Land use map 2018

Project deliverable D1.1
Mapping Land Use 2018 in Luxembourg: an approach based on aerial images, LiDAR and ancillary GIS data

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«Using Space to provide Space for the Environment»

DOCUMENT RELEASE SHEET

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LIST OF ACRONYMS

CIR	Colour Infrared Images
DEM	Digital Elevation Model
DSM	Digital Surface Model
EO	Earth Observation
GIS	Geographic Information System
HRLC'18	High-resolution land cover map 2018
LC	Land Cover
LiDAR	Light Detection and Ranging
LIS-L	Land Information System Luxembourg
LU	Land Use
LU'18	Land Use map 2018
MDDI	Ministère du Développement Durable et des Infrastructures
nDSM	normalised Digital Surface Model

1 BACKGROUND OF THE DOCUMENT

The land use 2018 (LU'18) project has the objective to develop and implement an approach to obtain land use information based on aerial images, LiDAR data, and other ancillary data for the Grand Duchy of Luxembourg.

A major component of the project is to produce an up-to-date land use map of the Grand Duchy of Luxembourg for 2018 with an MMU of 100 m² for settlement classes (S.1.1-S.1.5), standing water (W.2.1-W.2.2) and transport (T.1.1-T.1.2), and 500 m² for all other classes. We also improved the land use map of 2015 produced in the context of the Land Information System Luxembourg (LIS-L) project, and generated a change layer for the 2015-2018 time stamp. In addition, we tested the importance of using 3D topographical data obtained based on Light Detection and Ranging (LiDAR) to obtain a high quality forest management classification in terms of detecting clear cut and young forest. The project is a follow-up of the LIS-L project aiming at mapping land cover (LC) and land use (LU) in Luxembourg for 2015.

1.1 DOCUMENT CONTENT

This document provides the methodological approach to generate a land use map of the Grand Duchy of Luxembourg for 2018 based on colour infrared aerial images, LiDAR data, and other ancillary geographic information system (GIS) data. The proposed methodology is developed with applying automatic GIS processing of data and manual digitisation approach.

The document is structured in seven main sections. Section 1 introduces the content of this document and main goals of the project. Section 2 introduces the most important information about the project and its technical specifications. Sections 3 and 4 provide an overview description of study area and used data, while section 5 offers a detailed description of the methodology used to produce Land Use map. Remaining sections 6 and 7 provided details on the generated land use maps and conclusions drawn from the project.

1.2 RELATED DOCUMENTS

Document ID	**Descriptor**
20181203_Commande_Space4Environment.pdf	Project proposal

2 INTRODUCTION

According to INSPIRE definition (Directive 2007/2/EC) a Land Use is a "*territory characterised according to its current and future planned functional dimension or socio–economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational)*". In the LU'18 project we use a land use map of 2015 produced in LIS-L project as an input source to produce a land use map of 2018 with the use of different earth observation (EO) data, such as: aerial photos, LiDAR data, and other ancillary GIS data such as road and water network and FLIK agricultural parcels available for the Grand Duchy of Luxembourg.

In this study, we present a follow up of the methodological approach for 2015 described in Deliverable 2.3 of the LIS-L project for the entire area of Luxembourg. The goal is to progress on the methodology based on LiDAR which we tested to identify forest management for 2018 and to develop a methodological approach for land use mapping 2018 in Luxembourg based on colour infrared (CIR) aerial images, LiDAR and ancillary data.

The aerial image campaigns are organized for the Grand Duchy of Luxembourg at an annual interval, what allows to perform the land use update once each year in terms of forest management and new settlement objects. However, the new / changed land use of a parcel where the new building was constructed (residential, agricultural, industry and commerce, social, cultural, and other) sometimes cannot be assigned without using other ancillary data such as external Internet databases or verification in the field. Comparing the new LU map of 2018 with old datasets allows identifying the LU changes across the entire country.

2.1 TECHNICAL SPECIFICATION OF THE LAND USE CLASSES

We performed the land use classification into six main classes which were:

1. Settlement (S),
2. Agriculture (A),
3. Forest (F),
4. Natural surfaces (N),
5. Water (W) and
6. Transport (T)

described in

Table 2-1, and 23 subclasses in level 2, and 46 classes in level 3. In comparison with the LU classification carried out in the LIS-L project, we merged – on request of the client – settlement and estate classes into one class. In order to be consistent with the classification for 2015, we kept the terminologies and individual numbers of classes as it was used in the LIS-L project. To be consistent with the new LU map we also updated the land use map of 2015 in terms of merging the classes and improving whenever possible in terms of incorrect classification and the delineation of polygon boundaries.

For a detailed description of LU'18 land use classes, please see Annex I.

Table 2-1: Land use classes.

Thematic block	Land use class	Sub-type 1 class	Sub-type 1 acronym	Sub-type 1 LU class
Settlement (S)	Settlement & Estate (S.1)	Settlement types - 5	Types - 5	Types - 5
		Residential **(S.1.1)**	S.1.1	111
		Agriculture facilities **(S.1.2)**	S.1.2	112
		Industry & Commerce **(S.1.3)**	S.1.3	113
		Unused urban areas, brownfields **(S.1.4)**	S.1.4	114
		Social, cultural, and other **(S.1.5)**	S.1.5	115
	Public facilities (S.3)	Public facilities types - 4	Types – 4	Types – 4
		Cemetery **(S.3.1)**	S.3.1	131
		Square **(S.3.2)**	S.3.2	132
		Park **(S.3.3)**	S.3.3	133
		Other **(S.3.4)**	S.3.4	134
	Sports and leisure (S.4)	Sports and leisure types - 4	Types – 4	Types – 4
		Golf course **(S.4.1)**	S.4.1	141
		Camp ground **(S.4.2)**	S.4.2	142
		Other sport facilities **(S.4.3)**	S.4.3	143
		Other recreation facilities **(S.4.4)**	S.4.4	144
	Technical infrastructure (S.5)	Technical infrastructure types - 2	Types – 2	Types – 2
		Utility (production, disposal facilities) **(S.5.1)**	S.5.1	151
		Mining / extraction **(S.5.2)**	S.5.2	152
	Construction site (S.6)	Types - 1	S.6.0	160
Transport (T)	Roads (T.1)	Roads types - 2	Types – 2	Types – 2
		Rural roads **(T.1.1)**	T.1.1	611
		Main roads **(T.1.2)**	T.1.2	612
	Railways (T.2)	Types - 1	T.2.0	620
	Air traffic (T.3)	Air traffic types - 2	Types – 2	Types – 2
		Commercial **(T.3.1)**	T.3.1	631
		Sport & Leisure **(T.3.2)**	T.3.2	632
	Water traffic (T.4)	Types - 1	T.4.0	640
	Parking (T.5)	Types - 1	T.5.0	650
Agriculture (A)	Arable land (A.1)	Types - 1	A.1.0	210
	Grassland (A.2)	Types - 1	A.2.0	220
	Special cultures (A.3)	Special cultures types - 4	Types - 4	Types - 4
		Wine **(A.3.1)**	A.3.1	231
		Fruit trees **(A.3.2)**	A.3.2	232
		Orchard **(A.3.3)**	A.3.3	233
		Other **(A.3.4)**	A.3.4	234
Forest (F)	Forest block (F.1)	Forest types - 4	Types - 4	Types - 4
		Coniferous **(F.1.1)**	F.1.1	311

Thematic block	Land use class	Sub-type 1 class	Sub-type 1 acronym	Sub-type 1 LU class
		Mixed **(F.1.2)**	F.1.2	312
		Deciduous **(F.1.3)**	F.1.3	313
		Young forest **(F.1.4)**	F.1.4	314
	Clearing **(F.2)**	Cause types - 3	Types - 3	Types - 3
		Burnt area **(F.2.1)**	F.2.1	321
		Storm damage **(F.2.2)**	F.2.2	322
		Clear cuts & Other **(F.2.3)**	F.2.3	323
Natural surfaces **(N)**	Gravel **(N.1)**	Types – 1	N.1.0	410
	Rocks **(N.2)**	Types – 1	N.2.0	420
	Natural grassland **(N.3)**	Types – 1	N.3.0	430
	Heathland **(N.4)**	Types – 1	N.4.0	440
	Bushes **(N.5)**	Types – 1	N.5.0	450
	Wetland **(N.6)**	Types – 1	N.6.0	460
Water **(W)**	Running water **(W.1)**	Running water types – 2	Types – 2	Types – 2
		Natural **(W.1.1)**	W.1.1	511
		Artificial **(W.1.2)**	W.1.2	512
	Standing water **(W.2)**	Standing water types – 2	Types – 2	Types – 2
		Natural **(W.2.1)**	W.2.1	521
		Artificial **(W.2.2)**	W.2.2	522

3 STUDY AREA

The study area in this project contains the entire Grand Duchy of Luxembourg equal to 2,593.1 km² and representing variety of LU classes. The northern part of the country is characterised by the dominance of agriculture and forestry with the river Sûre, whereas the southern part is more urbanised with many settlements (Luxembourg and Esch-sur-Alzette cantons; Figure 3-1). In the eastern part occurs orchards and fruit trees and in the south-eastern part exist many vineyards (Grevenmacher and Remich cantons; Figure 3-1).

