Policy Specialist, United Nations Development Programme), Aurelia Spataru (Project manager, United Nations Development Programme), Bruno Goes (CIO, Orange Moldova) and Zoltan Bartalis (ESA Coordinator and Technical Officer).


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# 1 Development Context and Background

## 1.1 Chişinău Urban Development

Chişinău is the capital and largest city of the Republic of Moldova and the country's main industrial and commercial centre and transportation hub. The city is located in the middle of the country, on the river Bâc, a tributary of Dniester. The population of Chişinău dropped during the 1990's after the demise of the Soviet Union and has grown at a 1.2% rate annually since 2004. According to the results of the 2014 census, the city had a population of 532.513, while the number of population in the Municipality of Chişinău (including the inner city and nearby communities) was 662.836.[1] While still being the least urbanised European country with over 55% of the population residing in rural areas (as of 2014), particularly Chişinău is expected to be faced with a strong inflow of new residents putting even more pressure on city's infrastructure and services, while also creating considerable social and environmental challenges. Thus, the management of the urbanization and rural-urban migration process has been gaining attention as one of the key national development priorities.[2]

One of the main issues related to urban development of Chişinău is urban mobility, i.e. the lack of adequate public transport capacities despite a growing population in the greater city area, resulting in substantial uncoordinated urban expansion and recurrent traffic jams. As stated in a recent press release from UNDP[3], *"Chişinău is [...] one of those urban centres that attracts an increasing number of residents but is not always prepared to adapt its infrastructure to the growing demand"*. Both the Government of Moldova and the Municipality of Chişinău are interested in characterising and under-standing the urban development patterns and in co-designing safe-to-fail experimental solutions to solve emerging problems or anticipate what might happen in the next 5–10 years. This has been the main justification for kicking-off the development of an **urban mobility plan**[4] for the city, **supported by UNDP as part of the Moldova Sustainable Green Cities Project** funded by the Global Environment Facility (GEF).

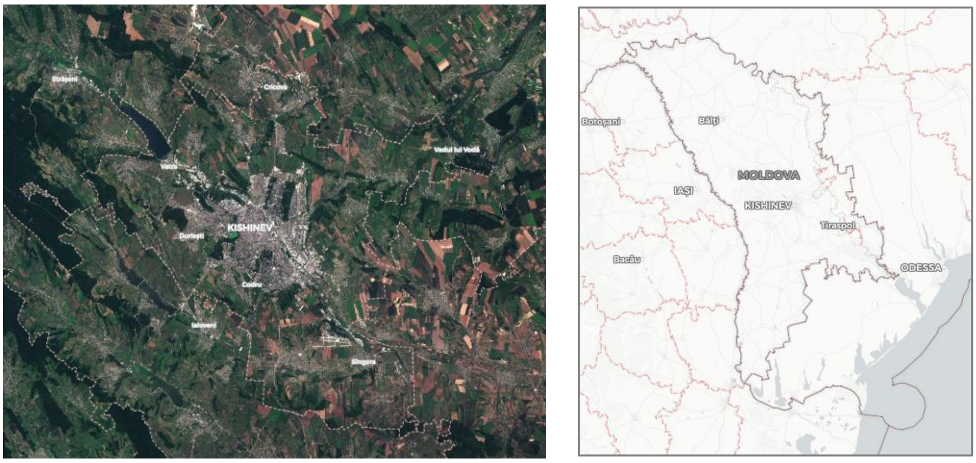


*Figure 1: Sentinel-2 image of Chişinău acquired on July 2nd, 2019 (Source: European Space Agency).*

[1] https://en.wikipedia.org/wiki/Chi%C8%99in%C4%83u

[2] http://www.md.undp.org/content/moldova/en/home/projects/Moldova-Sustainable-Green-Cities.html

[3] http://www.md.undp.org/content/moldova/en/home/presscenter/pressreleases/2019/chisinau-paves-the-way-towards-innovative-and-green-urban-develo.html

[4] http://www.md.undp.org/content/moldova/en/home/presscenter/pressreleases/2019/chi_in_ul-va-avea--in-premier--un-plan-de-mobilitate-urban.html

**UNDP Moldova** is establishing a new ***evidence platform*** for engaging all relevant stakeholders in the generation and use of new evidence to generate insights and understand development patterns and then use the new evidence for experimentation work, i.e. generation and testing of **safe-to-fail solutions to achieve SDGs at local level**. Starting with the Municipality of Chișinău, the longer-term ambition is to connect other municipalities, in particular smaller cities that could become poles of growth in the future (Cahul, Ungheni, Balti, Orhei and similar) as well as other partners and donors. New evidence, for example from Earth Observation data and geospatial information technologies, are expected to support promotion and accelerated achievement of the SDGs at local level as well as corporate citizenship and participation.

## 1.2 Objectives

**UNDP Moldova Office** has requested Technical Assistance from the ESA EO Clinic to support in the development of the Urban Mobility Plan, in which existing and new options for urban transport will be developed (including public transport). Detailed, up-to-date, consistent and reliable information is needed on various urban development and mobility issues, such as

- the size and distribution of the population,
- the proportion of the population that has convenient access to public transport,
- the location and occurrence patterns of traffic congestions,
- on gaps in small infrastructure (bike lanes, paved surfaces, sidewalks, etc.) that could alleviate congestions.
- the long-term evolution of land use and fragmentation patterns, for urban planning, for the prevention of the negative impacts of urbanisation, and especially for the siting of new infrastructure (e.g. for a planned city bypass road) and the access to green areas.

Besides those information gaps, UNDP requires support with the cross-checking and innovative merging of satellite-based information with existing non-satellite data (see Chapter 3), and the generation of specific insights and patterns.

Hence, the aim of the activity is to support UNDP, the Government of Moldova and the Municipality of Chișinău in the Urban Mobility Plan Development through the provision of innovative Earth observation based products and information services for a test area within the Municipality of Chișinău, covering the administrative sectors of Centru, Botanica and Ciocana (the portions within the City of Chișinău), as well as the suburban town of Codru (administered by the sector Centru).

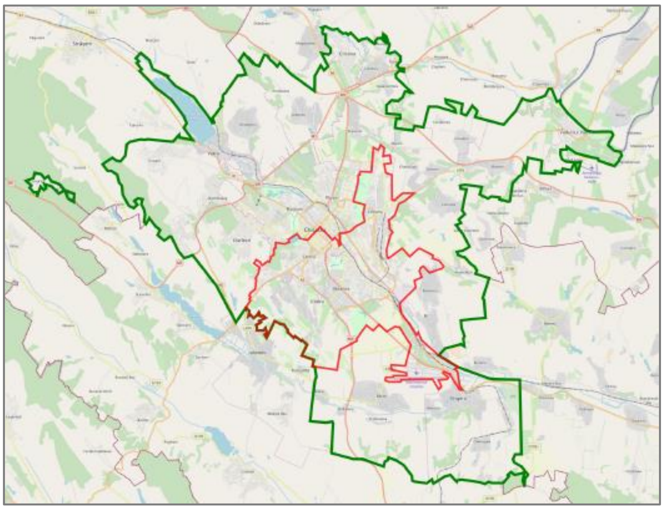

*Figure 2: Area of Interest for the EO Clinic technical assistance (red) within the Municipality of Chișinău (green). Source: https://www.openstreetmap.org.*

The following information services have been requested:

- ***Service 1: Urban and Peri-Urban Land Use / Land Cover Classification and Associated Changes*** – providing detailed land use and land cover classification maps for the epochs 2004-2014-2019 as a basic planning support tool for assessing urban development and main evolution trends in and around Chișinău.
- ***Service 2: Census-Based Population Distribution*** – delivering small-area population estimates adding significant spatial detail to the official statistics from the National Bureau of Statistics.
- ***Service 3: Case Study Definition and First Insights into Recent Population and Mobility Trends*** - building on the previous two services and supporting the UNDP Moldova with dedicated use cases and analyses of the overall situation in Chișinău.

The initial set of information products and insights generated within this activity shall be used mainly by UNDP Moldova, the local administration of Chișinău and private sector companies to experiment with co-designed solutions to existing urban problems. Moreover, outcomes shall serve to further encourage the adoption of EO within UNDP Moldova and the Municipality of Chișinău, the Government and the private sector. The goal is to expand the analysis to the entire Municipality of Chișinău, and to advance the ideas and first results delivered by Service 3 to a more operational and integrated level. In the longer-term, the intention is to transfer the lessons learned to other municipalities in the region and beyond (in cooperation with the UNDP Regional Bureau for Europe and the Commonwealth of Independent States, RBEC), depending on the interest of the specific UNDP country offices.

# 2 WORK LOGIC

The overall work logic and organisation between GeoVille (coordinator of EO-Clinic framework contract, interface towards ESA and UNDP, and service provider) and SIRS (service provider) is presented in the figure below. GeoVille has acted as focal point towards ESA as the contracting authority, UNDP and Orange Moldova.

During the implementation phase the following stakeholder representatives were involved:

- Dumitru Vasilescu (Policy Specialist, United Nations Development Programme)
- Aurelia Spataru (Project manager, United Nations Development Programme)
- Bruno Goes (CIO Orange Moldova)

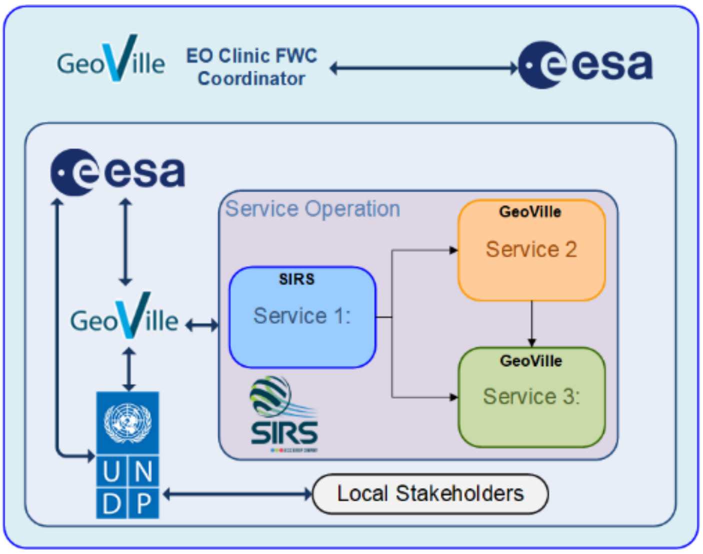


*Figure 3: Overall Work Logic and interaction between organisations and services*

Service 1 was implemented first by SIRS and was used as the basis for GeoVille to generate Service 2. Service 3 was also implemented by GeoVille. This work has been initially planned over a tight period with a Work Completion Deadline (WCD) for all three services of 6 weeks from the issuing of the Work Order (WO). Due to delays in data delivery the Work Completion Deadline was extended in agreement with all stakeholders to July 17, 2019.

The time plan for implementing the work order was as follows:

*Table 1: Time plan for work implementation*

| Item | Date |
|---|---|
| **Request for Proposal issued by ESA** | 21.03.2019 |
| **Submission of Technical and Financial Proposal** | 16.04.2019 |
| **Start of Work Order** | 07.05.2019 |
| Call with representative of UNDP to discuss time schedule of implementation | 08.05.2019 |
| SPOT images for 2019 for Service 1 received | 12.05.2019 |
| Census data for 2014 from the NBS (National Bureau of Statistics of the Republic of Moldova) received | 13.05.2019 |

| | |
|---|---|
| Chisinau statistics from the NBS (National Bureau of Statistics of the Republic of Moldova) received | 13.05.2019 |
| **Extension of deadline to July 2nd, 2019 due to delayed data provision** | **20.05.2019** |
| Cadastral dataset for Chisinau received | 23.05.2019 |
| Orthophoto dataset for Chisinau (deleted from Cadastre Agency) | 23.05.2019 |
| Building footprint dataset for Chisinau (corrupt) | 23.05.2019 |
| Update building footprint dataset | 05.06.2019 |
| SPOT images for 2014 for Service 1 ordered and received due to unavailability of orthophotos | 06.06.2019 |
| Call with representative of UNDP, ESA and statistical office to discuss the project progress | 11.06.2019 |
| Sample dataset (24h) of CDR files from Orange Moldova received | 17.06.2019 |
| **Finalisation of Service 1 products by SIRS** | **18.06.2019** |
| Call with representative of UNDP to discuss the outcome of Service 1 | 18.06.2019 |
| Population data Chisinau from the NBS (National Bureau of Statistics of the Republic of Moldova) | 18.06.2019 |
| **Finalisation of Service 2 products by GeoVille** | **25.06.2019** |
| **Extension of deadline to July 17th, 2019 due to delayed CDR data provision** | **26.06.2019** |
| Transport data from Chisinau from City Hall on transport, stations and itineraries received | 26.06.2019 |
| Call with representative of UNDP and statistical office to discuss the outcome of Service 2 and project progress | 03.07.2019 |
| **Finalisation of Service 3 products by GeoVille** | **16.07.2019** |
| **Delivery of Final Data Package (incl. Service 1, Service 2 and Service 3, as well as the final report)** | **17.07.2019** |
| **Deadline Work Order** | **17.07.2019** |

# 3 DELIVERED EO-BASED PRODUCTS AND SERVICES

## 3.1 Service 1 - Urban and Peri-Urban Land Use / Land Cover Classification and Associated Changes

Land use / land cover datasets such as the European Urban Atlas[1], one of the Copernicus land monitoring services, were originally developed to support better planning decisions and assess the impact of infrastructural investment by the European Regional Development Fund. Several studies were developed by DG Regio based on the European Urban Atlas to compare the requirements of European cities in terms of access to public transportation[2] and green areas[3]. The European Urban Atlas provides harmonised mapping specifications of land cover / land use across Europe for all cities above 50.000 inhabitants.

