Assessing the Agreement between Deforestation Maps of Kalimantan from Various Sources

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Abstract. Due to its multiscale impacts, deforestation of tropical rainforests had become a global concern. A number of stakeholders comprising government, research agencies, and NGOs; ranging from local to international levels; have developed their own forest monitoring systems for detecting forest loss. However, discrepancies on deforestation reports from various producers often trigger public debates; which mostly degenerate the productivity of efforts in providing salient, legitimate and credible data on deforestation. Thus, we should reconcile the dispute by acknowledging the deforestation data from all sources. This study assessed the agreement between deforestation maps from various sources. In this case, deforestation maps of Kalimantan within 2009-2013 period from 4 sources were used; i.e. deforestation maps from European Space Agency - Climate Change Initiative (ESA-CCI), Forest Watch Indonesia (FWI), Global Forest Watch (GFW), and Indonesian Ministry of Environment and Forestry (MoEF). We found that the inter-rater agreement between deforestation maps were relatively low, as indicated by Cohen's kappa ($\kappa$), ranging from slight ($\kappa=0.18$ between ESA-CCI and GFW) to fair (0.24 $\leq \kappa \leq$ 0.35 for other pairs of sources); due to omission/commission disagreements (47.82% to 87.58%). It suggests that in order to reconcile the dispute, we should remove the omission disagreement by forming the union of deforestation maps. The results from further analyses proved that the union of deforestation maps increased the agreement to moderate ($\kappa=0.44$ between union map and FWI) and even substantial ($\kappa=0.79$ between union map and GFW). Findings of this study should support the implementation of one map policy.

Keywords: agreement assessment, deforestation maps, Kalimantan, one map policy

1. Introduction
Due to its multiscale impacts, deforestation of tropical rainforests had become a global concern [1,2, 3, 4, 5, 6, 7]. A number of stakeholders comprising government, research agencies, and NGOs; ranging from local to international levels; have developed their own forest monitoring systems for detecting forest loss [8,9, 10]. However, discrepancies on deforestation reports from various producers often trigger public debates, e.g. public response to [11]; which mostly degenerate the productivity of efforts in providing salient, legitimate and credible data on deforestation for policy formulation [12, 13]. Thus, we should reconcile the dispute by acknowledging the deforestation data from all sources [14].
In this respect, this study is aimed at assessing the agreement between deforestation maps from various sources and exploring possibility to reconcile the disparities in the deforestation estimates.

2. Window area and data

2.1. Window area
Kalimantan, Indonesia as part of Borneo Island was selected as the window area to assess the agreement between deforestation maps from various sources (Figure 1).

![Figure 1. Window area of the study, situated in Kalimantan, Indonesia.](image)

2.2. Data
Deforestation maps of Kalimantan within 2009-2013 period from 4 sources were used (Table 1); i.e. deforestation maps from European Space Agency - Climate Change Initiative (ESA-CCI) [15], Forest Watch Indonesia (FWI) [16], Global Forest Watch (GFW) [17], and Indonesian Ministry of Environment and Forestry (MoEF) [18, 19].

| Sources | Satellite imageries | Remote sensing/interpretation methods | Resolution (m) |
|---------|---------------------|--------------------------------------|----------------|
| ESA-CCI | MERIS, SPOT Vegetation, PROBA V, AVHRR | Digital | 300 |
| FWI     | Landsat 8           | Visual                              | 30          |
| GFW     | Landsat 8           | Digital                              | 30          |
| MoEF    | Landsat 8           | Visual                              | 30          |
3. Methods

Work flow to assess the agreement between a pair of deforestation maps from 2 sources is shown in Figure 2. In this case, measurement of agreement indicators was carried out using raster maps. Thus, all deforestation maps from 4 different sources used in this study were converted into raster maps at the highest resolution of 30-m.

Moreover, measurement of agreement indicators of omission and commission disagreements (%) were carried out using equations provided by [20]; while inter-rated agreement of Cohen kappa coefficient ($\kappa$) was carried out using equation provided by [21]. Since, omission disagreement of map i relative to map j equals to commission disagreement of map j relative to map i; and inter-rated agreement of Cohen kappa coefficient ($\kappa$) is bidirectional; hence, measurement of agreement indicators was carried out using 6 pairs of deforestation maps, as listed in Table 2.

**Table 2.** Assessment of agreement between deforestation maps of Kalimantan from 4 different sources was carried out using the checked pairs of maps.

| Pair of deforestation maps ij | ESA-CCI | FWI | GFW | MoEF |
|-------------------------------|---------|-----|-----|------|
| ESA-CCI                       | √       |     |     |      |
| FWI                           |         | √   |     |      |
| GFW                           |         |     | √   |      |

Furthermore, omission disagreement (%) of deforestation map i relative to deforestation map j ($O_{ij}$) was calculated as follows:

$$O_{ij} = 100 \frac{\sum d_j - \sum d_{ij}}{\sum d_j} \quad (1)$$

Where, $\sum d_j$ denotes total deforested area found in map j and $\sum d_{ij}$ denotes total deforested area found in both maps, i and j (total matching area of deforestation). In this case, producer agreement (%) was defined as 100% - omission disagreement.