We developed an approach for generating the land use map of 2018, improving the classification of land use map of 2015 and generating the change map between 2015 and 2018 that exclude technical changes within one geodatabase. Therefore, we performed the work for the entire country of Luxembourg shown in Figure 3-1.

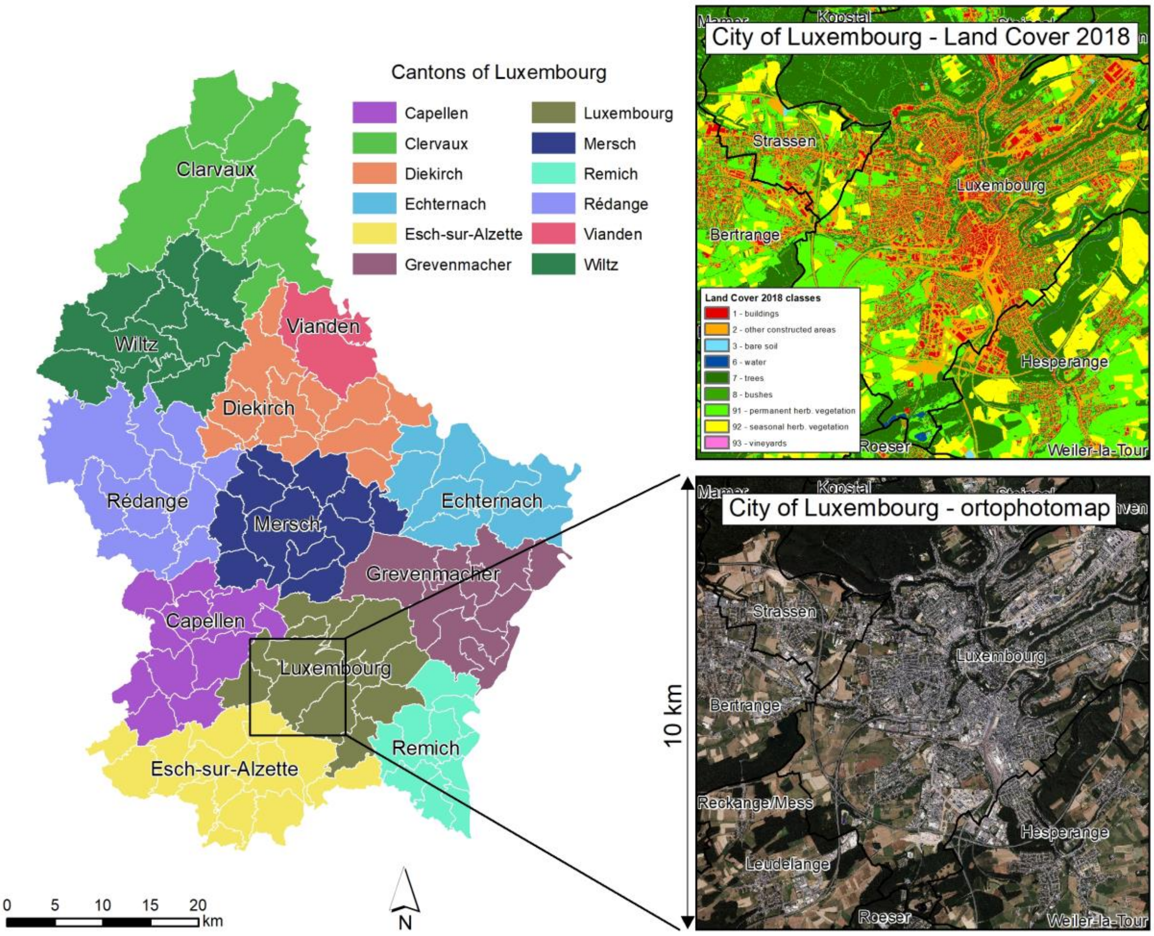


Figure 3-1: Study area for generating a land use map of 2018 with zoom to the ortophotomap used as input data and an overview of land cover map of 2018 generated for the entire country of Luxembourg in a previous HRLC'18 project.

4 INPUT DATASETS

We developed an approach for producing a land use map by assigning changes to the 2015 LU map based on high-resolution RGB aerial images with the spatial resolution of 0.2m gathered in 2018. We used the ortophotomap 2018 as the main input for updating the land use map of 2015 produced in the LIS-L project. The ortophotomap was mainly used to verify new settlement objects and to assess their land use class. We also applied ancillary data taken from the topographical map of the Grand Duchy of Luxembourg to help classify buildings, road and railway networks as artificial areas and water surfaces. For more details on input data, see Table 4-1. We visually verified the ancillary data with aerial images for 2018 and improved them in areas where the major land use changes occurred, for example on a new highway or where new large buildings were built.

In addition, we used LiDAR data with a spatial resolution of 1 m gathered in October 2017 to classify biotic classes and separate clear cuts from young forest. Based on the digital surface model (DSM) and digital elevation model (DEM) we evaluated the normalized difference surface model (nDSM) using the equation 1.

(1) nDSM = DSM – DEM

where:

DSM – digital surface model

DEM – digital elevation model

Table 4-1: Technical characteristics of input data used for generating land use map of 2018.

INPUT DATASETS		
Name	**Type**	**Spatial resolution**
Land Use map of 2015	Vector	-
Ortophotomap for 2018	Raster	0.2m
Pleiades images for 2015	Raster	1
Water	Vector	-
Railways	Vector	-
Roads	Vector	-
Buildings	Vector	-
FLIK data	Vector	-
Digital Elevation Model (DEM)	Raster	1m
Digital Surface Model (DSM)	Raster	1m
Difference Elevation Model (nDSM)	Raster	1m

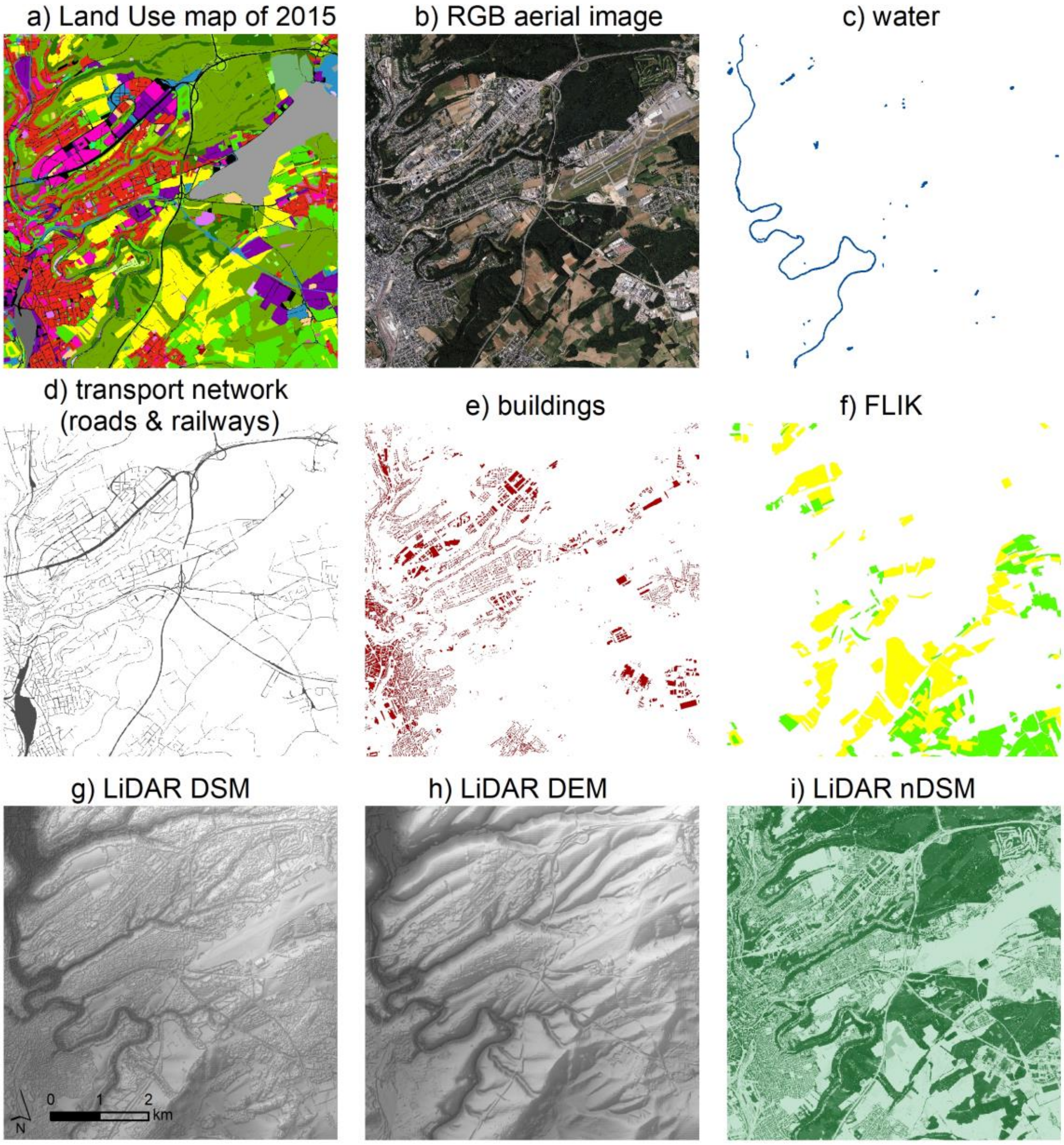


Figure 4-1: Data used for developing the approach for land use mapping for the year of 2018; a) land use map of 2015; b) RGB aerial image for 2018; c) ancillary water surfaces data used for classification; d) ancillary transport network (roads and railways) data used for classification; e) ancillary buildings data used for classification; f) ancillary FLIK data used for classification; g) LiDAR digital surface model (DSM); h) LiDAR digital elevation model (DEM); and i) LiDAR normalised digital surface model (nDSM).