### 3.1.1 Specifications

The specifications applicable for generating the detailed LULC and change mapping over the Area of Interest (AOI) within the Municipality of Chișinău are exactly the ones defined for the European Urban Atlas, which enables the analysis of urban and peri-urban land development trends in the past 15 years and to characterize residential/industrial land use changes, changes in the urban green areas, changes in the transport network and urban fragmentation, and the evolution of agriculture and ecosystem-related processes in the peri-urban areas. Morover, the data can be used to compare the city with other neighbouring and similar cities within the European Environment Agency (EEA) 39 member and associated countries.

*Table 2: Product specifications for Service 1*

| | |
|---|---|
| **Geometric positional accuracy:** | 1 pixel or better |
| ***Thematic accuracy:*** | |
| **Urban area (class 1)** | 85% |
| **Rural area (classes 2-5)** | 80% |
| **Overall** | 80% |
| ***Minimum Mapping Unit (MMU) and Width (MMW)*** | |
| **Class 1:** | 0,24 ha / 0,1h for change mapping |
| **Class 2* – 5** | 1 ha / 0,25ha for change mapping |

<u>Data input (cf. chapters 4.1-4.4 for a detailed discussion on data suitability)</u>

- Very High Resolution satellite data:
  - SPOT 7 scene from 03/04/2019, 1.5 m spatial resolution and 4 spectral bands
  - SPOT 6 scene from 13/04/2014, 1.5 m spatial resolution and 4 spectral bands
  - SPOT 5 scene from 10/06/2004, 5m spatial resolution, panchromatic band
- Road and railway network data (OSM)

[1] https://land.copernicus.eu/local/urban-atlas

[2] https://ec.europa.eu/regional_policy/sources/docgener/work/2015_01_publ_transp.pdf

[3] https://ec.europa.eu/regional_policy/sources/docgener/work/2018_01_green_urban_area.pdf

- Cadastral land parcels and building footprints

<u>Method</u>

*Primary vector layer generation*

Road and railway network data from OSM (line features) were visually checked and refined for completeness, then automatically checked and corrected for ensuring the topological consistency of the dataset. Finally, the line features were converted in area features by applying buffer whose distance depends on road type / railway. Topological checks were also applied on cadastral land parcels before integrating them.

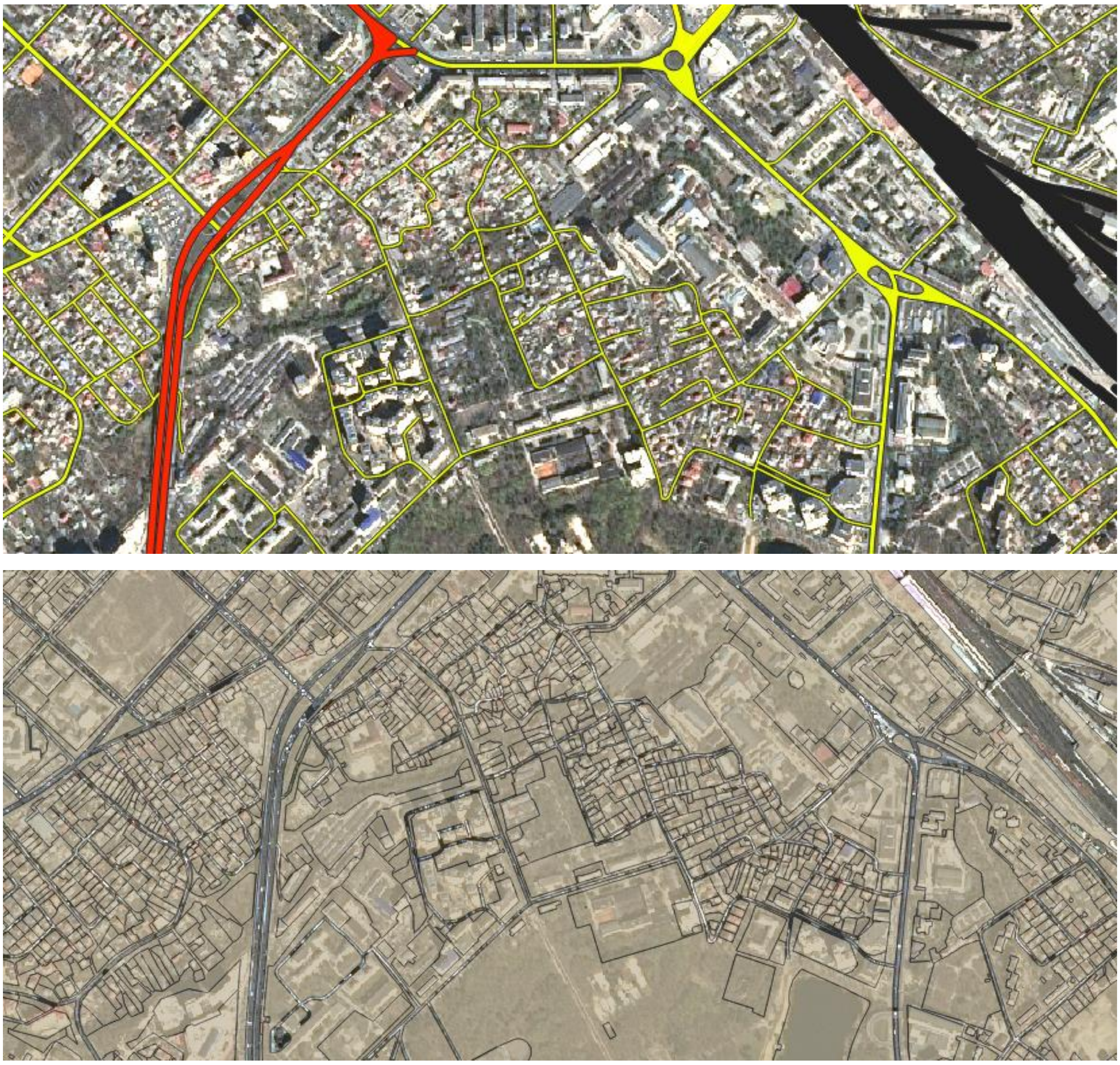

*Figure 4: Refined road & railway network data and cadastral land parcels for generating the primary vector layer*

*Land Use / Land Cover (LULC) classification mapping for a first epoch*

By default, the LULC classification mapping was performed for Epoch 3 i.e. the most recent situation (2019) starting from the primary vector layer in which navigation data network and land parcels have been integrated.

The LULC classification mapping was carried out exclusively by means of visual interpretation using VHR satellite data in accordance with the technical specifications of the European Urban Atlas. Land cover classification at level 1 of the nomenclature by means of semi-automated approach could have been implemented but only in case of larger area of interest with significant presence of non-urban areas.

Cadastral building dataset as well as Google Maps / Street View were used as ancillary data for supporting the identification of the actual use/function of buildings, especially within the densely built-up areas.

*Urban fabric unit classification at level 4*

Urban fabric units (1.1) are defined in the Urban Atlas mapping guide as built-up areas and their associated land, such as gardens, parks, planted areas and non-surfaced public areas and the infrastructure, if these areas are not suitable to be mapped separately regarding the minimum mapping unit size. Residential structures and patterns are predominant, but also downtown areas and city centres, including the Central Business Districts (CBD) and areas with partial residential use, are included.

The urban fabric classes (1.1) are distinguished only by their degree of soil sealing not by their type of buildings (single family houses or apartment blocks). Detailed description and interpretation keys were provided to image analysts for supporting the identification and delineation of those units with homogeneous sealing density. After visual interpretation, the finest classification at level 4 (11100, 11210, 11220, 11230 and 11240) was carried out considering the imperviousness degree calculated for each urban fabric unit using cadastral building footprints and relevant OSM features (service roads and car parks mainly).

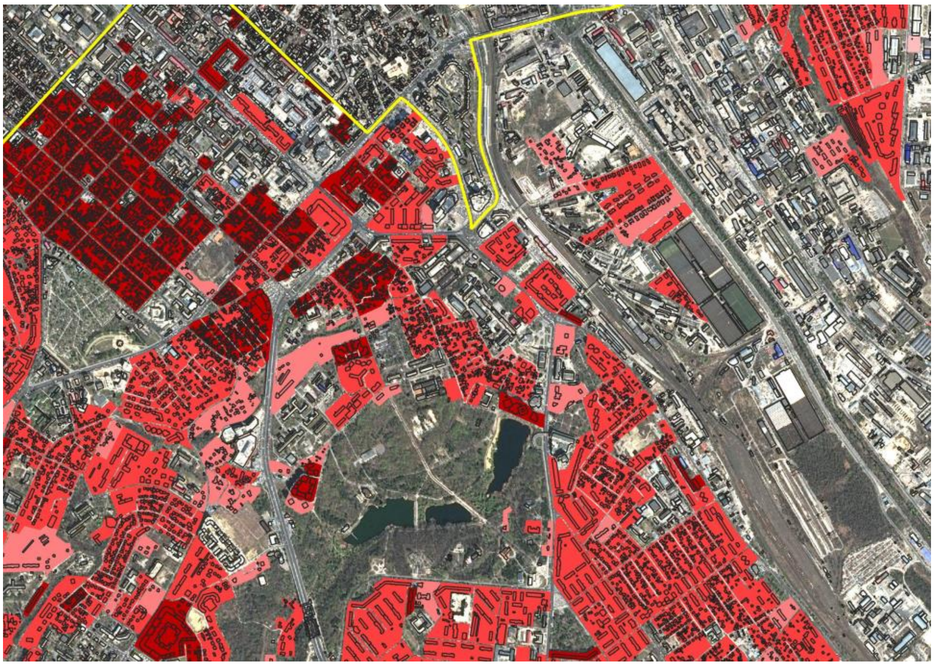

*Figure 5: Urban fabric units (1.1) classified at level 4 using cadastral building footprints*

*Change detection*

Once the LULC classification mapping for Epoch 3 was completed and validated, change detection and mapping was performed by means of visual interpretation comparing the input EO data from the different epochs in accordance with the technical specifications and mapping rules specific for changes. The procedure was to detect, delineate the extent and thematically classify the changes occurred over the period 2014-2019, then over the period 2004-2014 for which the challenge was higher due to the lower spatial resolution of input EO data (5 meters).

*Quality Control and Validation*

Quality Control (QC) was part of the production phase and consists in an internal quality check with independent reference data. QC included the following checks, with check-ups of the completeness, logical consistency and geometric accuracy mainly implemented in an automated manner:

- Thematic accuracy performed by means of visual check by another image analyst to ensure the product quality and homogeneity
- Geometric and thematic compliance by means of visual check over randomly selected area samples
- Absence of unlikely changes
- Completeness (omissions/commissions)
- Topological consistency (absence of null geometries, duplicates, multipart features, missing connections due to under/overshoots, invalid slivers, overlaps, gaps, …)
- Conceptual and domain consistency (attribute table structure and values)

Validation of the thematic product accuracy (overall accuracy, classification correctness and completeness) was implemented independently from the production and once the products are generated for ensuring the compliance with the specifications. The quality control design applied was as follows:

- **Sampling design** – Generation of 150 point samples using a single stage stratified random sampling approach. Two strata were defined, artificial surfaces (class 1 at level 1 of the nomenclature) and non-artificial surfaces, in which respectively 100 and 50 point samples were randomly selected taking care of a minimum distance between them for ensuring homogeneous spatial distribution.
- **Response design** – The reference data were generated independently (double-blind approach) by means of visual interpretation using the EO satellite imagery used for the production as no better resolution and/or ground-truth data were made available.
- **Analysis** – The analysis method consists in the comparison of the classes assigned to features from the product with the reference data. The result of this assessment is presented through confusion matrices.

Confusion matrices were established for each LULC product of each epoch (2019, 2014, 2004) and weights have been applied to the points considering the stratified sampling approach (2 defined strata: artificial areas and non-artificial areas) for calculating the accuracy indicators (user accuracy, producer accuracy, overall accuracy).

The resulting overall accuracy is satisfactory as compliant with the technical specifications (>85%). Individual confusion matrices can be made available upon request.

- LULC 2019 – 94.5%
- LULC 2014 – 96.7%
- LULC 2004 – 89.6%

### 3.1.2 Outputs

The outputs from Service 1 are:

- Vector layers in ESRI shapefile format or any other compatible GIS vector format
    - LULC classification maps for each epoch (2004, 2014, 2019),
    - LULC change maps between those epochs (2004-2014, 2014-2019, 2004-2019).
    - Additional LULC change maps highlighting specific urban dynamics can be made available upon request (e.g. residential/industrial land use changes, urban densification/fragmentation, urban green area evolution, transport network evolution etc.)

- INSPIRE compliant metadata .xml files
- A summary report with statistics is provided under service 3 (chapter 3.3.3.1)

The LULC map generated for 2019 reference year is presented in Figure 6. A cartographic version of the map layout is provided as a pdf file in addition to the geo-spatial product.

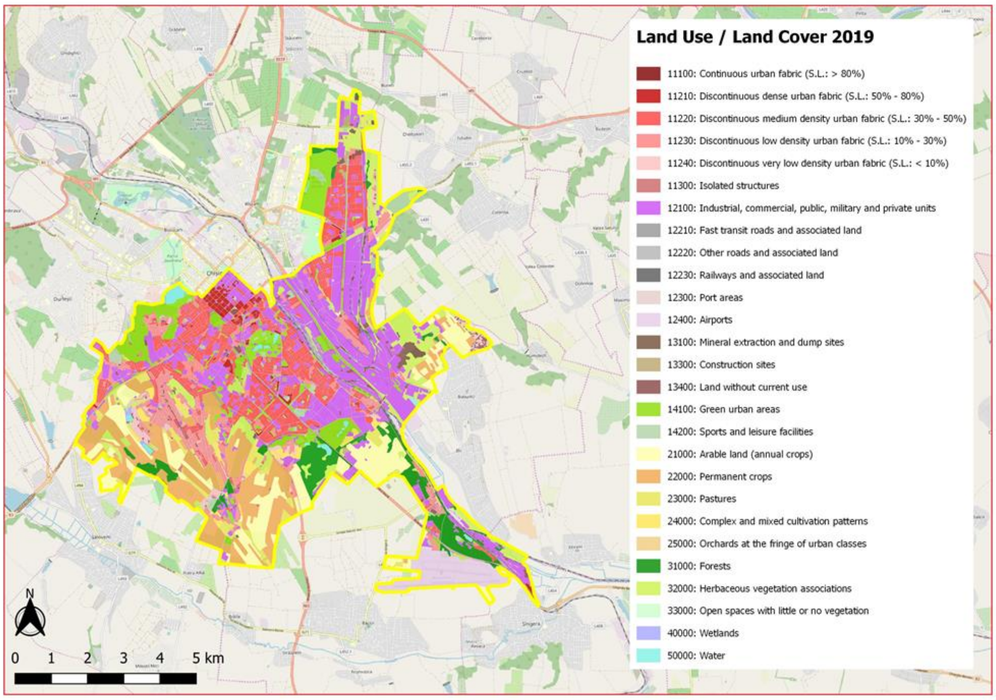


*Figure 6: Land Use Land Cover 2019 product respecting the European Urban Atlas specifications*

Based on LULC products generated for the three requested epochs (2004, 2014, 2019), LULC changes can be easily isolated and analysed. Figure 7 shows the spatial distribution, extent and type of the changes occurred over the whole period 2004-2019.

