Validation of Copernicus High Resolution Layer on Imperviousness degree for 2006, 2009 and 2012

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Abtract
The validation of a dataset such as the Copernicus Pan-European imperviousness degree high resolution layer requires considerable effort. A stratified systematic sampling approach was developed based on the LUCAS sampling frame focusing on a 2 stage stratification approach. A two-stage stratified sample of 20,164 1ha square primary sampling units (PSU) was selected over EEA39 based on countries or groups of countries which area was greater than 90,000km² and a series of omission and commission strata. In each PSU, a grid of 5 x 5 Secondary Sample units (SSUs) with a 20 m step was applied. These points were photo-interpreted on orthophotos with a resolution better than 2.5m.
Initial results based on the binary conversion of the map by applying the 30% threshold indicate a level of omission and commission errors substantially greater than the required maximum level of 15% set in the product specifications. However, this assumes that complete information is available for each PSU which is not the case. An alternative procedure was applied to the quantitative continuous data considering the sampling error due to the SSUs selection which is expected to exhibit a more realistic assessment of the amount of omission and commission.

Keywords
Sratified systematic sampling approach, LUCAS, Binomial confidence interval, Omission error, Commission error

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I INTRODUCTION

Pan-European High Resolution Layers (HRL) provide information on specific land cover characteristics, and are complementary to land cover / land use mapping such as in the CORINE Land Cover (CLC) datasets (Büttner et al. 2012) as part of the Land Monitoring Service (land.copernicus.eu) of the Copernicus programme, managed by the EC. The HRLs are produced from 20 m spatial resolution satellite imagery through a combination of automatic processing and interactive rule-based classification.

Five themes have been identified so far, corresponding with the main themes from CLC, i.e. imperviousness (the level of sealed soil), tree cover density and forest type, permanent grasslands, wetlands and water bodies. Products with an initial pixel size of 20 by 20 m are aggregated into 100 by 100 m grid cells for final pan-European mosaic products. The imperviousness layer was the first to be produced during 2006-2008 from multi-sensor, bi-temporal and ortho-rectified satellite imagery, the same as used for the CORINE Land Cover 2006 update. The production of IMD2006 covered 38 European countries (32 EEA Member States and 6 West-Balkan countries). Since the 2006 production, a time series of imperviousness has been produced for reference years 2009 and recently 2012 over the whole area covered by the 39 member and cooperating countries of the European Environment Agency (EEA) representing a total of 6 million km². For each year it is available as a raster layer with 20 m resolution. At the time of undertaking this study, the area delivered for the year 2012 was around 90% of the total area and the study is based on this area (Spain, Greece, Cyprus and the French overseas regions are missing).

Built-up areas are characterized by the substitution of the original (semi-) natural land cover or water surface with an artificial, often impervious cover. These artificial surfaces are usually maintained over long periods of time. The imperviousness HRL captures the spatial distribution of artificially sealed areas, including the level of sealing of the soil per area unit. The level of sealed soil (imperviousness degree 1-100%) is produced using an automatic algorithm based on a calibrated normalised difference vegetation index (NDVI). A description of the Copernicus Imperviousness layer methodology was described by Gangkofner et al. (2010) for the 2009 update and by Lefebvre et al (2013) for the 2012 update. Similar methods were also applied in the USA for the development of the National Land Cover database (Xian et al. 2011).