5 Methodological approach for land use mapping with aerial images and LiDAR

We performed an automatic data processing in GIS software. The main steps of automatic processing were: 1) automatic update of water classes; 2) automatic update of railways and new roads, 3) automatic indication of agriculture change (arable land/grassland); 4) automatic indication on new clear cuts and young forest; and 5) automatic indication of new settlements. The next steps included manual digitising of polygons with new land use in combination with an indication of polygon change between 2015 and 2018, as well as correcting errors detected in the classification of LU map for 2015 and improving the polygon border if necessary.

The flowchart in Figure 5-1 shows the main steps of our processing approach developed in GIS software. A detailed approach is described in the following subsections of this chapter

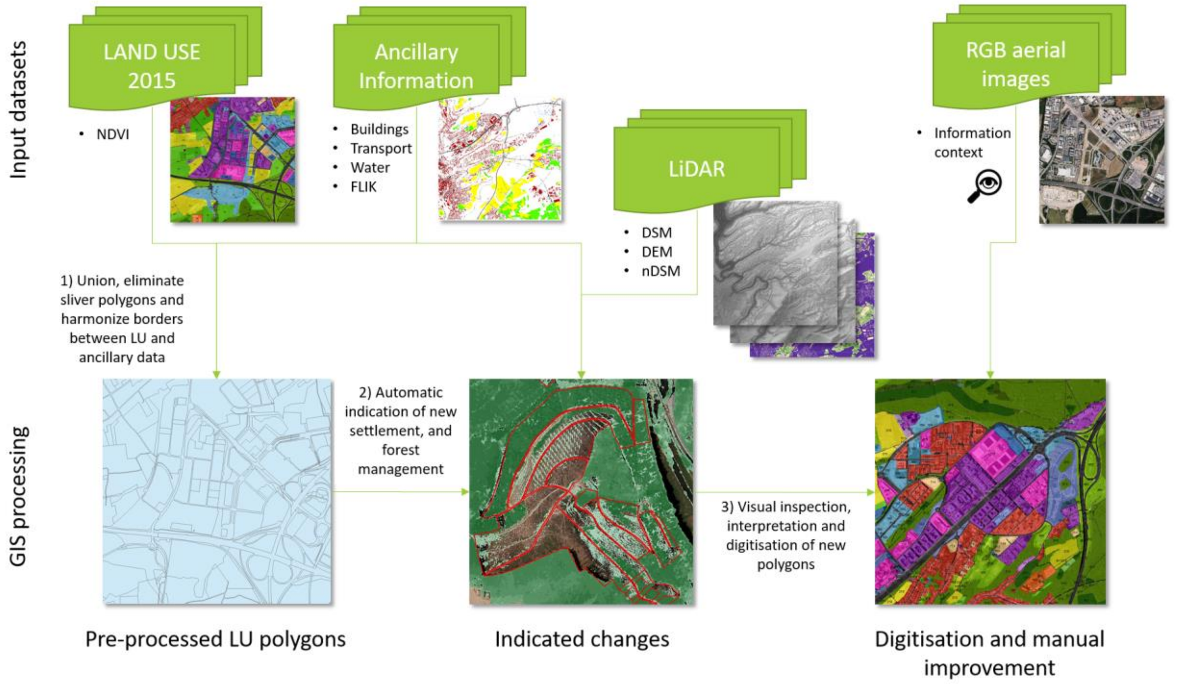


Figure 5-1 Workflow developed in GIS software for mapping the land use 2018 with aerial images, LiDAR and ancillary GIS data. The numbers 1, 2, and 3 on figure correspond to the main processing steps

5.1 PRE-PROCESSING OF INPUT DATA

We performed the processing in GIS software. As the main set of input data, we used the LU 2015 vector geodatabase, which was generated in the LIS-L project. We started processing by automatically changing the classification of all Estate classes to the corresponding classes in the LU Settlement class. The estate class was removed at the customer's request, as redundant information making further statistical analysis of the product more complex. We performed the reclassification as follows:

a) Estate - class S.2.1 (121) > Settlement - class S.1.1 (111);

b) Estate - class S.2.2 (122) > Settlement - S.1.2 (class 112);

c) Estate - class S.2.3 (123) > Settlement - S.1.3 (class 113);

d) Estate - class S.2.4 (124) > Settlement - S.1.4 (class 114);

e) Estate - class S.2.5 (125) > Settlement - S.1.5 (class 115).

5.2 GIS PROCESSING AND GENERATING LU 2018

In the first step we cross check the LU 2015 database with the water network, which was used to generate a high-resolution land cover map 2018 (HRLC'18) of the Grand Duchy of Luxembourg, conducting a "union" analysis. We decided to update the water class, because the water network we used in HRLC'18 was more detailed and up-to-date than the one existing in LU 2015. In the following step, we removed the sliver polygons that were generated by applying the union function. We performed the same steps to update road and water networks with the ancillary data.

In the second step, we split the transport network into one square kilometre tiles shown in Figure 5-2, to enable their improved opening and further processing. We did this, because the road network consists of only a few polygons throughout the country. The polygons were large, which prevented the data set from being quickly opened and further processed.

Further, we created layers that were used to indicate potential areas with: 1) the new settlement, 2) areas where the settlement was demolished, 3) new clear cuts and 4) areas with new grow of forest in the entire area of Luxembourg. We detected changes in the settlement by cross-checking polygons in the building class from the LC 2018 map based on their location with the polygons in our LU geodatabase. While changes in the forest management we found by cross-checking the LU geodatabase with nDSM gathered from LiDAR data. We set that a clear cut is represented by vegetation not exceeding 0.5 m in height, and the young forest is in the range of 0.5-3 meters. All polygons indicating changes in the settlement and forest we exported and used as support in updating the LU 2015 geodatabase.

In the case of a newly built settlement, for which there was no information in the ancillary data, which class this building represents, we used an additional source on the Internet to verify the LU class. We mainly used Google Maps, and Google Earth to verify that information about the company, organisation or public administration already exists. In many cases there was a map note or ground-based photo for this building, so we were able to classify it correctly. For the remaining settlement, we found information on local websites with news about current investments in municipalities throughout Luxembourg. Ultimately, there was no need for field verification using various online sources.

In the following step, we created a new column called "LU_2018" in the LU 2015 geodatabase representing the land use class in 2018, and we copied the 2015 classification, which we took from the "LU_2015" column. We also created an additional column called "Change_2015_2018" indicating changes between 2015 and 2018, in which we set the value of one for each polygon with a change, and set the default value <Zero> for all other unchanged ones. Then, by visual inspection of the ortophotomap for 2018, we updated the "LU_2018" column for polygons with changes and assigned the value one in the "Change_2015_2018" column for all polygons with changes. We also improved the polygon classification in the "LU_2018" column in case of incorrect classification of the LU 2015 dataset. To avoid mistakes during such simultaneous update of two columns and to speed-up the processing work, we did not update the column "LU_2015" while doing it for "LU_2018", but we did it automatically after the update for the entire country. We did it by selecting all polygons without changes and rewriting the classification from the "LU_2018" column.