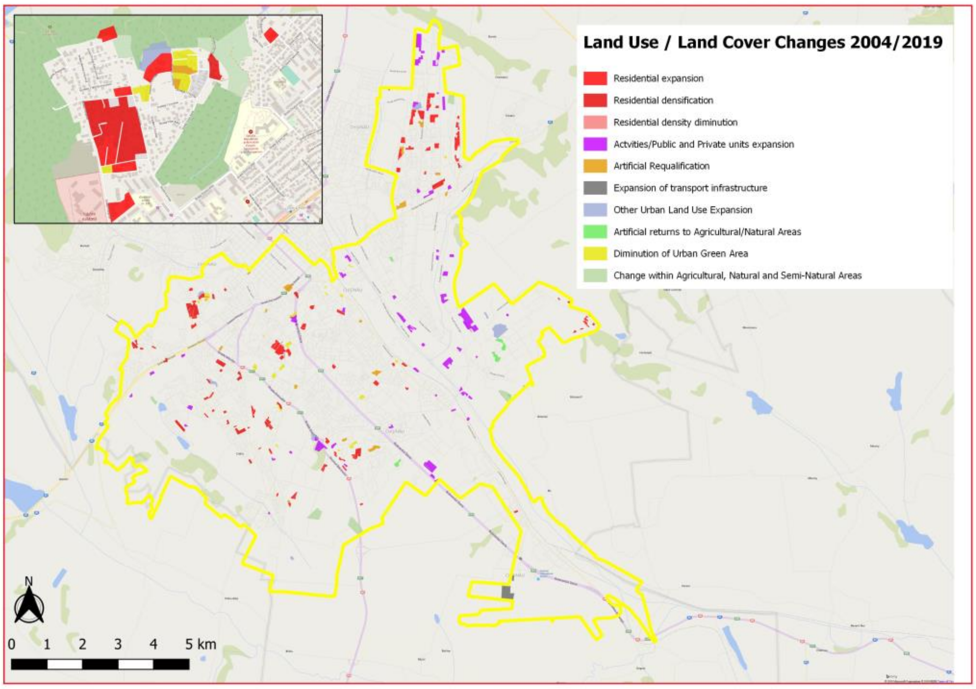


*Figure 7: LULC changes occurred over the period 2004-2019*

### 3.1.3 Usage, Limitations and Constraints

Satellite-derived Land Use Land Cover information offers a strong baseline for implementing a wide range of indicators and analyses for addressing many challenges and supporting smart city development and investment. It provides quantitative information for a better understanding of the structural characteristics of a given city area and its change dynamics over time. This kind of data provide relevant support in decision-making for land use planning which generally requires to consider many challenges related to population mobility or urban development in a sustainable way.

The LULC product generated through Service 1 is aligned with the European Urban Atlas and allows deeper insight on the urban areas and change dynamics through the years. Analyses related to urban sprawl and detailed change trends occurring within the urban extent can be conducted easily. Such product can also be used as a basis for developing indicators relevant for assessing and monitoring the situation such as the proportion of urban green areas or sport and leisure facilities per inhabitant, or the access to public transportation or green areas among other urban challenges. Finally, it is also an efficient tool to compare the city with other neighbouring and similar cities within the area covered by the European Environment Agency (EEA) 39 member and associated countries.

The limitations and constraints are mainly related to the technical specifications of the product. Especially the thematic classification and the exploitation scale (1:10,000) imply to use it for disseminating information and analysis results for building blocks or homogeneous LULC units at city or district level. However, the LULC information combined with other data can be used for conducting further analyses and generating meaningful indicators for supporting the decision-making in land use planning in a sustainable way:

- Population distribution using local census data and even cadastral building footprints for disaggregation at the finest level (Service 2)
- Access to urban green areas and/or sport and leisure facilities using topologically consistent road network for calculating the best routes from residential units (walking distance and time, proportion of inhabitants with easy/fast access) allowing to determine which populated areas/districts would require development investments

- Access to public transport facilities using topologically consistent road network and local data providing the location of the facilities (bus stops, metro/tram/train stations, etc.) for calculating the best routes from residential units (walking distance and time, proportion of inhabitants with easy/fast access) allowing to determine which populated areas/districts would require development investments

## 3.2 Service 2 – Census-Based Population Distribution

Common population statistics provide aggregated numbers on the inhabitants of an administrative unit based on their place of residence. Such statistical data convey the wrong impression of a uniform population density within an administrative unit (e.g. city district, but including uninhabited places like green spaces, industrial complexes or road infrastructure), and therefore does not provide a ‘real-world’ representation of where people live within this unit.

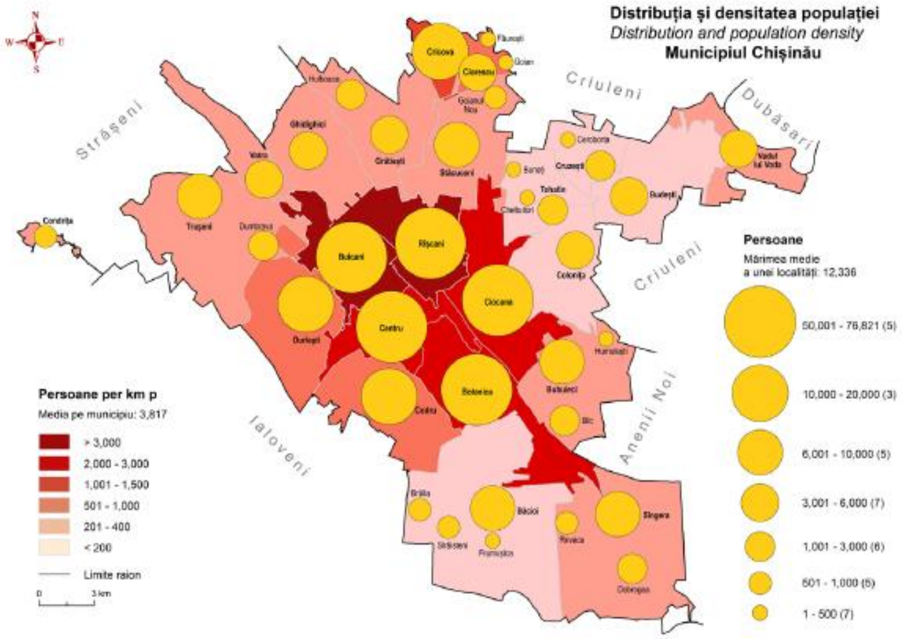


*Figure 8: Aggregated population statistics of Chişinău Source: National Bureau of Statistics of the Republic of Moldova (http://recensamant.statistica.md/en/maps/districts)*

Services 2 spatially disaggregates census-based population data to achieve a more accurate map of the actual spatial distribution of the Chișinău’s residential population. The service allocates residents to inhabited areas which provides a far better basis for subsequent urban development and mobility analyses.

### 3.2.1 Specifications

The product delivers a population density grid with 10 m grid cell size for the specific years 2004 and 2014. In order to guarantee a seamless provision of key information for the support of the mobility trend analysis (Service 3) a population density raster for the most recent date (2019) has been produced. Moreover, thanks to the availability of building footprints, population estimates are also provided on building block level.

Data input (cf. chapters 4.4-4.5 for a detailed discussion on data suitability)

- Land use and land cover information (Service 1)
- Census data / Administrative Boundaries on district level
- Building footprints

Method

In order to spatially disaggregate Chișinău's population to more realistic smaller spatial units, a dasymetric spatial method was applied based on the GeoVille's EO-STAT model[1]. For the case of Chişinău, aggregated statistical data on population numbers on district level were used and the LULC data generated in service 1 were applied to resemble the actual spatial location of residential areas.

For the analysis of population patterns and density within a district, the allocation of the residential (=night-time) population within the district to the areas of residential housing was necessary. Therefore, the available census data for the corresponding years were spatially disaggregated based on the LU information from Service 1.

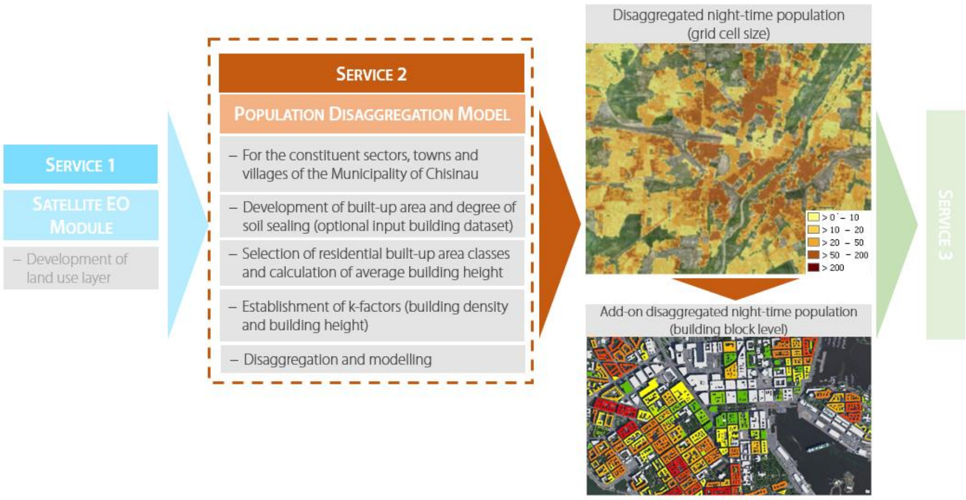


*Figure 9: Schematic diagram of the EO-STAT population disaggregation modelling*

The LULC dataset from service 1 was enriched with the building footprints and the building height information from the cadastral building database. The sealed surface was calculated for 2004, 2014 and 2018.

For the disaggregation of the population, two different mapping approaches have been applied:

1. *Population allocated to the land cover class "Urban Fabric" (produced in Service 1).*
2. *Population allocated to building footprints*

For both methods, the degree of sealing was determined:

> Approach 1: The sealing density of each LC polygon was determined by calculating the percentage of residential buildings within the total polygon area.
>
> Approach 2: The sealing density of each grid cell covered by residential buildings was calculated by intersecting the building footprints with the raster cells.

Afterwards, the mean building height was determined for each LC polygon (Method 1) and grid cell (Method 2). The following population disaggregation was done by calculating the k-factors for each administrative unit (e.g. districts), which were then used as weights for disaggregating the population to the raster cells.

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[1] EO-STAT project (ESRIN/Contract No. 18713/05/I-LG), PopLoc project (ESRIN/Contract No. 22197/09/I-OL), AgeSpot Feasibiltiy project (4000121369/17/UK/ND) and AgeSpot Demonstration project (4000126408/19/NL/FGL), DECUMANUS project (European Commission, FP7 607183)

k-factor = population / (sealing density * avg. building height)

population = sealing density * avg. building height * k-factor

To summarize, the first method averages the population density over the whole area of each LC polygon, while for the second approach only the raster cells covered by residential buildings are used to disaggregate the population.

Quality Control and Validation

The validation of the disaggregated population data quantifies the degree to which the spatially refined distribution of the population meets the truth. Automated checks were implemented in the workflow to guarantee that the disaggregated population numbers, once aggregated back to their original statistical units, equal the input census data (the so-called ‘pycnophylactic integrity’). Validation with higher resolution population data through statistical measures such as the mean absolute error and root mean squared error was not possible due to the lack of more detailed (i.e. better than district-level) actual census and address data. Furthermore, the files were compared for alignment and consistency regarding spatial resolution (10m), extent and coordinate reference system (EPSG 4026; MOLDREF99).