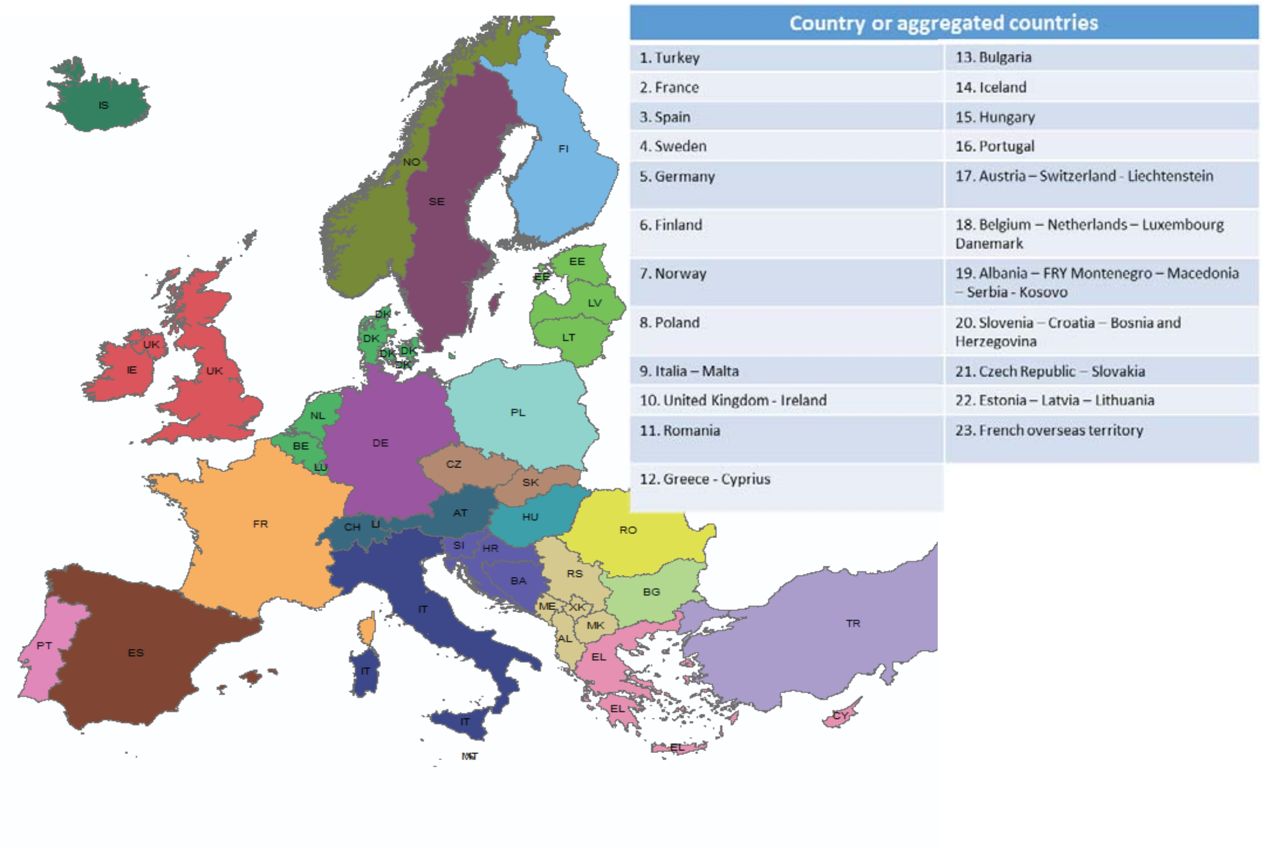
A density threshold of 30% was used to derive the built-up layer from the imperviousness layer. This was not intended to be a separate product, but instead was calculated for the verification process only, because density products cannot be verified.

The objectives of this study were to develop and implement an accuracy assessment exercise (i) capable to confirm the results obtained by participating countries during the verification phase based on the built-up mask (Büttner, 2012), (ii) suitable to assess the accuracy of the imperviousness layer at EE39 (iii) whilst ensuring that the results can be analysed at bio-geographical region or large country level to ensure that there are no major regional differences.

II METHODS

The validation of this dataset over such a large area requires considerable and mostly unprecedented effort. Much of the literature on the assessment of the accuracy of impervious surface delineation from remotely sensed data tend to focus on relatively small areas (Ji & Jensen 1999, Yang et al. 2003, Chabaeva et al. 2007). The only comparable example is that of the National Land Cover Database of the Conterminous United States (Wickham et al. 2013) and a recent study from Hansen et al. (2014). However, this study focuses primarily on imperviousness changes and the accuracy assessment is therefore combined with that of the other land cover classes. In fact, relatively low accuracies are reported for the imperviousness change class, which is partially linked to the fact that imperviousness areas although constantly increasing, still occupy a very small portion of the total land area. In Europe, it is currently estimated that artificial surfaces represent less than 5% of the total EEA39 (Büttner et al. 2012) and it should be expected that impervious surfaces would only represent a subset of this area, which makes it a very rare class and a particular challenge to assess its accuracy with a high degree of precision.

Wickham et al. (2013) applied a stratified random sampling approach using the land cover classes as strata. This ensured that sampling intensity is adapted to the occurrence of each class to reach a sufficient level of user's accuracy even for rare classes (Wickham et al. 2013). For the European Imperviousness layer, a similar approach was applied but based on a stratified systematic sampling approach using the EUROSTAT Land Use / Cover Area fram statistical Survey (LUCAS) sampling frame (Gallego and Delincé 2010) and focusing on a 2 stage stratification approach. The main advantage of using a LUCAS based approach is that a systematic approach ensures full traceability and it is also possible that sampling units will be shared for assessing several products, thus providing potential economies of scale. The first stage was to identify countries or groups of countries with an area greater than 90,000km² (see figure 1 below). This step allowed the analyse of the results for different countries and biogeographical regions to assess whether any heterogeneity in the quality of the data across different regions did emerge.