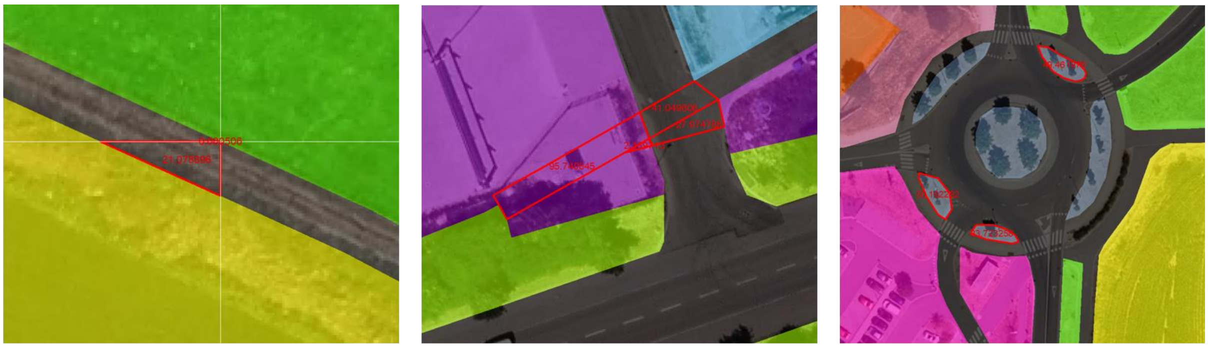
Figure 5-2 Tiles used to split the transport network in the land use 2018.

5.3 VISUAL INSPECTION & FINAL REFINEMENT

In the last step, we verified the remaining polygons below the MMU and, if necessary, we reclassified to the largest neighbour. We have not verified the polygons belongings to the transport network, because these polygons were automatically split into 1 km² tiles, what produced many small-scale polygons, which can be seen in Figure 5-3 a.

Furthermore, many polygons representing the change between 2015 and 2018 are smaller than the MMU because they are a part of a change that took place between several different LU classes in 2015 and few different new classes in 2018. On Figure 5-3 b we see that two polygons are part of a road and could be merged with their neighbours. In this way, however, we lost information about the change and could not visualize the data using LU 2015. Therefore, in order to preserve all information and allow the dataset to be updated in the future without the technical changes, we decided not to dissolve the LU 2018 dataset.

In addition, a number of polygons that are below the MMU are part of a larger polygon that is split by a road network. Such an example is shown in Figure 5-3 c; in total, the polygons marked in blue exceed MMU, but separately some of them are below MMU. We decided to keep such polygons as important objects to preserve the LU thematic context.



a) polygons smaller than MMU due to splitting the road network to 1km² tiles

b) polygons smaller than MMU due to LU change between 2015 and 2018

c) polygons smaller than MMU due to road network

Figure 5-3 Polygons smaller than predefined MMU due to different issues. The polygons below the MMU and their size are marked with the red outline.

We exported the final LU classification as a File Geodatabase containing the attributes of LU 2015, LU 2018 and change between 2015 and 2018, enabling further visualisation and analysis of statistics. In addition, we generated a GeoTiff file with a spatial resolution of 1 meter for LU 2015, LU 2018 and the change between 2015 and 2018.

5.4 QUALITY ASSESSMENT

We verified the quality of the LU 2018 map by sampling the random polygons across the country generated based on the LU polygons (Fig 5-4). Around 30 observations were randomly selected within each mapped class (1227 polygons in total); additionally to estimate omission errors in the settlement, a set of 200 random sampling observations were collected based on a group of settlement LU classes, which was used as a generic reference domain. Stratifying map by reference domains, allows to more frequently selected artificial objects on the ground and assess their omission in the final map. In total we performed the quality check based on 1427 randomly selected polygons across the entire Grand Duchy of Luxembourg.

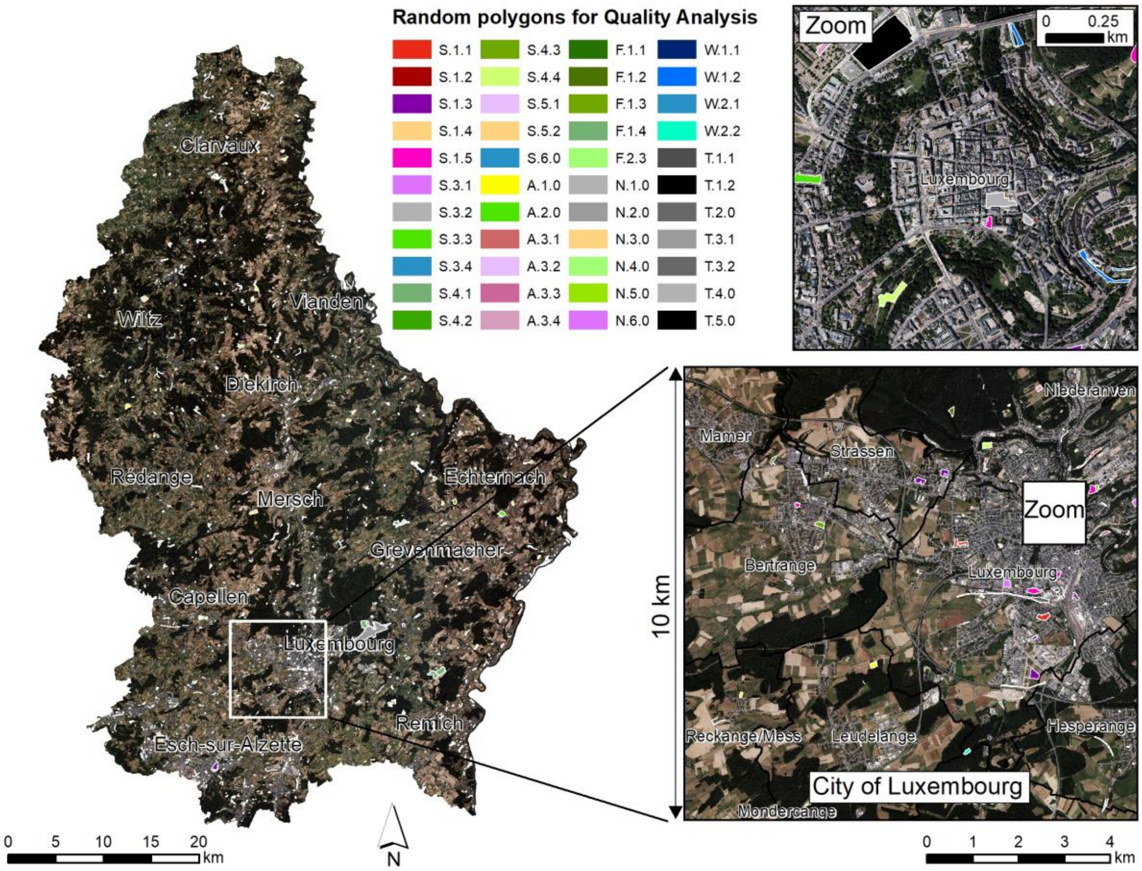


Figure 5-4: Random polygons across the entire Grand Duchy of Luxembourg for quality check of generated LU map of 2018.

The quality check presented on the matrix in Table 5-1, shows, that the commission errors do not exceed 10.0% for the majority of individual classes, and that the standard deviation of the errors at the 95% confidence level are always inferior to 15%. 20 out of 45 classes (the class 322 – F.2.2 does not exists in the entire country, therefore 45 classes in total instead of 46) have a commission error equal to zero and a User's Accuracy equal to 100%. Only for class A.3.2 (132 – town squares) the commission error is equal to 30% what means that some objects do not belonging to this class were classified as town square. More than a half of the classes (25 out of 45) have the Producers' Accuracies equal to 100% with the Omission Errors equal to 0%. The overall accuracy of the classification for the entire area of Grand Duchy of Luxembourg is equal to 96.5%.

After the quality check we corrected the classification of all polygons assigned as false. Because the commission error was large and the class 132 – A.3.2 contains only 41 polygons in total, in the remaining step we also verified all polygons and corrected their classification if necessary to deliver high quality data.

Table 5-1: Accuracy metrics for land use classification with respect to 1427 randomly selected reference polygons; Overall Accuracy [%], Producer's Accuracy [%]; Users Accuracy [%], Errors of Commission [%], Errors of Omission [%], and Confidence Intervals [Min and Max CI] computed at 0.05 significance level.