### 3.2.2 Outputs

The output of Service 2 is a residential population density raster with a spatial resolution of 10m for the years 2004, 2014 and 2018:

- Population grids in GeoTiff format or any other compatible GIS raster format. For representing the spatial distribution of the local population, two product levels are available.
    - Population allocated to the land cover class "Urban Fabric" (produced in Service 1) –population density is averaged over the whole area of each LC polygon
    - Population allocated to building footprints – population density averaged per building polygon
- INSPIRE compliant metadata .xml files
- A summary report with statistics is provided under service 3 (chapter 3.3.2.2)

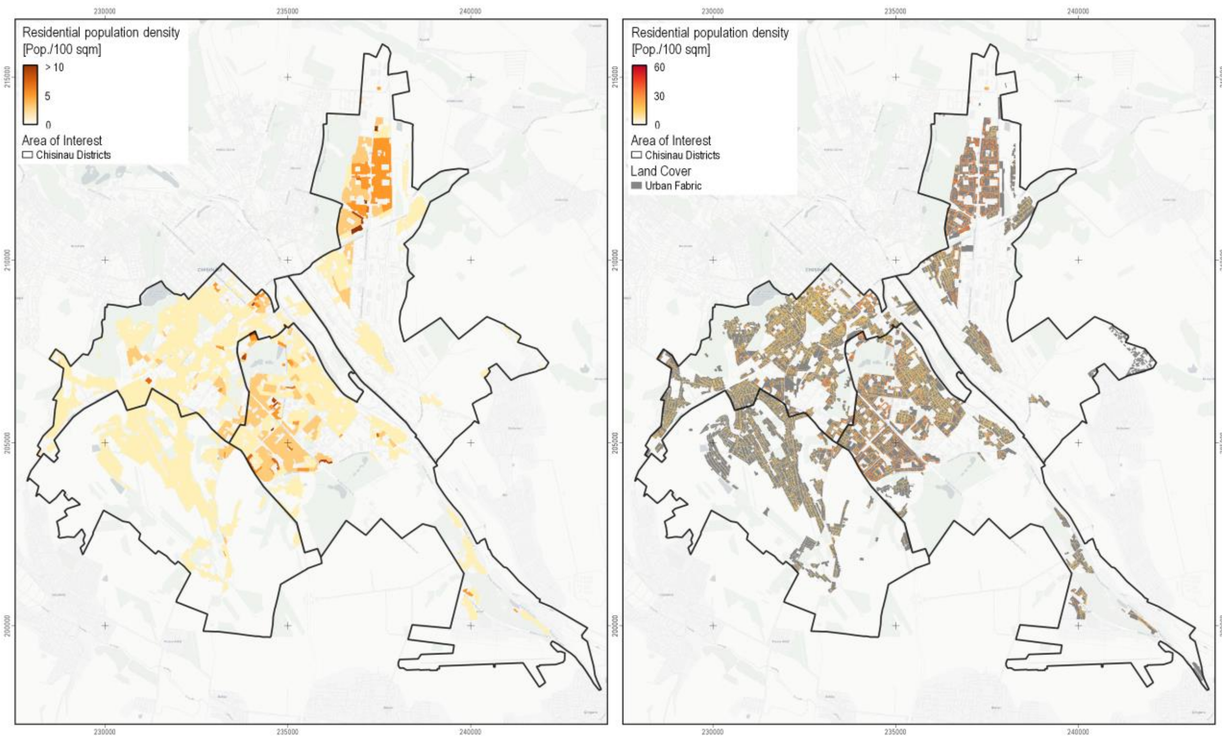



*Figure 10: Detailed population estimates for the AOI based on LC polygons (left) and residential buildings (right)*

### 3.2.3 Usage, Limitations and Constraints

Residential population density data can be used as input for further geospatial analysis, such as migration of population within a city or mobility behaviour analysis.

Limitations for the population disaggregation are the availability of georeferenced census data on district or sub-district level and, in case not available from service 1, the land cover / land use classification that is used to exclude all non-residential areas. If available, building footprints and corresponding height information improve the result, as the space to disaggregate the population is on one side reduced two-dimensionally by excluding all non-built up areas (e.g. green urban areas between buildings), and on the other side expanded to three dimensions by including the height information. Further data, e.g. on energy consumption per house, could further improve the results.

## 3.3 Service 3: Case Study Definition and First Insights into Recent Population and Mobility Trends

> *"Chişinău suffers from chronic traffic jams, road infrastructure is overburdened, public spaces and sidewalks degrade due to illegal parking, and the air pollution level is steadily rising. It is necessary to rethink the transport network so that we can offer safe and comfortable alternatives to Chişinău either by public transport, by private transport, by bicycle or by walking,"*
>
> Inga Podoroghin, Programme Specialist, Energy & Environment, UNDP programme[1]

Service 3 builds on the previous two services and considers additional resources to support the UNDP Moldova with use cases and analyses of the overall situation in Chișinău. Questions of highest interest identified together with UNDP were the following:

- What are the trends in urban development and where are major changes in the urban landscape?
- What are trends in population size and density over the considered area?
- What is a recent typical daytime and nighttime distribution of the population and what is the mobility behavior of the population?
- Where are the hotspots of urban congestion and what are the associated infrastructure gaps?
- Which portion of the population has convenient access to public transport?
- What are the trends of the population accessing natural and urban green areas, for recreational or other purposes?

Out from these policy questions, we have designed a set of use cases demonstrating how EO- and non-EO data can be combined. The aim of the analysis is to support decision-making for urban development and mobility planning and deliver fact-based decision support to e.g. plan for public service provision, locate problem areas, safeguard public investments, assess vulnerabilities, and ensure sustainable expansion. Service 3 thereby provides initial analyses to identify trends in the development of the urban fabric in the past 15 years, recent development of the population patterns and a first set of indicators regarding urban mobility and living environments.

### 3.3.1 Specifications

Service 3 encompasses a set of use cases in response to selected issues relevant for urban development and mobility planning in Chișinău. Relevant input data, the applied methodology as well as current drawbacks and limitations are explained. **It has to be noted that, in accordance to the service request to ESA, these initial cases are preliminary, under given data availability and with only brief descriptions of the generated insights. Those preliminary results might be, as an extension to the current Technical Assistance, further developed to a more integrated solution in close collaboration with UNDP and other stakeholders.**

[1] http://www.md.undp.org/content/moldova/en/home/presscenter/pressreleases/2019/chi_in_ul-va-avea--in-premier--un-plan-de-mobilitate-urban.html

Data input (cf. chapters 4.6-4.7 for a detailed discussion on data suitability)

Service 3 is ingesting a heterogeneous set of data sources and analyses are based on a fusion of the outputs from Service 1 (Land Cover / Land Use) and 2 (Census-based population distribution) with a range of additional data resources, such as available Call Record Detail (CDR) data from telecommunication providers.

- LU and LC information for 2004, 2014 and 2018 from Service 1
- Residential population for 2004, 2014 and 2018 on building level from Service 2
- Call Detail Record (CDR) data
- Routable network (streets, paths, public transport lines, railways)

Method

For the first two use cases presented in chapter 3.3.2.1 and 3.3.2.2, GIS-based analytical operations were performed to derive statistics on land use composition and changes thereof (based on service 1 inputs) as well as the population distribution and changes in population density (based on service 2 inputs).

In order to move into the urban mobility domain, a wide variety of models are available for an analysis of the performance and connectivity of an urban transportation network. In the present case, two main analyses were performed:

- a CDR data and road-network based mobility and day-time population estimation (with outputs described in chapter 3.3.2.3) and
- a service area network analysis to identify bottlenecks in current infrastructure capacity (results summarized in chapter 3.3.2.4).

*CDR data analysis*

The first step of the CDR analysis was to clean the dataset of irrelevant entries outside of the area of interest and to filter out inactive antennas with no records. Secondly, the location of a telecommunication event was approximated by using a *Voronoi tessellation* of the area, as depicted in Figure 3Figure 11. Based on this segmentation an activity analysis for four different time windows during the day was performed which highlights regions and districts and their changing population movement during day/night – an indicator for the inter- and intra-district population flow.

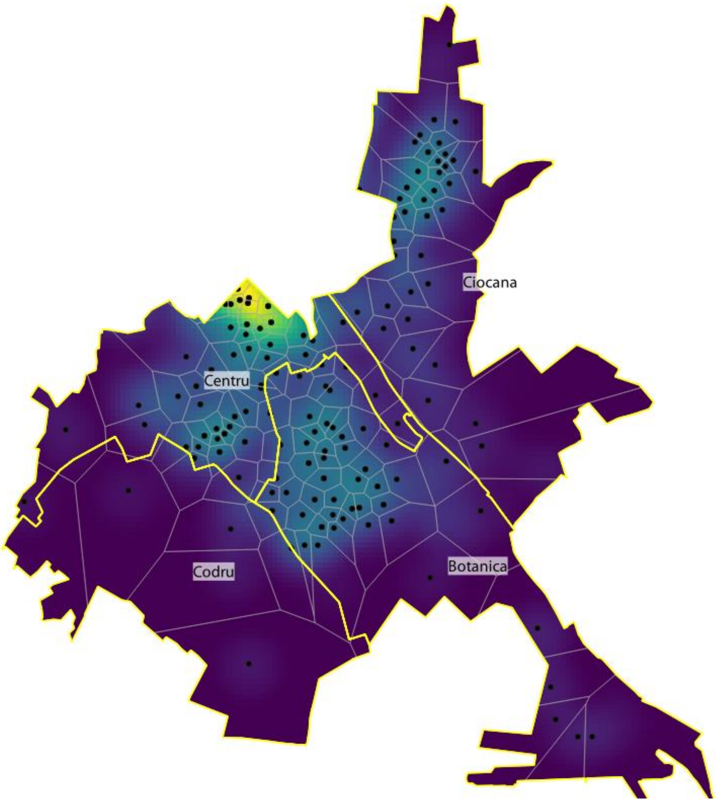



*Figure 11: Voronoi tessellation of the area of Chişinău from 2019 cleaned CDR test data. Black points indicate antennas, grey lines are boundaries of derived antenna service regions and the background colour (from blue to yellow) indicates the density of the antennas (from low to high).*

In a next step, the movement of CDR agents (single persons) was analysed in more detail. For each activity the closest road was identified and the fastest path through a refined road network to the next activity entry of the same agent was calculated. This analysis yields more detailed insights into movement patterns and pinpoints precisely to roads and areas that are heavily used. This information is of great value for capacity assessments and an invaluable basis for urban development plans and transportation networks to for example minimise traffic congestions or optimize the public transport network.

*Service area network analysis*

The road network is the basis for a service area network analysis. Two different datasets were used, the provided dataset by the Municipality of Chişinău as well as an OSM dataset. A point vector layer with bus stations in the city of Chişinău was furthermore provided and used as input.

With these datasets a line vector layer was created and a network with all lines within a specified distance based on each bus station. Convex hulls were generated from the output to show the service area of all bus stations. These polygons were created for three different distances, 250, 500 and 750 meters.

### 3.3.2 Outputs

The outputs from Service 3 are specific to the use cases presented below. Narrative descriptions of the analytical outputs can be found in chapters 3.3.2.1-3.3.2.6, and for each use case a dedicated set of maps is delivered in PDF format.

#### 3.3.2.1 Use Case: Long-term evolution of land use and fragmentation patterns

Outputs from service 1 have been used to perform a statistical analysis of the long-term changes of urban land use in Chișinău.

The AOI is mainly covered by artificial areas (64%) while the agricultural and natural areas are also well represented (respectively 23% and 12%). Figure 13 shows the relative distribution of LULC thematic classes within the artificial areas (class 1 at level 1 of the nomenclature) expressed in %.

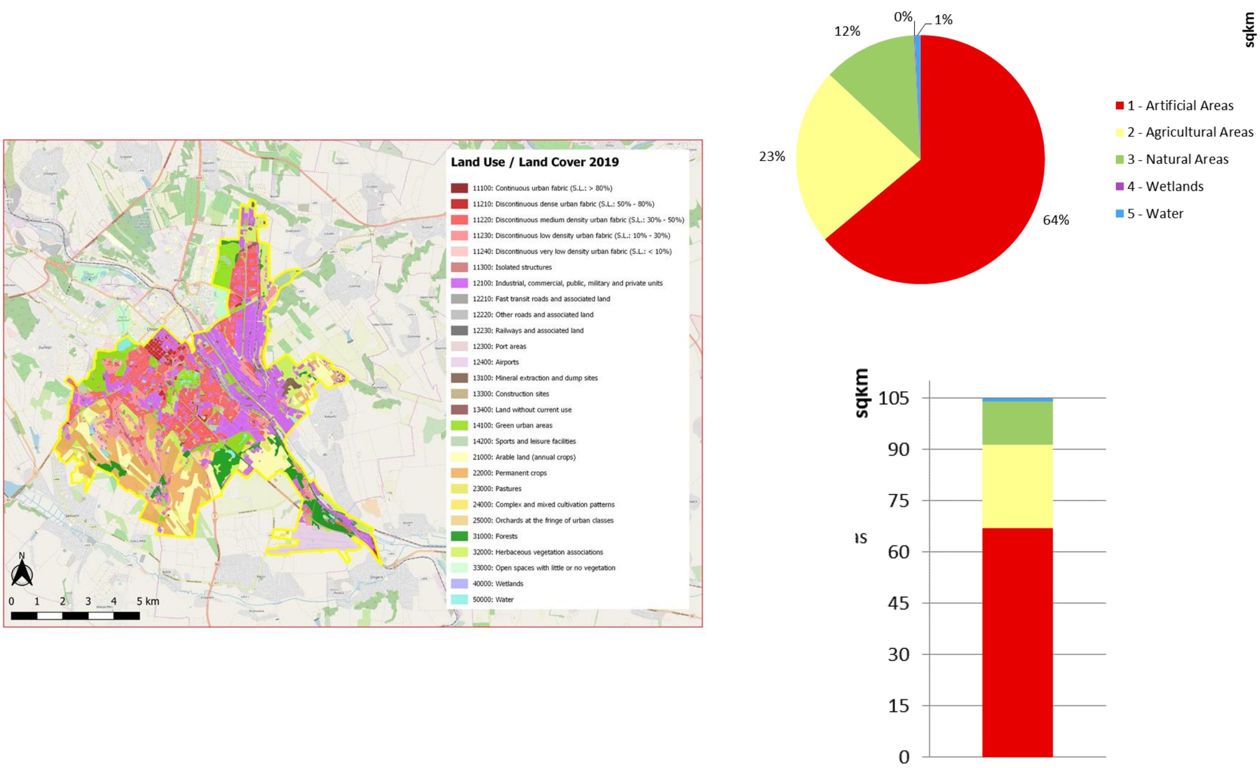



*Figure 12: Land Use Land Cover 2019 structure (level 1) presented as Overall in % (top right) and km² (bottom right)*

Detailed composition of the urban LULC is depicted in the figure below. It is worth to highlight that the LULC within the urban area extent is characterised by three main categories present in equal parts:

- Urban fabric units (34%) whose use is mainly residential; the built-up density is mainly low or medium for this part of the municipality which includes only a portion of the city centre and lots of residential pavilion areas in the suburbs.
- Industrial and commercial areas (32%) cover a significant part of the study area, particularly in the eastern sector along the railway lines.
- The remaining artificial areas are mainly related to the transportation infrastructure including roads, railways and the airport (15%) or green and recreational spaces (15%).