Country or aggregated countries	
1. Turkey	13. Bulgaria
2. France	14. Iceland
3. Spain	15. Hungary
4. Sweden	16. Portugal
5. Germany	17. Austria – Switzerland - Liechtenstein
6. Finland	18. Belgium – Netherlands – Luxembourg Danemark
7. Norway	19. Albania – FRY Montenegro – Macedonia – Serbia - Kosovo
8. Poland	20. Slovenia – Croatia – Bosnia and Herzegovina
9. Italia – Malta	21. Czech Republic – Slovakia
10. United Kingdom - Ireland	22. Estonia – Latvia – Lithuania
11. Romania	23. French overseas territory
12. Greece - Cyprius	

Figure 1. Level of reporting by country or aggregated countries as applied in the external validation.

Then as a second stage, for each country or groups of countries, omission, commission and commission change strata were determined as follows:

- Commission 2006-2009-2012-2015: Imperviousness Degree 30-100% in 2006-2009-2012

- Omission High Probability 2006-2009-2012: Imperviousness Degree 0-29% & CLC impervious classes 2006-2009-2012
- Omission Low Probability 2006-2009-2012-2015: Rest of the area 2006-2009-2012
- Commission Change 2006-2009: all changes [increased and decreased]
- Commission Change 2009-2012 : all changes [increased and decreased]

As indicated the commission strata were included to increase the precision of user's accuracy and the inclusion of a high probability omission error was to increase the precision of the producer's accuracy.

A minimum of 50-100 1ha square primary sampling units (PSU) were deemed sufficient to reach the required precision and were selected per stratum resulting in a total of 20,164 PSUs over the EEA39 area. Each 1ha PSU corresponds to a single 100m pixels in the aggregated imperviousness layer. A detailed procedure to map the imperviousness, involving field data or photo-interpretation, of all PSUs would be too time consuming and expensive. Therefore, in each PSU a grid of 5 x 5 secondary sample units (SSUs) with a 20 m step was defined (see figure 2). These SSUs were photo-interpreted against orthophotos with a spatial resolution better than 2.5m to determine if they were sealed. If a point falls on the boundary of an impervious element, a shifting rule is applied so that roughly half of the points in this situation are classified as impervious.

Figure 2: Example of SSUs organised in a 5x5 20m grid

III THEMATIC ACCURACY BASED ON 30% THRESHOLD

A 30% threshold was applied to the imperviousness degree product to convert the continuous density product to a binary mask (Büttner 2012).

Thematic accuracy is presented in the form of an error matrix made out of the results of the interpretation of the samples and their actual values in the impervious layer. As explained in (Selkowitz & Stehman, 2011), unequal sampling intensity resulting from the stratified systematic sampling approach should be accounted for by applying a weight factor (p) to each

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

sample unit based on the ratio between the number of samples and the size of the stratum considered:

(1)

where i and j are the columns and rows in the matrix, N is the total number of possible units (population) and π is the sampling intensity for a given stratum.

This is because the samples from smaller strata show a higher sampling intensity than those from the larger strata. Therefore, a correction for the sampling intensity will be applied to the error matrices produced, following the procedure described by (Selkowitz & Stehman, 2011) and applied by (Olofson et al., 2013). This leads to a weighting factor inversely proportional to the inclusion probability of samples from a given stratum. Not applying this correction could result in underestimating or overestimating map accuracies.

Initial results based on the binary conversion of the map by applying the 30% threshold indicate a level of omission and commission errors substantially greater than the required maximum level of 15% set in the product specifications. There is also considerable variability across different bio-geographical regions and group of countries and it should be noted that the 2012 layer exhibits higher accuracy to that of the 2009 and 2006 layer, which can be explained by the fact that there are always improvements made during the production of an updated dataset. However, omission errors appear to be heavily influenced by the presence of omissions in the low probability stratum which carry substantial weight. This may suggest that the stratification approach selected for omission probably needs to be revisited.

IV ANALYSIS OF IMPERVIOUSNESS DEGREE VALUES

In addition, the assessment based on the binary mask assumes that complete information is available for each PSU, which is not the case since the PSU level estimate of imperviousness is based on the SSUs. Therefore, an alternative procedure was applied to the quantitative continuous data considering the sampling error due to the SSUs selection, which is expected to exhibit a more realistic assessment of the amount of omission and commission errors.

If we had a complete information on the cell for our reference data, a reasonable measure of the commission φ and omission ψ errors would be:

$$\varphi = \frac{\sum_i pos(m_i - r_i)}{\sum_i m_i} \qquad \psi = \frac{\sum_i pos(r_i - m_i)}{\sum_i r_i} \tag{2}$$

where $pos(x)$ is the positive part, i.e. $pos(x) = x$ if x>0 and $pos(x) = 0$ if x≤0.