	Reference data																																													Grand Total	Errors of Commission	User's Accuracy	Min CI	Max CI
Classified data	111	112	113	114	115	131	132	133	134	141	142	143	144	151	152	160	210	220	231	232	233	234	311	312	313	314	321	323	410	420	430	440	450	460	511	512	521	522	611	612	620	631	632	640	650					
111	130																																													130	0.0	100.0	1.00	1.00
112		50																																												50	0.0	100.0	1.00	1.00
113			48						1																																					49	2.0	98.0	0.94	1.00
114				38																																										38	0.0	100.0	1.00	1.00
115					36																																								1	37	2.7	97.3	0.92	1.00
131					2	30		1																																						33	9.1	90.9	0.81	1.00
132							21	4	1				1																																3	30	30.0	70.0	0.54	0.86
133								39					1					1																						1					1	43	9.3	90.7	0.82	0.99
134									39									1																												40	2.5	97.5	0.93	1.00
141										23								1																												24	4.2	95.8	0.88	1.00
142											31																																			31	0.0	100.0	1.00	1.00
143												32																																		32	0.0	100.0	1.00	1.00
144												1	30					1																												32	6.3	93.8	0.85	1.00
151														32																																32	0.0	100.0	1.00	1.00
152															30																															30	0.0	100.0	1.00	1.00
160																43																														43	0.0	100.0	1.00	1.00
210																	30																													30	0.0	100.0	1.00	1.00
220																		30																												30	0.0	100.0	1.00	1.00
231																			29														1													30	3.3	96.7	0.90	1.00
232																		2		28																										30	6.7	93.3	0.84	1.00
233																		1			29																									30	3.3	96.7	0.90	1.00
234																						30																								30	0.0	100.0	1.00	1.00
311																							29					1																		30	3.3	96.7	0.90	1.00
312																								27	2	1																				30	10.0	90.0	0.79	1.00
313																								1	28			1																		30	6.7	93.3	0.84	1.00
314																										30																				30	0.0	100.0	1.00	1.00
321																											1																			1	0.0	100.0	1.00	1.00
323																										2		28																		30	6.7	93.3	0.84	1.00
410																													30																	30	0.0	100.0	1.00	1.00
420																									1					15																16	6.3	93.8	0.82	1.00
430									1					1						1					1						26															30	13.3	86.7	0.75	0.99
440																																28														28	0.0	100.0	1.00	1.00
450															1																		29													30	3.3	96.7	0.90	1.00
460																		1																29												30	3.3	96.7	0.90	1.00
511																																			29	1										30	3.3	96.7	0.90	1.00
512																																			1	29										30	3.3	96.7	0.90	1.00

	Reference data																																													Grand Total	Errors of Commission	User's Accuracy	Min CI	Max CI
	111	112	113	114	115	131	132	133	134	141	142	143	144	151	152	160	210	220	231	232	233	234	311	312	313	314	321	323	410	420	430	440	450	460	511	512	521	522	611	612	620	631	632	640	650					
521																																					26	4								30	13.3	86.7	0.75	0.99
522																																						30								30	0.0	100.0	1.00	1.00
611																																							29	1						30	3.3	96.7	0.90	1.00
612																			1																					29						30	3.3	96.7	0.90	1.00
620																																									30					30	0.0	100.0	1.00	1.00
631																																										4				4	0.0	100.0	1.00	1.00
632																																											4			4	0.0	100.0	1.00	1.00
640														1																														9		10	10.0	90.0	0.71	1.00
650																																													30	30	0.0	100.0	1.00	1.00
Grand Total	130	50	48	38	38	30	21	44	42	23	31	33	32	34	31	43	30	38	30	29	29	30	29	28	32	33	1	30	30	15	26	28	30	29	30	30	26	34	29	31	30	4	4	9	35	1427				
Errors of Omission	0.0	0.0	0.0	0.0	5.3	0.0	0.0	11.4	7.1	0.0	0.0	3.0	6.3	5.9	3.2	0.0	0.0	21.1	3.3	3.4	0.0	0.0	0.0	3.6	12.5	9.1	0.0	6.7	0.0	0.0	0.0	3.4	0.0	0.0	3.3	3.3	0.0	11.8	0.0	6.5	0.0	0.0	0.0	0.0	14.3					
Producer's Accuracy	100.0	100.0	100.0	100.0	99.3	100.0	100.0	99.2	87.8	100.0	100.0	98.4	91.6	95.0	76.9	100.0	100.0	99.8	87.7	90.6	100.0	100.0	100.0	59.4	99.6	88.4	100.0	49.3	100.0	100.0	100.0	100.0	98.9	100.0	99.6	78.6	100.0	99.2	100.0	97.8	100.0	100.0	100.0	100.0	86.9			Overall Accuracy 96.5		
Min CI	1.00	1.00	0.96	1.00	0.94	0.89	0.77	0.90	0.68	0.92	1.00	0.95	0.72	0.85	0.39	1.00	1.00	1.00	0.66	0.66	0.93	1.00	0.93	0.12	0.90	0.76	1.00	0.10	1.00	0.87	0.86	1.00	0.92	0.93	0.93	0.31	0.86	0.98	0.93	0.90	1.00	1.00	1.00	0.79	0.67					
Max CI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					

6 Results and Discussion

As a result of this project we deliver the Land Use classification for 2018 of the entire Grand Duchy of Luxembourg in vector and raster formats as two products, which are:

1) Personal Geodatabase: **LU_2018.gdb** containing polygon vectors with the numerical LU class attribute named "LU_2018" that corresponds to the gridcode of raster dataset saved as "Value". We also deliver the corrected land use of 2015 saved as attribute named "LU_2015" and a change layer between 2015 and 2018 saved in the attribute named "Change_2015_2018". Additionally, we include the description of classes as text "LU_2015_name" and "LU_2018_name".
2) Raster datasets: **LU_2018_1m.tif** and **LU_2015_1m.tif** with 1 m spatial resolution and the LU classification saved in "Value", and **LU_change_2015_2018_1m.tif** with 1 m spatial resolution and the LU change saved in "Value".

We attach into both vector and raster datasets colours pallets saved in **LU_2018_vector_palette.lyr** and **LU_2018_raster_palette.lyr** files enabling their visualisation in the same standard colours.

The chart presented on Figure 6-1 and final LU map for 2018 shown on Figure 6-2 represent 45 land use classes in level 3. The biggest rate of the country constitutes agriculture covering 1286.0 km² of the analysed area (49.6%). Whereas the smallest rate constitutes water with only 11.6 km² what constitute 0.4% of the country.

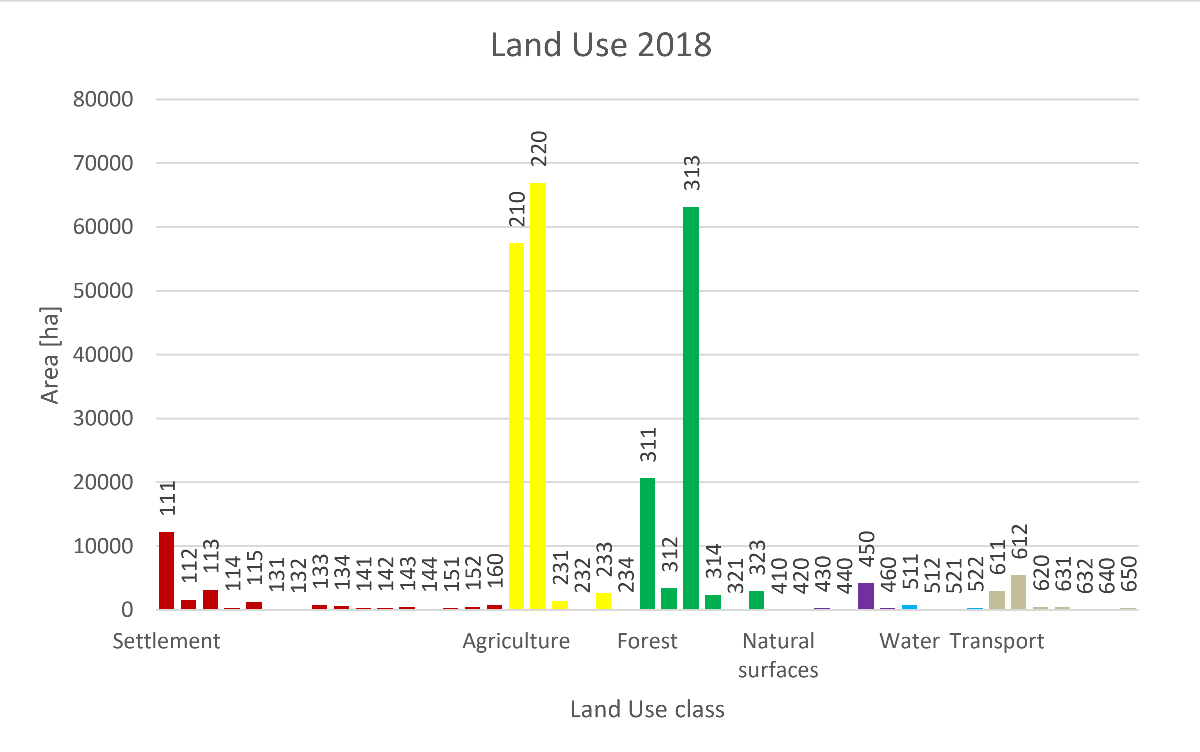
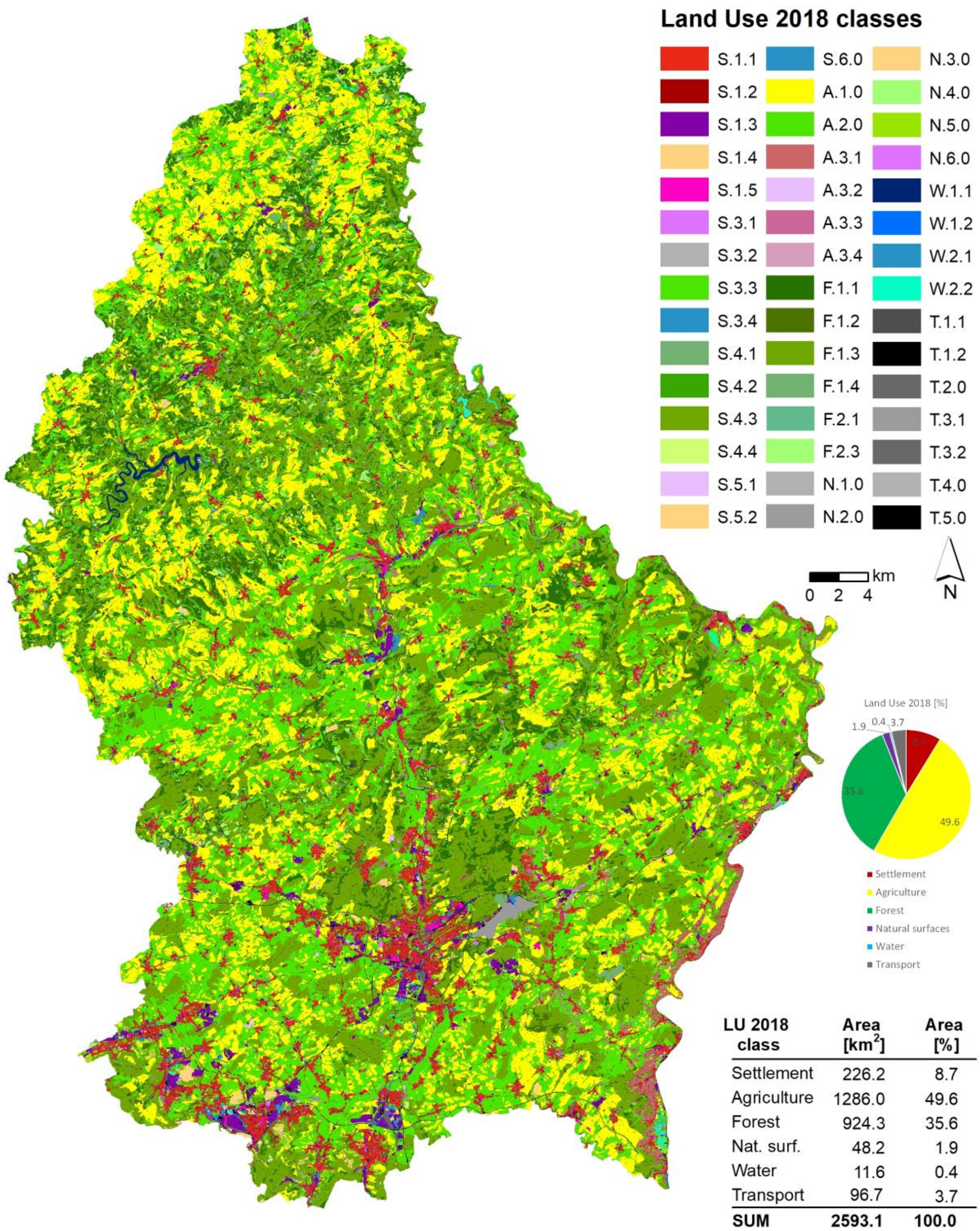