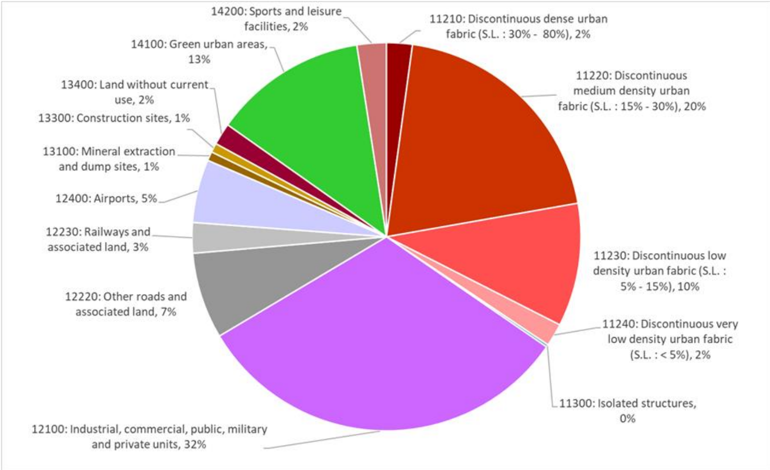



*Figure 13: Detailed LULC 2019 within the artificial areas expressed in %*

The LULC change maps gives insight into the urban dynamics of the last 15 years:

- Urban expansion is the most significant trend, especially:
    - Residential area expansion or densification
    - Industrial and commercial area expansion (including also potential public or private units)
- Changes are homogeneously distributed over the study area
- Urban change types are correlated with the immediate environment, i.e. new residential areas settled close to the existing ones and this is also true for industrial / commercial areas.

Figure 14 confirms this analysis:

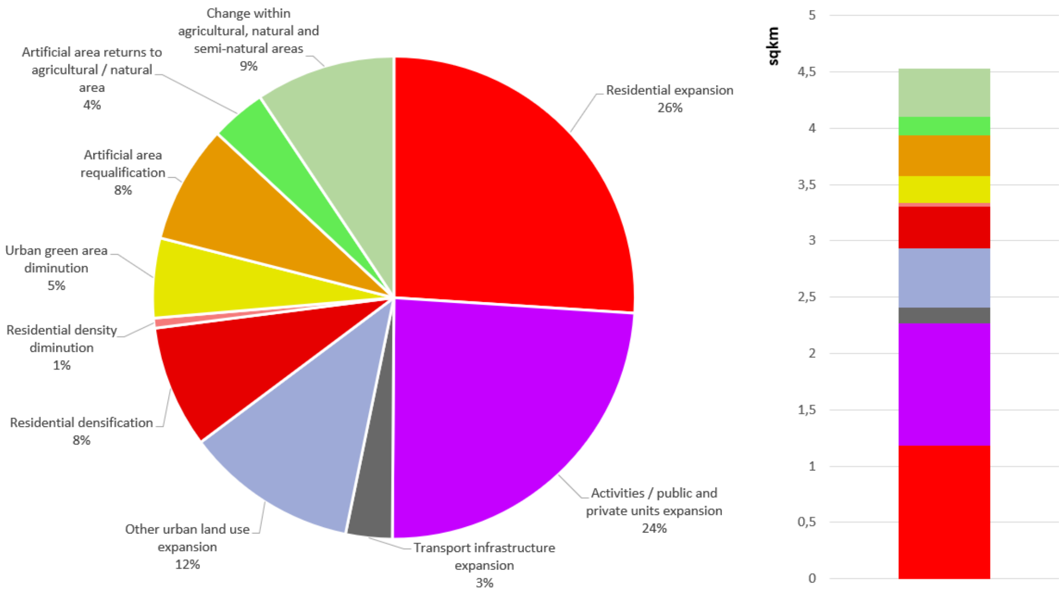



*Figure 14: Land Use Land Cover Changes 2004–2019 presented as Overall in % (left) and km² (right)*

- The overall change area is equal to 4.5 sqkm which represents 4.32% of the total AOI (104.8 sqkm).
- Urban expansion represents the most significant trend (64.8%, i.e. 2.9 sqkm) including mainly:
    - New residential areas (26%, 1.18 sqkm)
    - New industrial, commercial, public or private units (24%, 1.09 sqkm)

- Internal urban dynamics are relatively low (22.1%, 1 sqkm) but two main change types at least can be pointed out:
    - Built-up density within existing residential units can vary but the main trend is clearly in favour of residential densification (8%, 0.3 sqkm) while residential density diminution (1%, 0.03 sqkm) is a phenomenon occurring rarely.
    - Urban green areas have been tending to shrink (5%, 0.24 sqkm).
- The last category of changes that seems relevant to highlight concerns changes outside artificial areas, between agricultural, natural and semi-natural surfaces (13%, 0.59 sqkm).

Finally, Table 3 provides the area and percentage of total area that represents each class in 2019, 2014 and 2004 as well as its evolution over time. The area statistics of the LULC classes confirm the preliminary analysis in terms of change dynamics. Indeed, **artificial areas in general, and urban fabric units (corresponding to residential use most of the time) especially, significantly increased over the period**. Otherwise, the **city tends to be denser** as for example the "Discontinuous very low-density urban fabric units" are decreasing (-8.0% from 2004 to 2019) for the benefit of more densely built-up urban fabric units. This trend is logically accompanied by an **increase of construction sites** (0.51 km², +52.4%). The **new urban areas tend to be gained from the "Land without current use" (-46.9%) but also from agricultural and natural areas** such as "Herbaceous vegetation associations" (-9.2%) and "Pastures" (-8.3% in 15 years).

Looking at the two different periods separately, i.e. 2004-2014 and 2014-2019, **it does not reveal a significant evolution or change in terms of dynamics**, neither regarding change occurrence, extent and spatial distribution nor considering change types.

*Table 3: Detailed information on area and percentage of total area for each class in 2019, 2014 and 2004 as well as its evolution over time*

| **Class** | | **Area (sqkm)** | | | | | | **% Evolution** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Code** | **Designation** | **2019** | **%** | **2014** | **%** | **2004** | **%** | **2004-2014** | **2014-2019** | **2004-2019** |
| **11210** | Discontinuous dense urban fabric (S.L.: 50% - 80%) | 1.43 | 1.4% | 1.43 | 1.4% | 1.32 | 1.3% | 8.7% | 0.1% | 8.8% |
| **11220** | Discontinuous medium density urban fabric (S.L.: 30% - 50%) | 13.46 | 12.8% | 13.33 | 12.7% | 12.75 | 12.2% | 4.6% | 1.0% | 5.6% |
| **11230** | Discontinuous low density urban fabric (S.L.: 10% - 30%) | 6.88 | 6.6% | 6.76 | 6.5% | 6.35 | 6.1% | 6.5% | 1.7% | 8.3% |
| **11240** | Discontinuous very low density urban fabric (S.L.: < 10%) | 1.27 | 1.2% | 1.27 | 1.2% | 1.38 | 1.3% | -8.1% | 0.1% | -8.0% |
| **11300** | Isolated structures | 0.14 | 0.1% | 0.13 | 0.1% | 0.12 | 0.1% | 6.4% | 6.0% | 12.8% |
| **12100** | Industrial, commercial, public, military and private units | 21.34 | 20.4% | 21.25 | 20.3% | 20.36 | 19.4% | 4.4% | 0.4% | 4.8% |
| **12220** | Other roads and associated land | 4.81 | 4.6% | 4.81 | 4.6% | 4.80 | 4.6% | 0.2% | 0.0% | 0.2% |
| **12230** | Railways and associated land | 1.70 | 1.6% | 1.70 | 1.6% | 1.70 | 1.6% | 0.0% | 0.0% | 0.0% |
| **12400** | Airports | 3.53 | 3.4% | 3.53 | 3.4% | 3.39 | 3.2% | 3.9% | 0.0% | 3.9% |
| **13100** | Mineral extraction and dump sites | 0.51 | 0.5% | 0.49 | 0.5% | 0.39 | 0.4% | 24.6% | 4.5% | 30.2% |
| **13300** | Construction sites | 0.51 | 0.5% | 0.20 | 0.2% | 0.34 | 0.3% | -39.9% | 153.7% | 52.4% |
| **13400** | Land without current use | 1.22 | 1.2% | 1.58 | 1.5% | 2.30 | 2.2% | -31.3% | -22.7% | -46.9% |
| **14100** | Green urban areas | 8.55 | 8.2% | 8.60 | 8.2% | 8.84 | 8.4% | -2.8% | -0.5% | -3.3% |
| **14200** | Sports and leisure facilities | 1.64 | 1.6% | 1.63 | 1.6% | 1.68 | 1.6% | -2.5% | 0.1% | -2.4% |
| **21000** | Arable land (annual crops) | 9.11 | 8.7% | 8.96 | 8.6% | 9.09 | 8.7% | -1.5% | 1.7% | 0.1% |
| **22000** | Permanent crops | 11.41 | 10.9% | 11.64 | 11.1% | 11.62 | 11.1% | 0.1% | -2.0% | -1.8% |
| **23000** | Pastures | 2.49 | 2.4% | 2.52 | 2.4% | 2.72 | 2.6% | -7.3% | -1.0% | -8.3% |
| **24000** | Complex and mixed cultivation patterns | 1.12 | 1.1% | 1.13 | 1.1% | 1.19 | 1.1% | -5.5% | -0.7% | -6.2% |
| **31000** | Forests | 5.04 | 4.8% | 5.06 | 4.8% | 5.08 | 4.8% | -0.4% | -0.4% | -0.8% |
| **32000** | Herbaceous vegetation associations | 7.73 | 7.4% | 7.83 | 7.5% | 8.51 | 8.1% | -8.0% | -1.3% | -9.2% |
| **40000** | Wetlands | 0.11 | 0.1% | 0.11 | 0.1% | 0.11 | 0.1% | 0.0% | 0.0% | 0.0% |
| **50000** | Water | 0.78 | 0.7% | 0.81 | 0.8% | 0.72 | 0.7% | 12.8% | -3.8% | 8.5% |
| **Total** | | **104.77** | **100%** | **104.77** | **100%** | **104.77** | **100%** | - | - | - |

#### 3.3.2.2 Use Case: Trends in population size and density

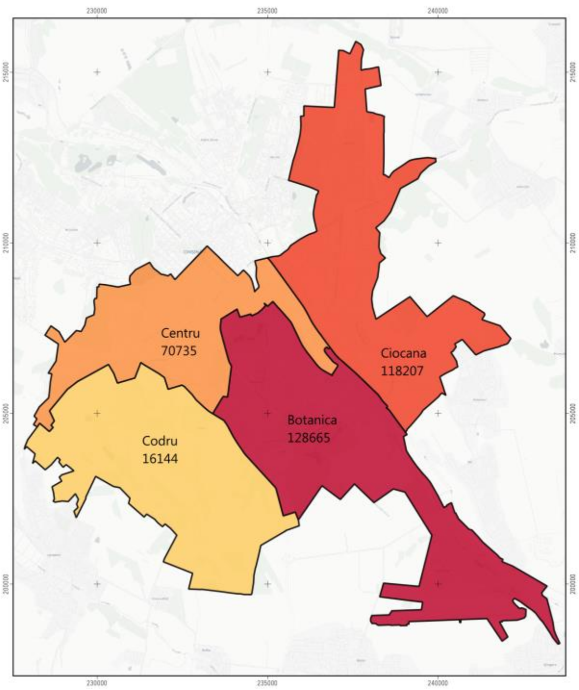
According to the official census data, the total population in the AOI developed as follows:

*Table 4: Population trends in selected districts between 2004 and 2018.*

| District | 2004 | 2014 | 2018 | 2004 - 2018 (absolut) | 2004 - 2018 |
|---|---|---|---|---|---|
| **Botanica** | 178.860 | 123.845 | 128.665 | -50.195 | 28,1% |
| **Codru** | 14.277 | 15.324 | 16.144 | +1867 | 13,12% |
| **Centru** | 90.494 | 68.301 | 70.735 | -19.759 | 21,8% |
| **Ciocana** | 125.659 | 113.780 | 118.207 | -7452 | 5,9% |

In general, it can be stated, that in contrast to the wider Municipality area, the total population numbers in the covered districts are decreasing between 2004 and 2018, "except Codru" where the population increased. Thanks to the spatial disaggregation performed in service 2, the resulting population raster provide a significantly more accurate representation of where people reside.

**Population 2018 on district level (official statistics)**




**Population 2018 on grid level (service 2)**

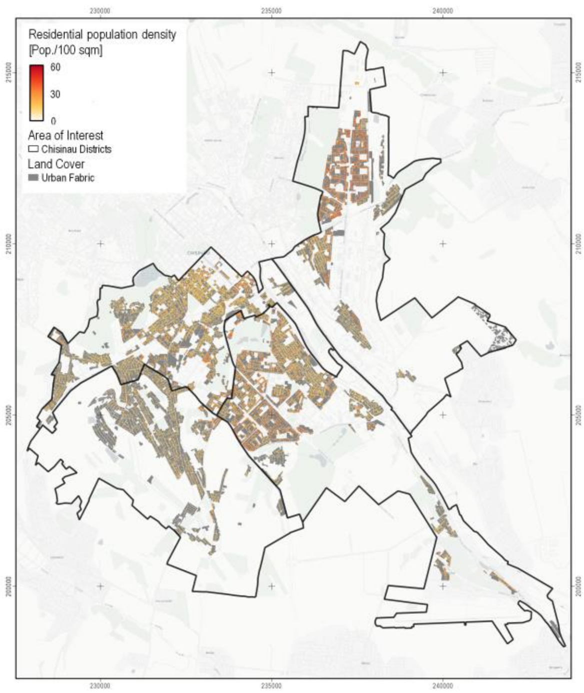



*Figure 15: Population 2018 on district (left) and on grid level (right)*

Figure 16 shows the significant contrast between low population density areas with single-family homes / semi-detached housing, usually characterised by a high portion of green spaces and gardens, and places with a higher population density. The latter are mainly found in the city centre or districts which are classified as medium to high urban fabric areas.