In this case, commission/omission disagreements with values less than 0-25% is poor, 25-50% is slight, 50-60% is fair, 60-70% is moderate, 70-80% is substantial and 80-100% is very strong.

Similarly, commission disagreement (%) of deforestation map i relative to deforestation map j ($C_{ij}$) was calculated as follows:

$$C_{ij} = 100 \frac{\sum d_i - \sum d_{ij}}{\sum d_i} \quad (2)$$

Where, $\sum d_i$ denotes total deforested area found in map i and $\sum d_{ij}$ denotes total deforested area found in both maps, i and j (total matching area of deforestation). In this case, user agreement (%) was defined as 100% - commission disagreement.
While in this study, omission and commission disagreements were calculated based on deforestation area only; inter-rater agreement of Cohen kappa coefficient ($\kappa$) of 2 deforestation maps was calculated by considering not-deforested area; indicating the overall agreement; with values ranging from -1 (totally in disagreement each other) to +1 (totally in agreement each other):

$$\kappa = \frac{\sum a (\sum d\,i + \sum r\,i) - (\sum d\,i \sum d\,j + \sum r\,i \sum r\,j)}{\left(\sum a \right)^2 - (\sum d\,i \sum d\,j + \sum r\,i \sum r\,j)}$$

(3)

Where, $\sum d_i$ denotes total deforested area found in map $i$, $\sum d_j$ denotes total deforested area found in map $j$, $\sum d_{ij}$ denotes total deforested area found in both maps, $i$ and $j$ (total matching area of deforestation), $\sum r_i$ denotes total not-deforested area found in map $i$, $\sum r_j$ denotes total not-deforested area found in map $j$, $\sum r_{ij}$ denotes total not-deforested area found in both maps, $i$ and $j$ (total matching area of non-deforestation), and $\sum a$ denotes total map area.

According to [21], strength of agreement of Cohen kappa coefficient ($\kappa$) with values less than 0.00 is poor, 0.00-0.20 is slight, 0.21-0.40 is fair, 0.41-0.60 is moderate, 0.61-0.80 is substantial and 0.81-1.00 is almost perfect.

Finally, reconciliation among 4 different deforestation maps was carried out in this study by removing omission disagreement ($O_{ij} = 0\%$) through union operation ($\cup$), combining those 4 maps into single map. It can be proven mathematically by expressing Equation (1) into set operation as follows:

$$O_{ij} = \frac{J - (I \cap J)}{J}$$

(4)

Thus, when $O_{ij} = 0$ then $J = (I \cup J)$, that can only be satisfied if $I$ is $I \cup J$. This proof is in line with [22] that reconciliation can be done through aggregation. After forming the union map, agreement assessment was again carried out to recheck the agreement between the union map with each of 4 deforestation maps used in this study.
4. Results and discussions

4.1. Results
Figure 3 shows deforestation maps from each of 4 sources, their union and total deforestation estimates. Deforestation estimate from GFW dominated other maps, thus close to the union.

Figure 3. Deforestation maps of 4 sources, their union map and total deforestation estimates.
Agreement between deforestation maps from 4 sources are shown in Figure 4; which agreement indicators are listed in Table 3.

Figure 4. Agreement between deforestation maps from pairs ij of 4 sources. White: not-deforested in both maps i and j (agreement on non-deforestation); red: not-deforested in map i but deforested in map j (omission disagreement on deforestation); green: deforested in map i but not-deforested in map j (commission disagreement on deforestation); blue: deforested in both maps i and j (agreement on deforestation).
Table 3. Agreement indicators between deforestation maps from 4 sources.

| Pair of deforestation maps | κ | Omission disagreement (%) | Commission disagreement (%) | Producer agreement (%) | User agreement (%) |
|-----------------------------|---|--------------------------|-----------------------------|------------------------|--------------------|
| ESA-CCI x FWI               | 0.25 | 79.45                     | 61.23                       | 20.55                  | 38.77              |
| ESA-CCI x GFW               | 0.18 | 87.58                     | 47.82                       | 12.42                  | 52.18              |
| ESA-CCI x MoEF              | 0.26 | 76.72                     | 65.69                       | 23.28                  | 34.31              |
| FWI x GFW                   | 0.24 | 80.48                     | 56.53                       | 19.52                  | 43.47              |
| FWI x MoEF                  | 0.35 | 58.12                     | 67.29                       | 41.88                  | 32.71              |
| GFW x MoEF                  | 0.24 | 49.75                     | 82.38                       | 50.25                  | 17.62              |

Moreover, agreement between the union of deforestation map with 4 sources are shown in Figure 5; which agreement indicators are listed in Table 4.