Figure 6-1 Land Use 2018 - distribution of land use classes in hectares across the Grand Duchy of Luxembourg

The accuracy assessment shows a good quality of the map. The match of classes with objects represented on the ortophotomap and other ancillary data is high.

The use of LiDAR data allows obtaining very precise information about the forest management. The application of nDSM was helpful in separating clear cuts and young trees based on their height. However, the LiDAR data we used were from 2017 and the update of LU map was done for 2018; therefore the forest clearing performed after October 2017 when the LiDAR campaign has been done disabled to detect these parcels in an automatic way.



LU 2018 class	Area [km^2]	Area [%]
Settlement	226.2	8.7
Agriculture	1286.0	49.6
Forest	924.3	35.6
Nat. surf.	48.2	1.9
Water	11.6	0.4
Transport	96.7	3.7
SUM	**2593.1**	**100.0**

Figure 6-2: Land Use 2018 for the Grand Duchy of Luxembourg with the statistics of the coverage of main LU classes.

Figure 6-3 shows a visual comparison of the LU 2018 classification with LU 2015. The examples show the main changes that have taken place in Luxembourg, including internal forest changes, such us: a new forest grows and clear cuts. Another clearly visible change is the new settlement and transportation networks in areas used for agriculture purposes.

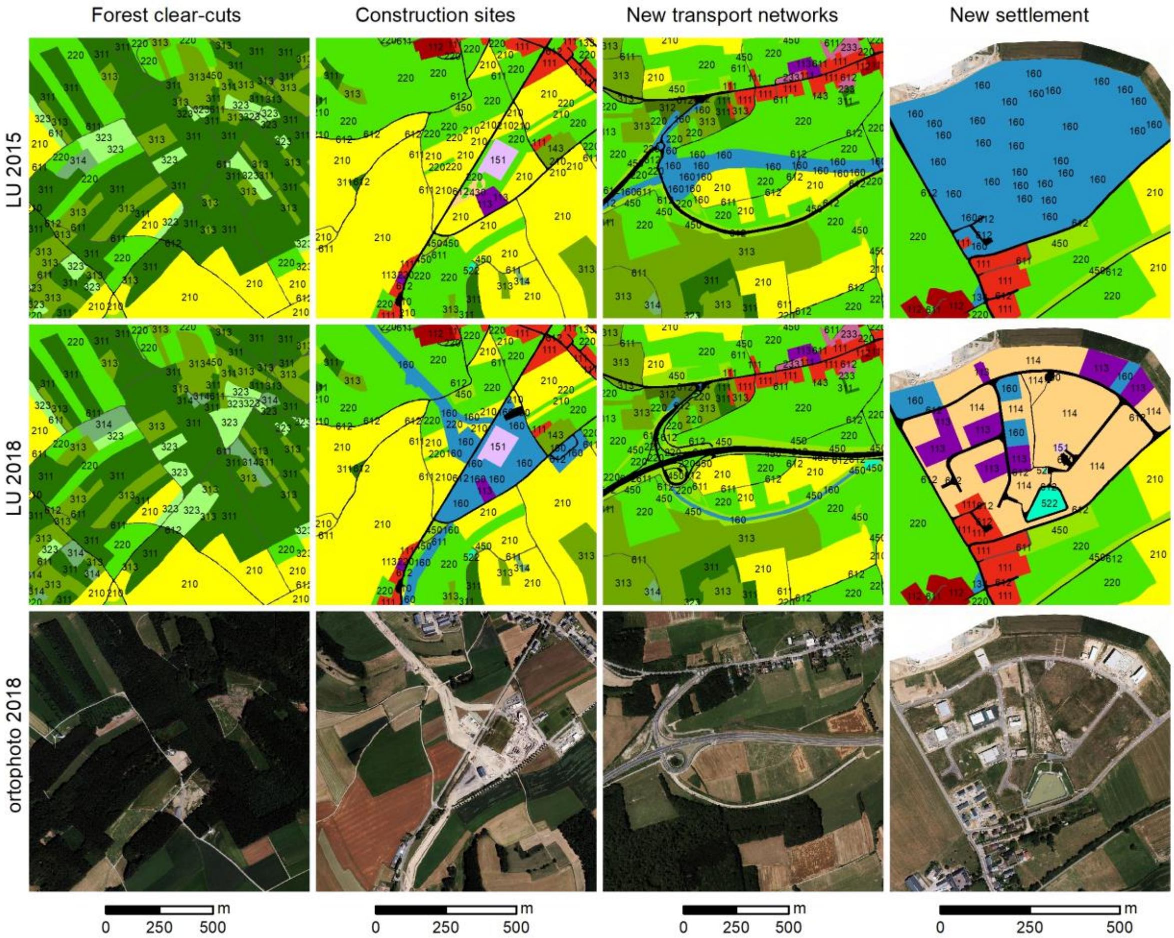


Figure 6-3: Visual comparison of land use classification in 2018 and 2015 for the Grand Duchy of Luxembourg and an overview of the ortophotomap for 2018. The numbers in the figure indicate the LU class.

The statistical comparison of LU 2015 with LU 2018 in the Table 6-1 and its generalised summary on Figure 6-4 shows that in three years the settlement class has increased by 5 km², while the agriculture class has shrunk by 5.1 km². We also observe a slight decrease in forest and natural vegetation, which amounted approximately 0.6 km² and 0.1 km², respectively. The water class remains the same, while the transport class increases by 0.8 km².

Table 6-1: Land use change between 2015 and 2018 in km².