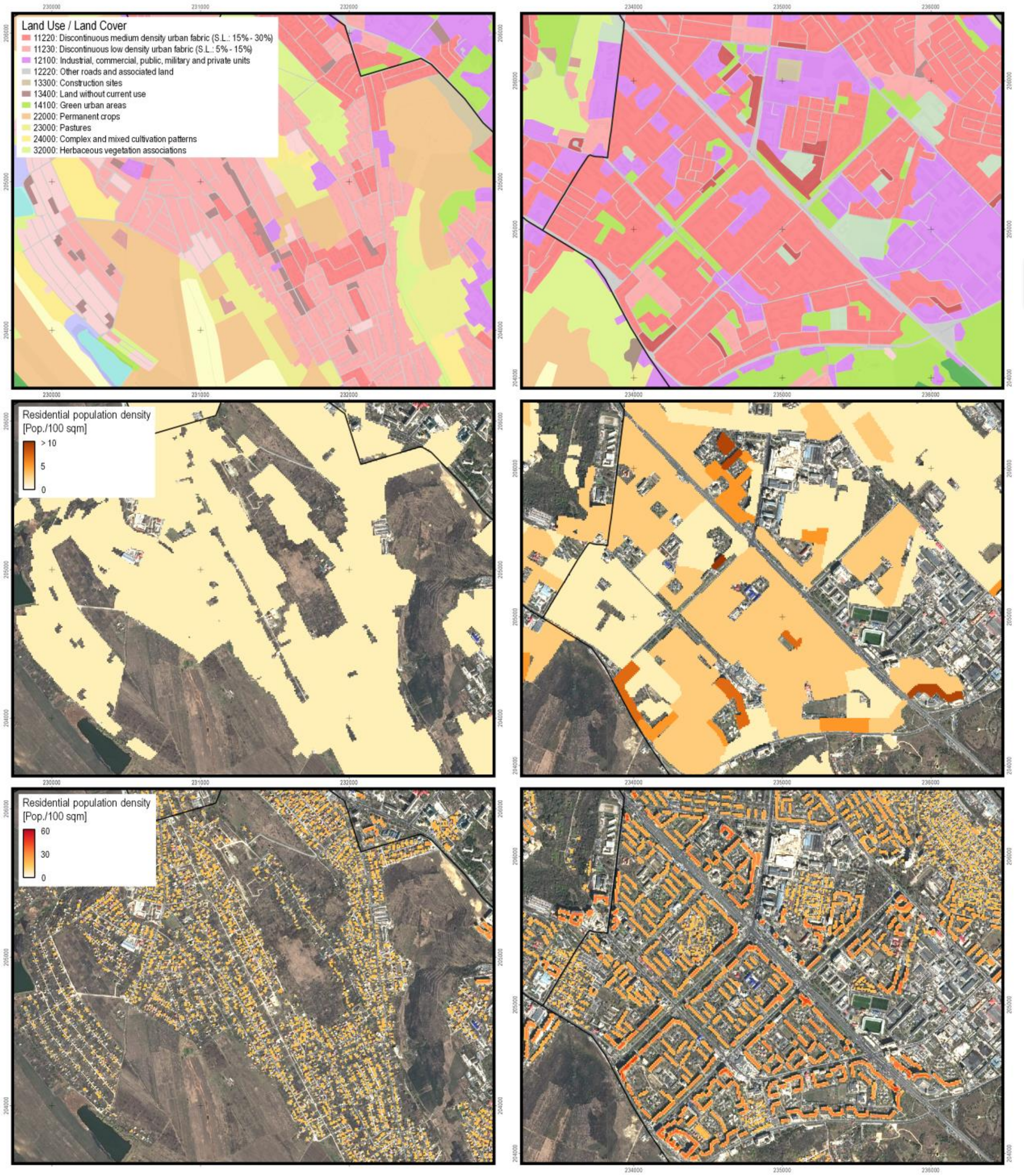



*Figure 16: Comparison of low (left) and high population density areas (right). On the top, the Land Cover Maps of Service 1 are shown.*

To identify population density hot spots, heatmaps with a radius of 500 m around each populated raster cell were created. Within Chişinău, two primary high density areas can be identified, one in central district "Botanica" and the other in the north-eastern district "Ciocana" (Figure 17). The overall decrease in total population can be seen, as well as some growth into new residential zones.

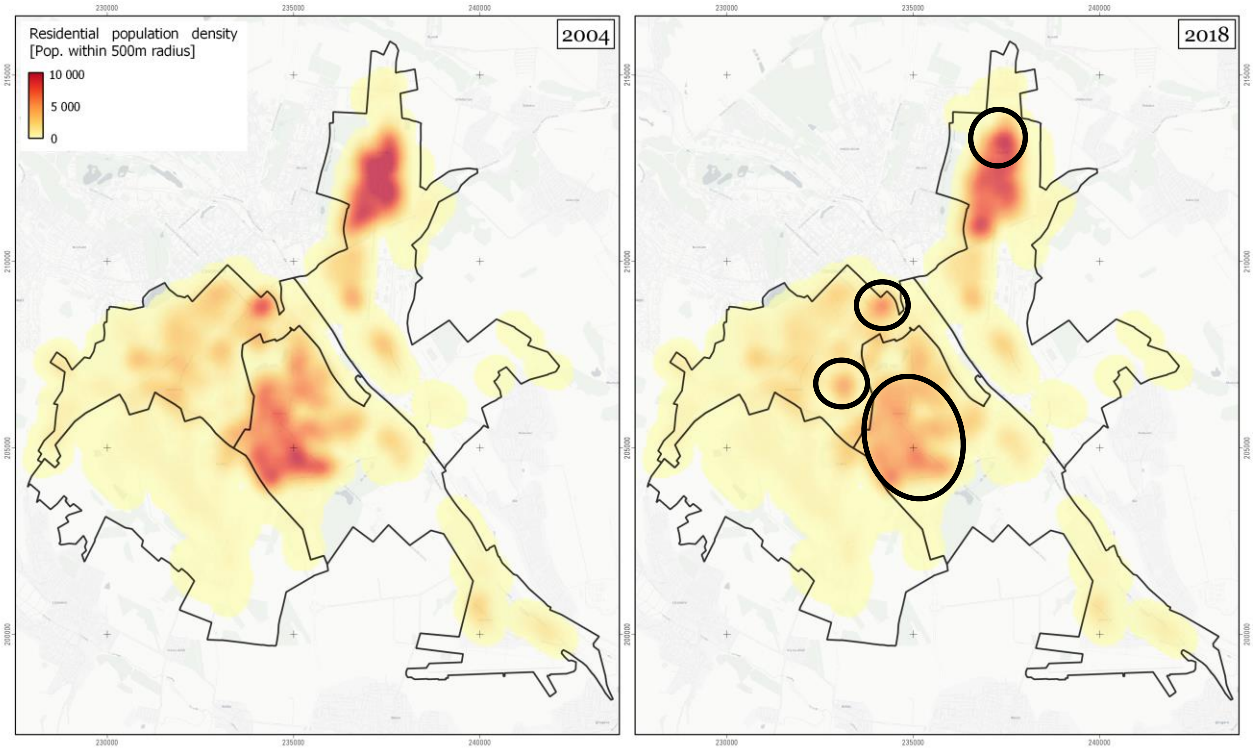



*Figure 17: Night-time population density shown as heatmap for 2004 (left) and 2018 (right). Major hot spots of change are shown in black circles.*

By comparing the population rasters on building level between 2004 and 2018 in more detail the redistribution of population into new residential areas is even more obvious. This in turn leads to a decrease of population density in older residential zones.


*Figure 18: Residential population distributed allocated to building polygons between 2004 and 2018. New residential areas are shown in black circles.*

In 2018, the average number of square metres per person results in 10 sqm, if only the building footprint is considered. When including the information about the number of floors, the number increases to 44 sqm per person.

#### 3.3.2.3 Use Case: Daytime distribution of the population and intra-day temporal variations

The first output of the analysis of CDR data in the city of Chișinău for the test data set from the 10th of June 2019 gives insights into the telecommunication activity of people per district and modelled sub areas (via a Voronoi tessellation). This analysis shows how busy certain areas in the city are during the day (strictly speaking of course only of those people logged into the telecommunication network of Orange), but represents a **proxy of day-time population distribution**. The derived information can be used to adjust the current public transportation coverage to further target busy areas to increase the service degree. Figure 19 depicts the aggregated activity of people throughout the day and highlights areas in the two busiest districts in Chișinău: "Centru" and "Botanica".

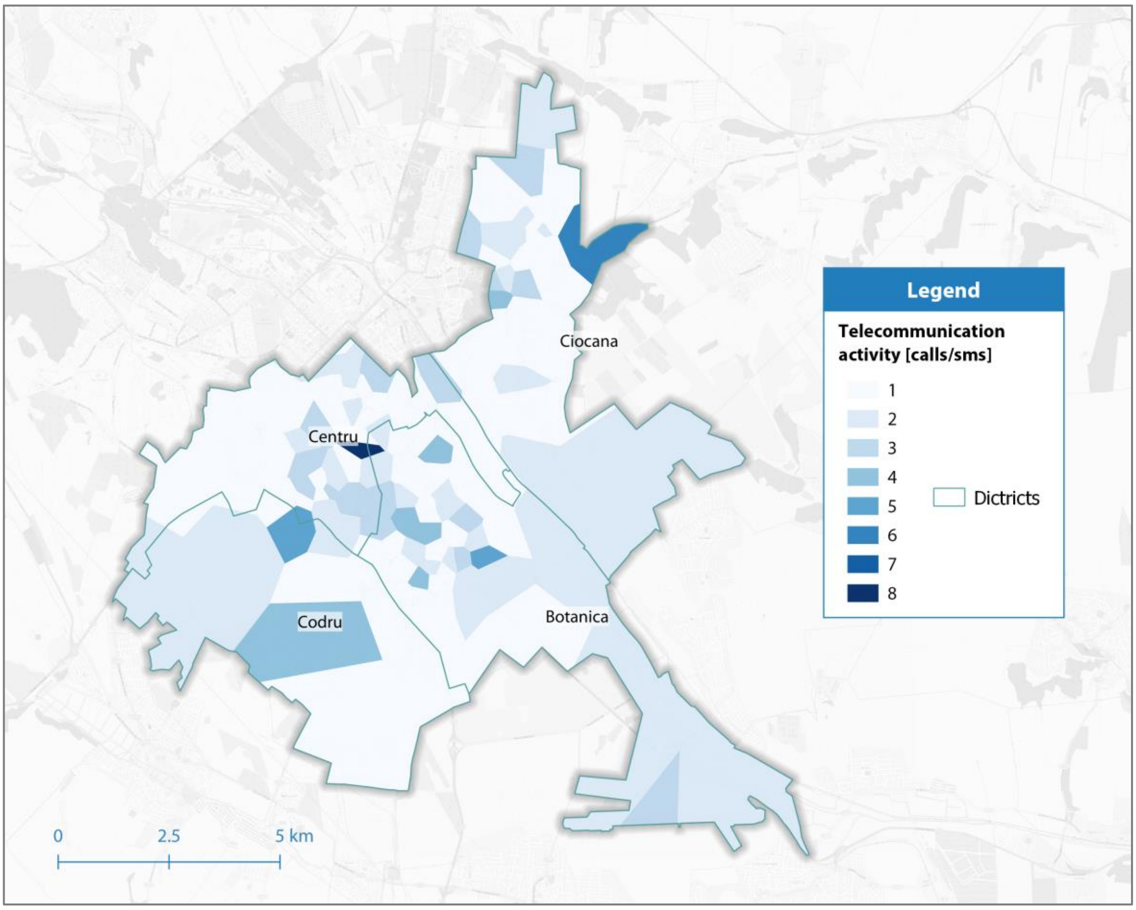



*Figure 19: Aggregated daily telecommunication activity per Voronoi cell in the city of Chişinău based on CDR data for June 24th. Light blue areas indicate areas of low activity, dark blue areas indicate busy areas with high activity throughout the day.*

Especially for mobility planning not only the spatial location and extent of the activity is of importance but also their intensity and temporal variations (peak hours). Therefore, in a next step the aggregation was further subdivided into four time windows each with a length of six hours.

Figure 20 shows the **temporal variation of activities throughout the day** in the city, i.e. where people concentrate during different times of the day. It can be seen that the activity (business) from 06:00 – 12:00 is much higher in the central district "Centru" as compared to surrounding districts. After midday the activity starts to spread out more throughout the city and districts such as "Botanica" and "Ciocana" also start to show high activity.