Figure 5. Agreement between union of deforestation maps (i) with 4 sources (j). White: not-deforested in both maps i and j (agreement on non-deforestation); red: not-deforested in map i but deforested in map j (omission disagreement on deforestation); green: deforested in map i but not-deforested in map j (commission disagreement on deforestation); blue: deforested in both maps i and j (agreement on deforestation).
Table 4. Agreement indicators between deforestation maps from 4 sources.

| Pair of deforestation maps | \( \kappa \) | Omission disagreement (%) | Commission disagreement (%) | Producer agreement (%) | User agreement (%) |
|----------------------------|-----------|---------------------------|----------------------------|------------------------|-------------------|
| Union x ESA-CCI            | 0.26      | 0.00                      | 83.88                      | 100.00                 | 16.12             |
| Union x FWI                | 0.44      | 0.00                      | 69.60                      | 100.00                 | 30.40             |
| Union x GFW                | 0.79      | 0.00                      | 32.30                      | 100.00                 | 67.70             |
| Union x MoEF               | 0.36      | 0.00                      | 76.26                      | 100.00                 | 23.74             |

4.2. Discussions

Table 3 suggests that the inter-rater agreement between deforestation maps were relatively low, as indicated by Cohen's kappa (\( \kappa \)), ranging from slight (\( \kappa=0.18 \) between ESA-CCI and GFW) to fair (0.24 \( \leq \kappa \leq 0.35 \) for other pairs of sources); due to relatively high omission/commission disagreements of deforested areas (47.82% to 87.58%).

The inter-rater agreement with \( \kappa \) of 0.35 achieved by pair of FWI x MoEF deforestation maps; suggests that even when the deforestation maps were developed using the same satellite imageries, i.e. Landsat 8; the same remote sensing/interpretation methods, i.e. visual; and the same resolution, i.e. 30-m (see Table 1); the agreement was still categorised as “fair agreement” according to [21]. However, since the agreement between FWI and MoEF was the highest among other pairs; it should be considered that standardising the methodology on deforestation map development into a protocol might be a promising option that can be adopted in one map policy formulation. In the case of FWI x MoEF, since they applied visual interpretation methods; subjectivity or robustness of the methods can then become the source of disparities in the estimates [14]. Suggestion by [14] is confirmed by the lowest inter-rater agreement with \( \kappa \) of 0.18 achieved by pair of ESA-CCI x GFW deforestation maps; where satellite imageries and resolution used by both providers are different (see Table 1). However; developing a protocol, agreed by all stakeholders; is in fact complicated, especially when deforestation issue become “political” [23]; thus, can potentially decrease its legitimacy and its adoptability within the relevant policy formulation framework [13].

Furthermore; Table 4 suggests that when the omission disagreement was removed by developing a union of deforestation maps from 4 sources; the agreement between the union map and 4 sources increased to moderate (\( \kappa=0.44 \) between union map and FWI) and even to substantial (\( \kappa=0.79 \) between union map and GFW). All Cohen's kappa coefficients (\( \kappa \)) between the union map and 4 sources (Table 4) were in fact highly correlated with total deforested area (Figure 3). Thus, lower deforestation estimate from a source was compensated with lower \( \kappa \) agreement or higher commission disagreement to the union; and vice-versa. In other words, deforestation map with the highest estimate was apparently “benefited” by the union; and vice-versa. However, we should remind that the aggregation through union map formation is aimed at removing omission disagreement; implying to accepting deforestation estimates by others, which not included.

However, this finding proved that combination of deforestation maps through union can be considered as alternative to reconcile the ongoing dispute on deforestation estimates, instead of locking the method into a protocol. As long as the producers of deforestation maps are responsible on the credibility of their works by among other providing publicly accessible documentation on the methods and accuracy assessment report; we can let the development of deforestation maps be “democratic”; done by as many producers as possible, since crowds of the experts can provide the wisdom, as the basis for a smart and yet better policy [24].

Finally; with regards to deforestation maps with different resolution; in the future, we will apply a multiple resolution procedure as suggested by [25] to assess the agreement between deforestation maps from various sources with different resolutions.
5. Conclusion
Based on deforestation maps of Kalimantan within 2009-2013 period from 4 sources; i.e. deforestation maps from European Space Agency - Climate Change Initiative (ESA-CCI), Forest Watch Indonesia (FWI), Global Forest Watch (GFW), and Indonesian Ministry of Environment and Forestry (MoEF), this study found that the inter-rater agreement between deforestation maps were relatively low, as indicated by Cohen’s kappa (κ), ranging from slight (κ=0.18 between ESA-CCI and GFW) to fair (0.24 ≤ κ ≤ 0.35 for other pairs of sources); due to omission/commission disagreements (47.82% to 87.58%). It suggests that in order to reconcile the dispute, we should remove the omission disagreement by forming the union of deforestation maps. The results from further analyses proved that the union of deforestation maps increased the agreement to moderate (κ=0.44 between union map and FWI) and even substantial (κ=0.79 between union map and GFW). Findings of this study should support the implementation of one map policy.

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