LU 2015 / LU 2018	111	112	113	114	115	131	132	133	134	141	142	143	144	151	152	160	210	220	231	232	233	234	311	312	313	314	321	323	410	420	430	440	450	460	511	512	521	522	611	612	620	631	632	640	650	Grand Total
111	119.53		0.00	0.10	0.00			0.00	0.00			0.00				0.32	0.00	0.00															0.00						0.00	0.01					0.01	119.98
112	0.01	15.30		0.02												0.06		0.00																						0.00						15.39
113	0.02		29.51	0.02					0.00							0.30																							0.00	0.01	0.00				0.00	29.87
114	0.51	0.00	0.25	2.89	0.01			0.01	0.00			0.03	0.00	0.00		0.50	0.00	0.03															0.04						0.00	0.04					0.03	4.34
115				0.01	12.72							0.00				0.06		0.00																						0.01					0.00	12.79
131						1.56																																		0.00	0.00					1.56
132							0.06									0.00																													0.00	0.07
133	0.00		0.01		0.01			7.45								0.04																								0.01						7.52
134	0.01		0.01	0.00	0.00			0.00	5.43							0.12		0.01															0.00						0.00	0.00					0.00	5.60
141										2.90																																				2.90
142	0.00										2.96					0.00																							0.00	0.00						2.98
143				0.00	0.01							3.84				0.06		0.01																						0.00					0.00	3.92
144	0.00												2.04			0.01		0.01																						0.00					0.00	2.06
151														2.33		0.00	0.00	0.01																					0.00	0.00						2.34
152															4.55			0.02													0.09		0.07					0.03		0.01						4.76
160	0.71	0.04	0.82	0.30	0.14			0.01	0.04		0.01	0.00		0.04		1.99	0.01	0.30			0.00	0.02			0.00						0.00		0.19					0.01	0.01	0.24	0.15	0.07			0.04	5.15
210	0.09	0.10	0.09	0.05	0.01				0.00					0.01	0.04	1.23	574.36	0.04	0.01		0.07	0.04											0.00						0.02	0.05					0.02	576.23
220	0.64	0.39	0.28	0.01	0.06	0.00		0.01	0.00			0.02	0.00	0.02	0.00	2.21	0.01	668.75	0.01		0.07	0.03											0.02	0.01				0.00	0.04	0.14	0.00	0.01			0.04	672.78
231	0.00	0.00														0.01	0.00	0.01	13.27																				0.00	0.00						13.30
232																0.00			1.08																										1.08
233	0.04	0.00		0.00	0.00											0.05		0.02			25.82																			0.00					0.01	25.95
234															0.00		0.00				1.67																		0.00						1.67
311	0.01	0.00	0.00		0.00							0.00			0.01	0.04	0.03	0.01					205.61			0.05		7.90					0.00						0.00	0.00						213.66
312	0.00															0.01								34.21		0.01		0.18											0.00	0.00	0.00					34.41
313	0.02	0.01	0.04	0.02	0.00			0.01						0.00	0.04	0.11	0.00	0.04					0.02		631.63	0.03		1.95					0.01					0.00	0.00	0.01	0.00					633.92
314																0.01						0.25		0.12	8.72		0.16												0.00						9.27
321																										0.00																			0.00
323	0.00		0.01	0.00	0.01										0.01	0.10	0.03	0.05					0.01		0.02	14.54	0.05	18.84					0.00						0.00	0.00						33.69
410																												0.21																0.21
420																													0.03															0.03
430	0.00															0.02												0.00			3.05								0.00	0.00						3.08
440																											0.01				0.22														0.23
450	0.00	0.00	0.06		0.00							0.00		0.00	0.03	0.28		0.07			0.00	0.00			0.01			0.01					42.00					0.00	0.00	0.04	0.01				0.01	42.52
460																																	2.30												2.30
511																																		7.09											7.09
512															0.00																				0.90				0.00						0.90
521																																				0.20	0.00								0.20
522							0.00					0.00																									3.37								3.37

	LU 2018																																													Grand Total
	111	112	113	114	115	131	132	133	134	141	142	143	144	151	152	160	210	220	231	232	233	234	311	312	313	314	321	323	410	420	430	440	450	460	511	512	521	522	611	612	620	631	632	640	650	
611	0.00	0.00	0.00	0.00					0.00						0.00	0.02	0.01	0.00	0.00														0.00						29.93	0.01	0.00					29.98
612	0.00		0.00	0.00	0.00			0.00	0.00						0.00	0.09	0.00	0.01							0.00								0.00					0.00	0.00	53.50	0.03				0.00	53.65
620																0.00																								0.00	4.70				0.00	4.71
631			0.01																																							3.73			0.01	3.75
632																																											0.15			0.15
640																																												0.22		0.22
650	0.00		0.01	0.00	0.01				0.00							0.08																								0.00	0.00				3.33	3.44
Grand Total	121.60	15.85	31.12	3.43	12.99	1.56	0.06	7.49	5.49	2.90	2.97	3.90	2.05	2.40	4.69	7.73	574.47	669.40	13.30	1.08	25.96	1.76	205.89	34.21	631.78	23.34	0.05	29.05	0.21	0.03	3.14	0.22	42.33	2.31	7.09	0.90	0.20	3.40	30.02	54.10	4.89	3.81	0.15	0.22	3.51	**2593.06**

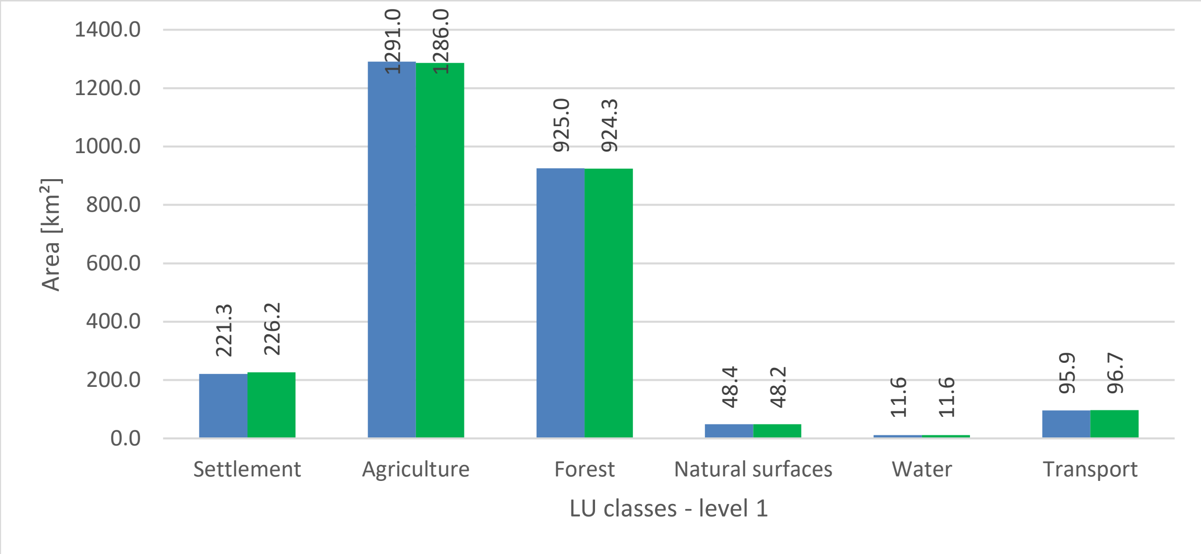


Figure 6-4 Statistical comparison of land use classification in 2018 and 2015 for the Grand Duchy of Luxembourg.

6.1 REMARKS WHILE UPDATING LU'18 IN THE FUTURE

The LU geodatabase for 2018 contains two datasets: LU for 2015 and LU for 2018. Additionally, it contains an attribute with information about the change in LU between 2015 and 2018 saved as 0/1 numbers, where 1 means a change. The data is not dissolved, which means that two polygons representing the same class may be adjacent. This is because in 2015, some of these polygons represented a different class and there was a change between 2015 and 2018. We suggest not to dissolve the delivered dataset to preserve the information on LU for 2015. This is also key when updating the LU in the future, we recommend adding a new attribute to the geodatabase and using the classification for 2018 as input datasets. This allows you to update the map and also correct errors in the input LU. If a technical error is found which was omitted in this project, the class can easily be updated backwards for all timestamps existing in the geodatabase. Also technical errors in delineating boundaries can be updated for all time stamps in one step.

7 CONCLUSIONS

In this report, we present a GIS approach for land use mapping that we performed for the entire area of the Grand Duchy of Luxembourg. This approach is based on combining information from RGB aerial images, LiDAR and thematic knowledge of recognising land use classes based on aerial images. Our approach uses a previous version of a land use map of 2015 and propose solution to produce an updated map of 2018 simultaneously by correcting errors found in the map of 2015 and generating a change map with omission of technical changes. The results presented in **Error! Reference source not found.** show high reliability in matching information on land use from aerial images with the support of LiDAR and expert knowledge. The accuracy of the GIS approach is high, which indicates its potential to be used in future LU updates for the entire country of Luxembourg.

ANNEX I

Detailed description of LU'18 land use classes

The land use classes have been divided into six main thematic blocks:

- Settlement
- Traffic
- Agriculture
- Forest
- Natural and semi-natural surfaces
- Water

S – SETTLEMENT

Settlements are built-up surfaces including buildings and their functionally associated surfaces, such as roads, driveways, gardens and other vegetated areas, storage and manipulation/handling places. Roads for the "inner development" of settlements and traffic lines between settlements are to be included in the "traffic" class. Therefore, settlement patches smaller than the pre-defined minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

S.1 – Settlement & Estate

The delineation of settlements can be derived from the orthophoto/satellite image or can be based on the ownership information in the cadastral map.