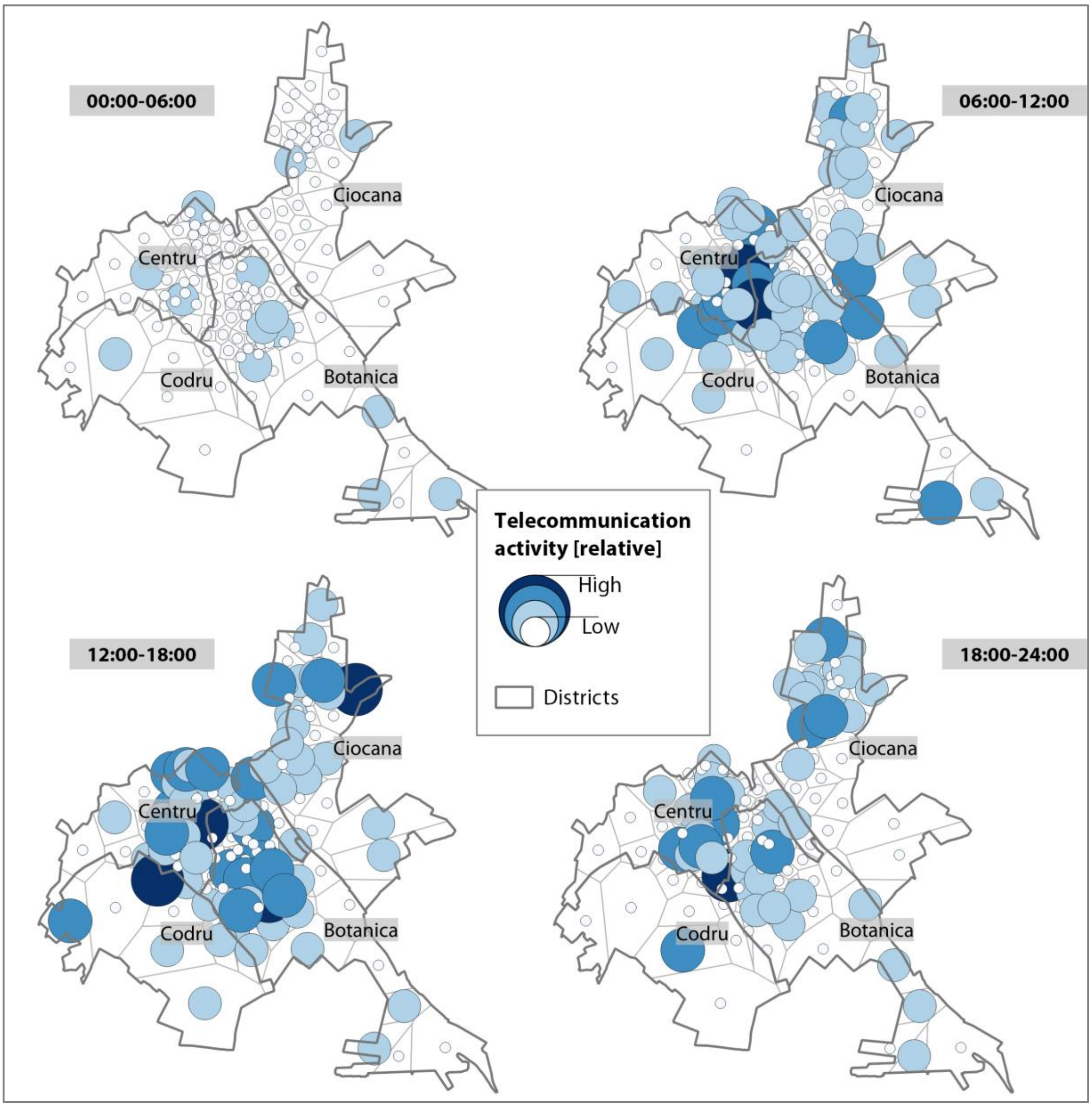



*Figure 20: Aggregated 6 hourly telecommunication per Voronoi cell in the city of Chişinău based on CDR data for one day. Small bright circles indicate areas of low activity, dark large circles indicate busy areas with high activity.*

#### *3.3.2.4 Use Case: Hotspots of urban congestion*

The non-equally distributed activity of people spreading across the city throughout time and space implies that city migration takes place from/to sub-urban residential areas to office buildings and commercial centres in the city. To **highlight the routes of daily intra- and inter (across city boundaries) population flow** the trajectories of the CDR agents were analysed, and the result can be seen in Figure 21. The analysis clearly identifies roads with higher traffic (bright purple colours). These can be considered as the **arterial roads and require special attention for urban development planning** – specially to minimise congestions i.e. through traffic light system optimization. The analysis also clearly uncovers the degree and path of migration inside, into and outside the city and for example shows that there are five to six main roads that are used to enter or exit the city.

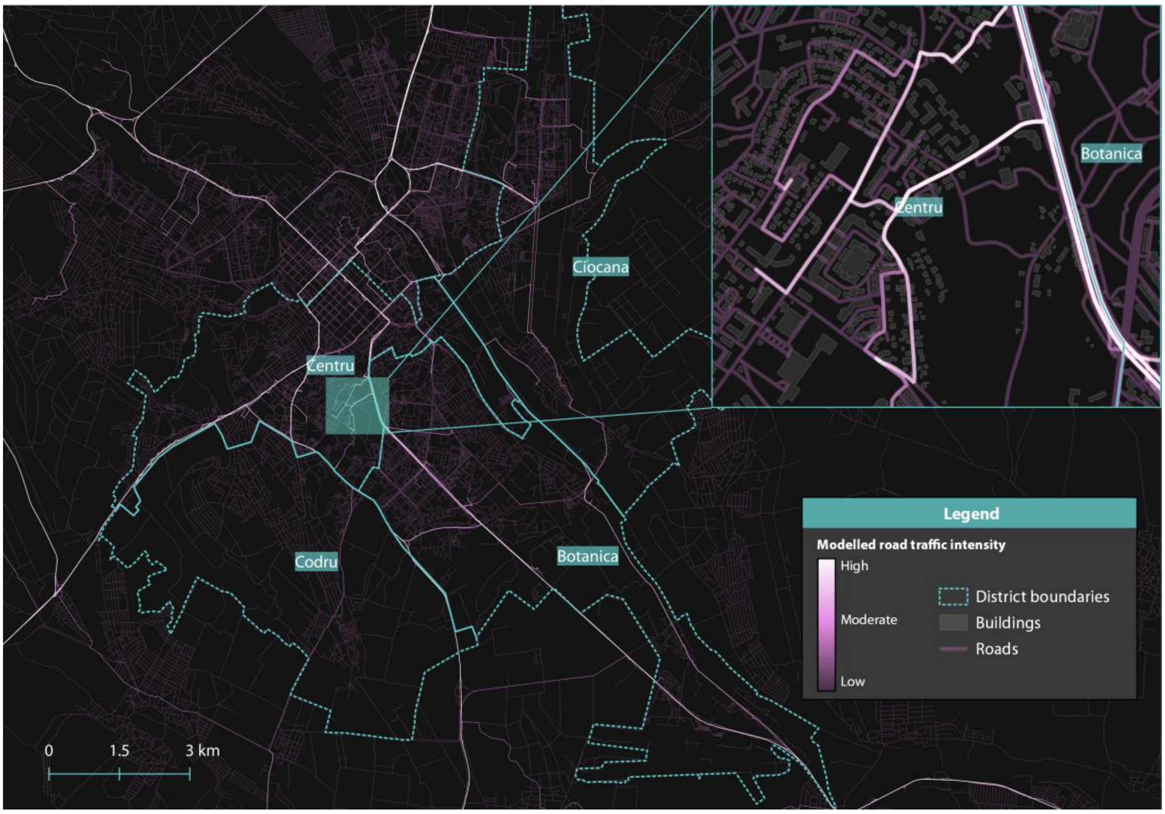



*Figure 21: Modelled road traffic in and around the city of Chişinău based on a subset of CDR data for the 10th of June 2019. Dark lines indicate roads with low traffic, bright lines correspond to roads with high traffic.*

Following that conceptual idea, the **service could be extended to analyse the mobility behaviour of people by overlaying the flow patterns from the CDR data, distinguished according to e.g. time of the day or year, with single transport lines and knowledge of their carrying capacity**, which could reveal if the carrying capacity is sufficient or if bottlenecks in the network infrastructure exist.

#### *3.3.2.5 Use Case: Population without convenient access to public transport*

Through GIS-based service area network analysis, the **degree of public transportation infrastructure availability for the population of Chişinău** (within the area of interest) was analysed. As a basis for the analysis walking distances to the bus stations of 250, 500 and 750 Meters were chosen. Such a network analysis can be done with various types of target locations, such as hospitals, schools or other public services.

The results show the availability of bus stations within the selected area of interest. As shown in

Figure 22, in some city parts the availability of public transport is quite high, especially in the centre of the city. But the analysis also reveals larger parts, especially in the south-western city area, that are not at all connected to the public transport infrastructure.

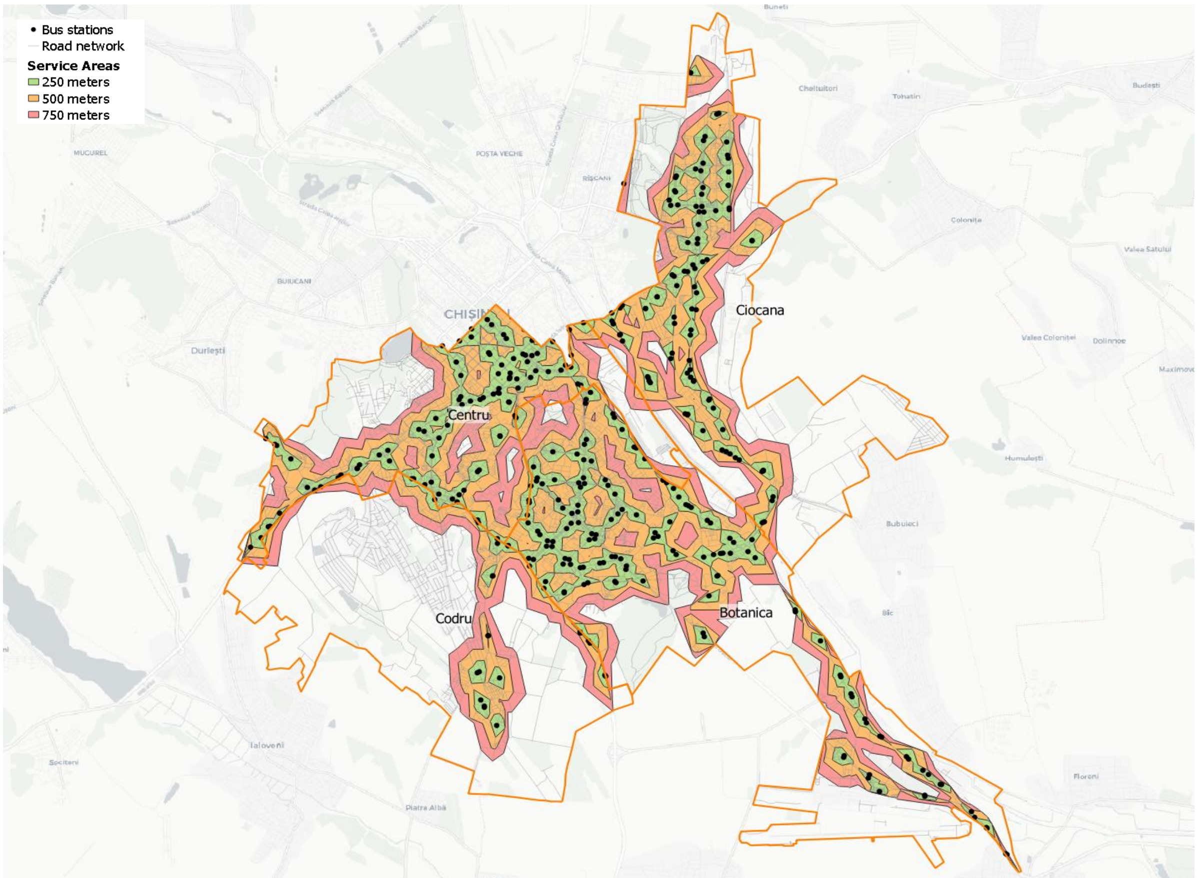



*Figure 22: Service area of bus transport in the city of Chișinău based on an OSM road network. The different colours show the applied walking distances of 250, 500 and 750 meters.*

Table 5 shows the absolute and relative number of people living within those Service Areas. The numbers are calculated based on the residential population derived in Service 2. Based on the calculation it can be stated that around half of the population reaches the next bus stop within 250 m walking distance, another 39 % of the population reaches the next bus stop within 500 m walking distance and about 10% reaches the next bus stop within 500 to 750 m walking distance. Looking at the total area of interest, about 14.800 or 4.5% of the total population are more than 750 m walking distance away from the next bus stop. The south-western part of the "Cordu" district has the poorest connection to public bus system, while being the district with an increase of population numbers (see 3.3.2.2).

*Table 5: Population living within each Service Area.*

| Population | Absolute | % of total population |
|---|---|---|
| **within 250 meters** | 157.091 | 47,1 |
| **within 500 meters** | 130.2019 | 39,0 |
| **within 750 meters** | 31.620 | 9,5 |
| **Outside service area** | 14.821 | 4,4 |
| **total** | 333.751 | 100 |

#### 3.3.2.6 Use Case: Access to natural and urban green areas for recreational or other purposes

Based on the concept of service areas, the access of the population to urban green areas (derived from Service 1) were analysed. Here, a buffer zone with Euclidean distances of 500, 1000 and 1500 meters were used as basic categories for the analysis.

Figure 23 shows that the majority of the population lives within the applied distances. The output reveals that 93,6 percent of the population lives within an distance of 500 to the next green area and almost all of the population lives at least within 1500 meters distance to the nearest green area (see Table 6).