If the map reports a proportion m_i and the reference data give a proportion r_i ,

For each sampling unit of 100 m we have a quantitative value in the map (estimated % in the satellite image classification) and a reference value that is an estimation obtained from a sample of 25 points. The number of impervious points that we are using as reference value has a probability distribution due to the within-cell sampling. If the within-sampling is random, the number of points follows a binomial B(25, p). In our case the sampling scheme is systematic, but we use anyhow the binomial as an approximation.

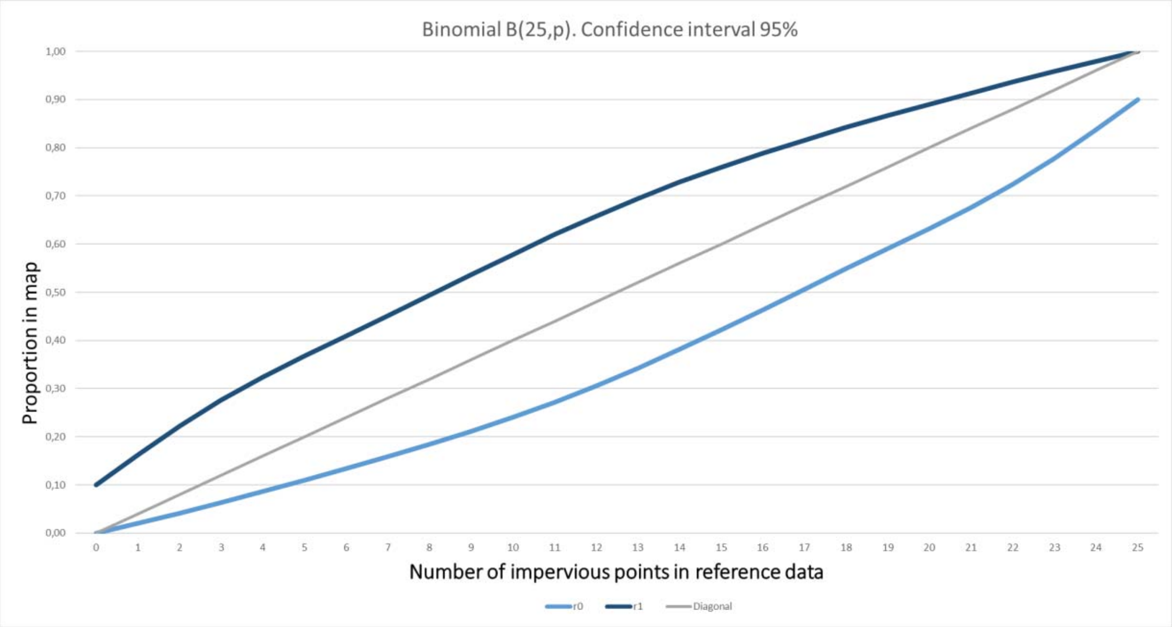


Figure 3: Representation of the behaviour of the 95% confidence interval for a 5x5 SSU grid over the whole range of imperviousness degree values

Therefore we cannot say that there is any significant disagreement if m_i lays within (r_{0i},r_{1i}), a confidence interval corresponding to B(25, r_i). Figure 3 represents the behaviour of the 95% confidence interval for B(25, r_i). Notice that only for proportions close to 0.5 we can apply the usual Gaussian approximation that leads to an interval approximately ($r_i \pm 2s_i$), while for proportions close to 0 or to 1 the intervals are strongly asymmetric.

A possible adaptation of the formulas above for the commission φ and omission errors ψ would be:

$$\varphi = \frac{\sum_i pos(m_i - r_{1i})}{\sum_i m_i} \qquad \psi = \frac{\sum_i pos(r_{0i} - m_i)}{\sum_i r_i} \tag{3}$$

The results obtained show that the amount of error is less than 10% for commission and just under 20% for omission, which exceeds the desired level of accuracy for this layer with regards to commission errors. But again this is heavily influenced by omissions included in the large area low omission strata. When removing just 39 points from the sample corresponding to these large strata (out of more than 20,000), the level of omission error is then reduced to 13%, which is within the acceptable range of accuracy expected for the imperviousness layer. This again suggests that the stratification approach for assessing omission errors needs to be revised to better target areas of potential omission.

V CONCLUSIONS

The results from the accuracy assessment exercise seem to suggest that the Copernicus Imperviousness High Resolution Layer appear to reach or even exceed the required level of accuracy (less than 10-15% error for both omission and commission errors) particularly with respect to commission errors, but the stratification approach would need to be further improved to better target omission errors.

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