Based on their use, five settlement types are defined:

S.1.1 (Class code = 111) – Residential (>50% of the surface dedicated to residential use);

S.1.2 (Class code = 112) – Agricultural facilities (>50% of the surface dedicated to agriculture);

S.1.3 (Class code = 113) – Industry & commerce (>50% of the surface dedicated to industry / commerce / trade);

S.1.4 (Class code = 114) – Unused urban areas or industrial brownfields (>50% of the surface includes open urban spaces without managed vegetation and that are not currently in use (e.g. are occupied by ruderal vegetation), as well as residential and industrial wastelands, whether contaminated or not);

S.1.5 (Class code = 115) – Social, Cultural and Other (>50% of the surface includes cultural and spiritual buildings, health, education, military, train station, administration and public services, indoor sports halls).

A minimum mapping unit of 100m² applies to individual objects of settlement types.

The separated LIS-L land cover map can be used to assess the density of the settlement classes (4th level). The LIS-L land cover layer has a spatial resolution of 1m² and can be used to attribute density to existing land use objects.

S.3 – Public facilities

- >50% of the surface includes cemeteries (**S.3.1; Class code = 131**), town squares (**S.3.2; Class code = 132**), parks and playground (**S.3.3; Class code = 133**) or other public facilities (**S.3.4; Class code = 134**; e.g. includes urban areas unused for recreational activities that are covered by significant green vegetation (e.g. green roundabout) and cannot be merged to the road network). A minimum mapping unit of 500m² applies.

S.4 – Sport and leisure

- >50% of the surface includes golf courses (**S.4.1; Class code = 141**), campgrounds (**S.4.2; Class code = 142**) or other sports facilities (**S.4.3; Class code = 143**; e.g. football, tennis, indoor/outdoor swimming-pools). A minimum mapping unit of 500m² applies.
- Includes other recreation facilities (**S.4.4; Class code = 144**) like allotment gardens and picnic areas. A minimum mapping unit of 500m² applies.

S.5 – Technical infrastructure

- Facility for the production and provision of water, electricity, gas or heat as well as for the evacuation, disposal or recycling of waste material or wastewater (**S.5.1; Class code = 151**). A minimum mapping unit of 500m² applies.
- Mining and extraction areas (**S.5.2; Class code = 152**). A minimum mapping unit of 500m² applies.

S.6 (Class code = 160) – Construction sites (Areas that are characterized as a construction site at the time of aerial survey, regardless of future use, e.g. street, commercial, housing). A minimum mapping unit of 500m² applies.

T – TRANSPORT

Transport includes all connecting roads between settlements (**T.1.1 – Rural roads; Class code = 611; T.1.2; Class code = 612– Main roads**), railway facilities (**T.2; Class code = 620**), airports (**T.3.1; Class code = 631 – commercial; T.3.2; Class code = 632– sports & leisure**), harbours (**T.4; Class code = 640**), parking lots (**T.5; Class code = 650**). A minimum mapping unit of 100m² applies to T.1.1 and T.1.2; a minimum mapping unit of 500m² applies to the other subclasses. Still, patches smaller than 500m² can be found in the final map when resulting from contiguous parcels split by the road network.

Traffic does NOT include single buildings. Only functionally associated buildings (e.g. service areas, gas stations, road maintenance depot) are included here.

Sub-classes are not foreseen, except for roads and air traffic.

A – AGRICULTURE

The classification of agricultural areas differentiates between three main land use categories: arable land, grassland and special crops.

Similar to “settlements”, which include individual buildings and their surroundings (e.g. urban gardens), individual fields are grouped into agricultural blocks which are delineated by roads, water courses or hedgerows.

A minimum mapping unit of 500m² applies. Patches smaller than the minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

A.1 (Class code = 210) – Arable land

Arable land can encompass various land cover classes, such as bare soil (fallow land), herbaceous (crops) and even woody (coppice < 30 years) vegetation.

A differentiation by crop type is not foreseen.

A.2 (Class code = 220) – Grassland

Contrary to "arable land" the grassland class is characterised by the lack of bare soil during the year (i.e. no ploughing). Nevertheless, woody vegetation can occur (orchards or surface overgrown by bushes).

The frequency of mowing can be included as a sub-type indicator of the management intensity, but it needs multi-temporal or other ancillary data to be distinguished.

A.3 – Special crops

Special crops include wine, fruits, orchards and other special crops (e.g. hop):

- Wine (sub-type **A.3.1; Class code = 231**) includes surfaces in flat as well as hilly terrain, with or without vegetation in between the rows.
- Fruits trees (sub-type **A.3.2; Class code = 232**) – contrary to orchards (sub-type **A.3.3; Class code = 233**) – are characterised by the linear arrangement of the plants.
- Other (sub-type **A.3.4; Class code = 234**) includes agricultural surfaces not included in the previous sub-types, such as greenhouses.

F – FOREST

The thematic block "forest" is mostly composed of the land cover class "woody vegetation". A "forest" is composed of woody vegetation of surfaces > 500m², although also multiple smaller patches can be classified as forest if overall they achieve a tree cover density of > 10% and a total surface of > 500m². Analogue to the class "settlement" and "agriculture", forest classes are delineated by "connecting" roads and water courses. Therefore, patches of forest classes smaller than 500m² can be found in the final map when resulting from contiguous forest parcels split by the road network.

F.1 – Forest block

The following forest types are mapped:

F.1.1 (Class code = 311) – Coniferous (>75% coniferous)

F.1.2 (Class code = 312) – Mixed (25% < coniferous < 75%)

F.1.3 (Class code = 313) – Deciduous (>75% deciduous)

F.1.4 (Class code = 314) – Young Forest (It represents forest regeneration / recolonization or natural succession with the mean vegetation height between 0.5 and 3 meters above the ground surface, such as young plants of broad–leaved and coniferous species, with herbaceous vegetation and dispersed solitary adult trees. If young trees cannot be identified in the plot, then it should be classified into class F.2 – clearing.

F.2 – Clearing

Area inside the "forest" temporarily without woody vegetation cover. Normally a clearing was wooded before and will be wooded again. Temporarily clearings can contain one or more land cover classes (e.g. bare soil or grassland < 500m²).

Clearings are mostly caused by normal forestry related activities (sub-type **F.2.3; Class code = 323** = "other"), but can also have specific origins (i.e. forest fire (**F.2.1; Class code = 321**), and storm damages (**F.2.2; Class code = 322**)).

N – NATURAL AND SEMI-NATURAL AREAS

Natural and semi-natural areas are mostly defined and monitored by specific inventories like the "Biotopkataster" and the "Grünlandkartierung". The delineation of these sites is a-priori defined by these specific inventories and EO are subsequently used to detect changes within these boundaries. A minimum mapping unit of 500m² applies. Patches of natural and semi-natural elements that are smaller than the pre-defined minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

N.1 (Class code = 410) – Gravel

Surfaces covered > 50% by land cover class "gravel".

N.2 (Class code = 420) – Rocks

Surfaces covered > 50% by the land cover class "rocks".

N.3 (Class code = 430) – Natural grasslands

Surfaces covered > 50% by the land cover class "grassland" that are also in the Biotopkataster mapped as natural or dry grasslands. The key characteristic of dry grasslands is that they have low-growing plants, causing the area to be quite open, and soils that are relatively dry and nutrient-poor.

N.4 (Class code = 440) - Heathland

Surfaces covered >50% by open, low growing woody vegetation (e.g. heath).

N.5 (Class code = 450) – Bushes

Surfaces covered > 50% by the land cover class "bushes". These areas are often found at the outer perimeter of forests or they represent a succession state from former agricultural use to a forest vegetation, e.g. former vineyards that have been abandoned and left to natural succession.

N.6 (Class code = 460) – Wetland

A wetland is a land area that is saturated with water, either permanently or seasonally. The delineation should be based on specific ancillary data, nonetheless evidence should also be present in the EO data.

W – WATER

The land use block Water includes permanently water covered surfaces, including adjacent, functionally associated areas such as slopes, riparian vegetation and foot paths.

W.1 – Running water

Permanently flowing water. Delineated is the water course itself plus the immediately adjacent water influenced area, e.g. 30-year flood return period. A minimum mapping unit of 500m² applies.

W.1.1 **(Class code = 511)** –Natural

Water course of natural origin (e.g. river, creek).

W.1.2 **(Class code = 512)** –Artificial

Man-made water course (e.g. channel).

W.2 – Standing water

Spatial information about the distribution of lakes and reservoirs is essential for the effective management of competing uses, such as flood and fire control, drought mitigation, agricultural irrigation, recreation, etc. Therefore, for this class, a minimum mapping unit of 100m² applies.

W.2.1 **(Class code = 521)** –Natural

Water body of natural origin (e.g. lake).

W.2.2 **(Class code = 522)** –Artificial

Man-made water body (e.g. reservoir).