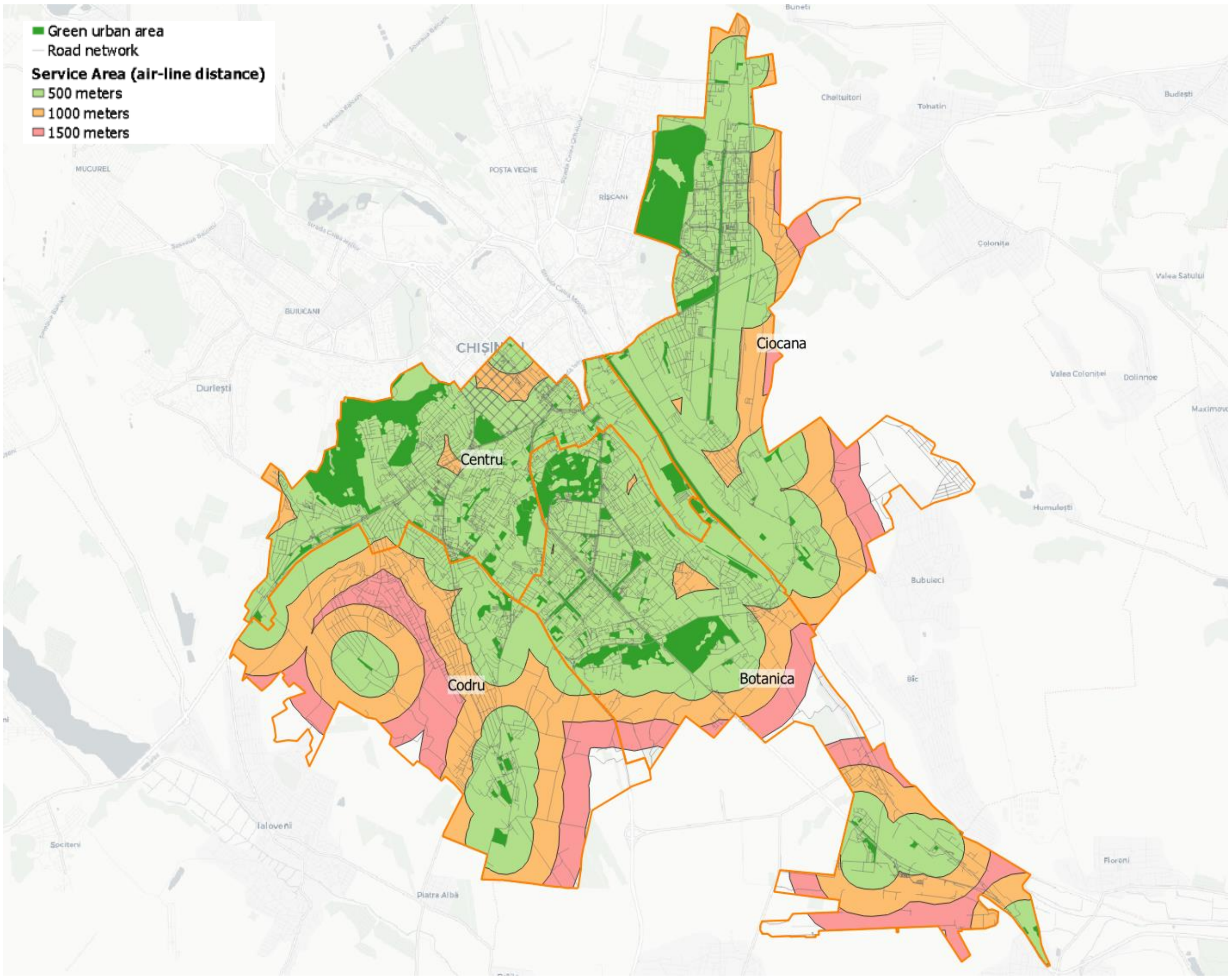



*Figure 23: Access to green urban areas in the city of Chișină. The different colours show the applied distances of 500, 1000 and 1500 meters.*

*Table 6: Population living within each Service Area.*

| Population | Absolute | % of total population |
|---|---|---|
| **within 500 meters** | 312.381 | 93,6 |
| **within 1000 meters** | 187.702 | 5,6 |

| | | |
|---|---|---|
| **within 1500 meters** | 2461 | 0,7 |
| **Outside service area** | 207 | 0,1 |
| **total** | 333.751 | 100 |

### 3.3.3 Usage, Limitations and Constraints

Limitations observed primarily relate to the CDR data which are a widely used data source for the analysis of day-time population, commuting patterns, and for the estimation of exposure or vulnerability of natural disasters. The above provided analyses provide first practical examples on how these data, as received from Orange Moldova, can be effectively used together with satellite derived information and other statistical data to feed into real-world planning applications in the city of Chișinău.

**The analyses represent preliminary examples based on limited test data available for 24 hours on June 10th, 2019. Given more complete datasets spanning over longer periods of time and with a higher number of 'CDR agents', long-term analyses could be performed to locate stable flow patterns of population and, for example, derive occurrence patterns of traffic congestions as a basis for targeted countermeasures.**

It has to be considered that Orange Moldova has a country wide telecommunication market share of more than 60%. Although more than 12.000 antennas are distributed throughout the country, only records for about 1000 antennas were received, from which about 230 antennas are located inside the area of interest. The CDR records were provided for the 10th June 2019 only and give an initial approximation of day-time population movement and mobility patterns. In total 1.200 records of phone calls and text messages are encompassed by the data set, however only about 250 records lie within the area of interest, therefore resulting in a rather sparse data foundation. **To model population flow and activity on a temporarily and spatially more precise level, more data over a longer period of time would be highly beneficial for urban planning applications**. With this dense data set recorded over at least a month, more detailed estimations about the day & night population flow as well as a detailed road traffic analysis in combination with existing transportation infrastructure data could be performed.

## 3.4 Data delivery package

Together with the Work Order Report, the following data packages are delivered to ESA and UNDP:

Service 1:

- Vector layers in ESRI shapefile format or any other compatible GIS vector format
    - LULC classification maps for each epoch (2004, 2014, 2019),
    - LULC change maps between those epochs (2004-2014, 2014-2019, 2004-2019).
    - Additional LULC change maps highlighting specific urban dynamics can be made available upon request (e.g. residential/industrial land use changes, urban densification/fragmentation, urban green area evolution, transport network evolution etc.)
- INSPIRE compliant metadata .xml files
- A summary report with statistics is provided as part of service 3 in this WOR, chapter 3.3.2

Service 2:

- Population grids in GeoTiff format or any other compatible GIS raster format. For representing the spatial distribution of the local population, two product levels are available:

  - Population allocated to the land cover class "Urban Fabric" (produced in Service 1) –population density is averaged over the whole area of each LC polygon
  - Population allocated to building footprints – population density averaged per building polygon
- INSPIRE compliant metadata .xml files
- A summary report with statistics is provided as part of service 3 in this WOR, chapter 3.3.2

<u>Service 3:</u>

- A summary report with various use cases and analytics is provided in this WOR, chapter 3.3.2

# 4 EVALUATION OF DATA AVAILABILITY AND SUITABILITY

This chapter evaluates the data used for the current activity describes any problems or deficiencies that must be taken into account for a potential service roll-out.

## 4.1 EO imagery

EO satellite data used for implementing Service 1 fit well with the need in terms of spatial, temporal and spectral resolutions. Considering the product specifications, SPOT imagery for extracting LULC information in 2019 and updating it for 2014 was the best option offering 1.5 m spatial resolution and 4 spectral bands (Green, Blue, Red and Near Infra-Red). Only SPOT-5 panchromatic scene et 5 m resolution used for detecting changes between 2004 and 2014 made the task a little bit more difficult, but it was the only one image available with a spatial resolution still acceptable for covering the area of interest.

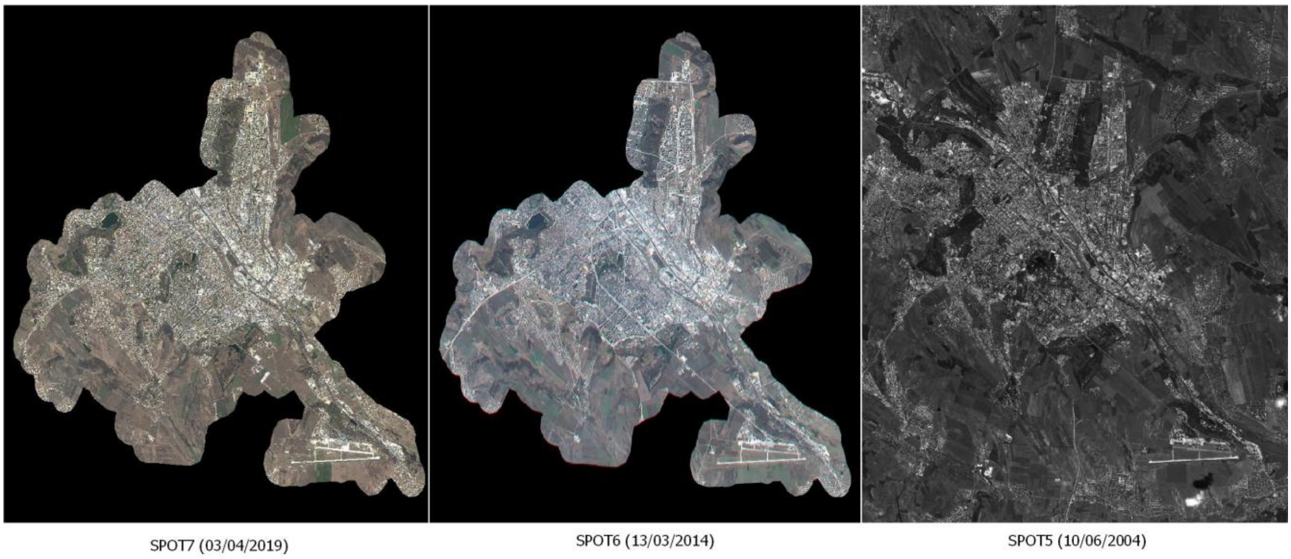



*Figure 24: VHR satellite data used as main input for Service 1 implementation*

Generally speaking, the European Urban Atlas is generated using mainly very high resolution satellite imagery with 2-2.5 m resolution and 4 spectral bands available (G-B-R-NIR). Using imagery with lower resolution makes more challenging change detection especially within urban areas and highly difficult for LULC creation.

## 4.2 Road network

OpenStreetMap (OSM) road and railway network data have been retrieved and used for the automatic generation of a geometric skeleton / baseline layer prior to further extracting the LULC information on the basis of EO data. OSM dataset for Chișinău was complete and accurate in general, but the visual check made revealed the necessity to correct some positioning errors and to complete the network in some areas before ensuring the topological consistency in an automatic manner.

A complete, up-to-date and topologically consistent road network data (routable for navigation is a key input for conducting a wide range of analyses and developing indicators based on network analysis tools (cf. service 3). It is mostly relevant for setting the best routes between two points of interest or determining service areas. **In the aim of supporting the work on urban mobility, highly accurate road and railway network**

**data and related infrastructures is highly recommended as a baseline.** More details are provided within section 4.7.

## 4.3 Cadastral parcels

Cadastral parcels are real estate data to be viewed at land level. Cadastral parcel elements were provided as polygons. The coordinate reference system is MOLDREF99 / Moldova TM. The data was created in May 2016 and revised in April 2019 and were used alongside the road network to provide a detailed skeleton as input to the land cover classification.

This up-to-date ancillary data was helpful for minimizing additional efforts related to the geometric segmentation and differentiating the different LULC themes. Only two steps were necessary before integration and exploitation:

- Eliminating very small cadastral parcels (below 250 sqm) by merging them with a neighbouring one, as they are not relevant to the LULC product specifications provided as part of the Service 1 and would slow down the production.
- Ensuring the topological consistency.

The exploitation of cadastral parcels as geometric skeleton / baseline for generating LULC products increases the chance to get consistent datasets with each other, even if not entirely due to the difference in specifications. Especially this makes easier to get the attribute information from one dataset to another by spatial or attribute joins, which is useful for conducting further GIS analyses.

## 4.4 Building footprints

Building footprints are a contour representation (polygon type) of the buildings (and also constructions) located on the field with their cadastral numbers. The data layer was provided as vector data set, in a MOLDREF99 (non-Earth) coordinate reference system from the Municipality of Chișinău. The database version is from July 2018.

For each building footprint, the roof elevation was provided as attribute. As not all building footprints included roof elevation, this was corrected manually by visual interpretation of the SPOT Image from April 2019. Building footprint data were used as input to derive more accurate built-up density estimates within polygons of residential urban fabric (service 1) as input to population disaggregation in service 2. Number of floors were used as height information to further refine the population density estimates.

For the population disaggregation only buildings categorized as “Apartment buildings”, “Individual homes”, “Cottages” and “Unfinished Construction” were considered. Latter only if the presence of a finished building was visible in the satellite imagery (Figure 25).


*Figure 25: Buildings categorized as "unfinished" were included, if the finished residential buildings could be identified on the satellite imagery.*

## 4.5 Population census data

Census data were provided by the National Bureau of Statistics of the Republic of Moldova and were mainly available on district level and only partly on dwelling types, age groups or sex. Thus, the night-time population density information is based on numbers provided on district level. With the availability of data on sub-district level, the results could be even further refined.

To allocate the census data to the correct areas, the corresponding borders have to be known. As country, district and sub-district borders change sometimes, it is necessary to have the right border files (any kind of georeferenced data, e.g. shapefiles or raster format) for the year of the census data to avoid pseudo changes of population density due to changing borders.

## 4.6 Anonymised call detail records (CDR)

Anonymized call detail records (CDR) were provided by Orange Moldova (1 day – 24 hours) and are a rich data repository to perform analyses and simulations of where population moves during the day (thereby complementing the night-time population distribution delivered from service 2). CDR data have attracted an increasing interest in the geospatial domain. In general, CDRs consist of communication logs, including duration, connected user and timestamps, and location traces (connected cellular tower).

<u>**The data used for Service 3 was available for one day only**</u> (24 hours, date: 10.06.2019). Each record of CDR data contains corresponding communication activities (e.g. voice, SMS, or data) and calling/called-party base station location for each time stamps. The provided position of the antenna allowed an estimation under the assumption that the signal quests the nearest antenna. That way it was possible to estimate where people stay throughout the day and identify commuting patterns.

The accuracy of such analyses would increase with the number of available data (e.g. from different providers). Further, with data over a longer period it would be possible to look at different patterns between working days and weekends.

## 4.7 Routable network (streets, paths, public transport lines, railways)

A routable network has been derived based on transport data provided by the Municipality of Chișinău as well as OSM data. The provided dataset from the Municipality of Chișinău included only main streets. As the OSM dataset has a more detailed road network, this dataset is advised to use for a roll-out. With additional information about the streets, such as length or maximum speed, the population living within a certain walking or driving distance away from a point of interest can be measured.

The routable network was used to generate ‘service areas’ for points of interest (cf. chapter 3.3.2.5). With a more detailed road network a more accurate analysis of service areas can be made. Service areas were calculated for the provided dataset of bus stations. For the roll-out this could be extended to several other categories such as educational facilities or medical services.