

Monitoring of Refugee and Camps for Internally Displaced Persons Using Sentinel-2 Imagery – A Feasibility Study

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Abstract

The Department of Geoinformatics of the University of Salzburg Z_GIS offers mapping products of camps of displaced people to support the operational work of Médecins Sans Frontières (MSF – Doctors Without Borders) and other humanitarian actors. These maps are usually based on very-high resolution satellite imagery, featuring a spatial resolution of up to 30cm/pixel. These very detailed satellite images allow the extraction of individual dwellings as the basis for a detailed estimation of the population of a particular camp. Such images are acquired on demand only, and are priced by square kilometre, making reconnaissance observations over larger areas or repetitive monitoring tasks very costly. In contrast, the European satellite Sentinel-2A, launched in June 2015, features global coverage, a ground resolution of 10m/pixel, and its imagery is available free of charge. In this ongoing study, we explore the potential of Sentinel-2A imagery for the monitoring of refugee camps and camps for internally displaced persons (IDPs), either using only Sentinel-2 images, or using a combination of Sentinel-2 and VHR imagery. As expected, the spatial resolution of Sentinel-2 is just at the limit of what is required for mapping such camps. Therefore, the operational use of it depends on the size and the structure of the camp (planned vs. spontaneously formed), and the season, governing the contrast between dwellings and soil/vegetation. Sentinel-2 imagery can be a valuable asset to increase situational awareness, can help guide the acquisition of VHR images, and, in conjunction with analyses on VHR images, can allow a semi-continuous monitoring of dwelling numbers with a reasonable margin of error, of around 10%, as compared to VHR analyses alone.

Keywords:

Earth Observation, humanitarian action, Sentinel-2, population estimation

1 Introduction

Over recent years, Earth Observation (EO) and Geographical Information Systems (GIS) have become ubiquitous tools for information gathering and management for humanitarian organizations, in particular in regions where data collection on the ground is either too time-consuming or too dangerous, as evidenced by the growing number of service providers in this field. Regular EO-based information products are provided by, for example,

UNOSAT/UNITAR and the related REACH initiative, as well as to a certain degree by the Copernicus Emergency Management Service (see overview in Lang et al., this issue); Z_GIS has been producing EO-based information products for Médecins Sans Frontières (MSF) since 2008 (Lang et al., 2015). The most-requested information products are population estimations for camps hosting refugees and internally displaced persons (IDPs). These estimations are based on single-dwelling extraction using very-high resolution imagery, and related advanced map products such as dwelling density and dwelling change analysis. In the current ongoing project EO4HumEn+, Z_GIS, the German Aerospace Center DLR, the University of Tübingen and Spatial Services GmbH, together with the humanitarian actors the Austrian Red Cross and the International Committee of the Red Cross (ICRC), MSF, SOS Children's Villages and Groundwater Relief, are striving to develop further EO applications and information products in new settings beyond the current portfolio, using either different datasets or addressing situations other than refugee/IDP camps.

One of the main drawbacks of the currently employed analyses based on very high resolution (VHR) imagery is the cost of this imagery, calling for alternative, less expensive data sources within the high resolution (HR) domain. If suitable, this HR imagery would be used as the basis for the analysis, effectively replacing the VHR imagery, or it could be used at least at a preliminary stage for rapid change assessment, situation awareness, and a better-posed pre-selection of VHR imagery. The potential of HR imagery to serve these purposes is addressed by this ongoing study. VHR imagery is now commercially available at ground resolutions of up to 30cm/pixel, allowing the extraction of individual dwellings for population estimation. However, the costs for such images are considerable for the humanitarian sector, in particular NGOs (Lang et al., 2015), and for relief logistics in general (Delmonteil & Rancourt, 2017). As an extreme example, tasking the 30cm-imagery already referred to can cost up to 9,810 US\$ for the minimum order size of 100 square kilometres¹. This makes reconnaissance over larger areas or repeated monitoring costly. The European Sentinel-2 satellite constellation provides HR satellite imagery with the highest resolution currently available for free. It features 10m/pixel ground resolution in the visible and near infrared spectrum (plus further bands with lower spatial resolution). It offers quasi-global coverage and a current revisit time of 10 days at the equator, which is going to fall to 5 days after commission of Sentinel 2B, launched in March 2017 (ESA, 2017a). Thanks to the large swathe width of 290km, the revisit time in mid-latitudes will be only 2 to 3 days (ESA, 2017b). Sentinel-2 records data in 12 different bands of the visible and near infrared part of the electromagnetic spectrum, but the spatial resolution varies between 10m/pixel and 60m/pixel (ESA, 2017c).

But how useful is this data for the monitoring of refugee camps? To test this, we compared VHR images of camps we had already analysed with Sentinel-2 images of approximately the same date. We selected two camps, one a planned camp with regularly spaced buildings/tents (Minawao, Cameroon, Lat. 10.563°N, Lon. 13.856°E), and one less-structured refugee/IDP settlement (Ngala in Nigeria, Lat. 12.360°N, Lon. 14.170°E). For the Minawao camp, a total of five dwelling extractions were made based on VHR images. Here, we acquired all available

¹ Based on WorldView Global Alliance Base Products' commercial Price list, 2 May 2016. Price example for Select Plus New Collection 4-band 30cm imagery: 54.50 US\$/km² + 80% uplift for high-demand countries, which include, among others, Nigeria and Syria.

cloud-free Sentinel-2 images over the course of approximately one year. The time between VHR and Sentinel-2 image acquisitions ranged between 3 and 33 days, due to varying cloud cover. For comparison, we used VHR images and the dwelling extractions we had made on them. These analyses were part of our operational service for MSF, and usually follow a 2-stage approach. In the first stage, object-based image analysis (OBIA) is employed to extract as many dwellings as possible in a semi-automatic manner. The efficiency of this stage depends on the spectral contrast between dwellings and the surrounding soil/vegetation and is thus governed by the dwelling types present and the season. In the second stage, the OBIA-based results are thoroughly checked and refined visually. Dwellings attached to each other, which had been merged in the OBIA analysis, are separated, and low-contrast dwellings are added. The procedure is described in more detail in Füreder et al. (2015), and Füreder et al. (2014). Similar approaches are also employed by Taubenböck et al. (2010) and others in informal settlements. In the operational service, the dwellings are distinguished by their shape and colour as observable in the VHR images, for example white tents vs traditional tukuls. In this study, we used the overall number of dwellings, regardless of their types. We also compared the dwelling numbers extracted from the VHR images and the dwelling numbers estimated from Sentinel-2 images with the total camp population as recorded by the UNHCR.

2 Increased situation awareness

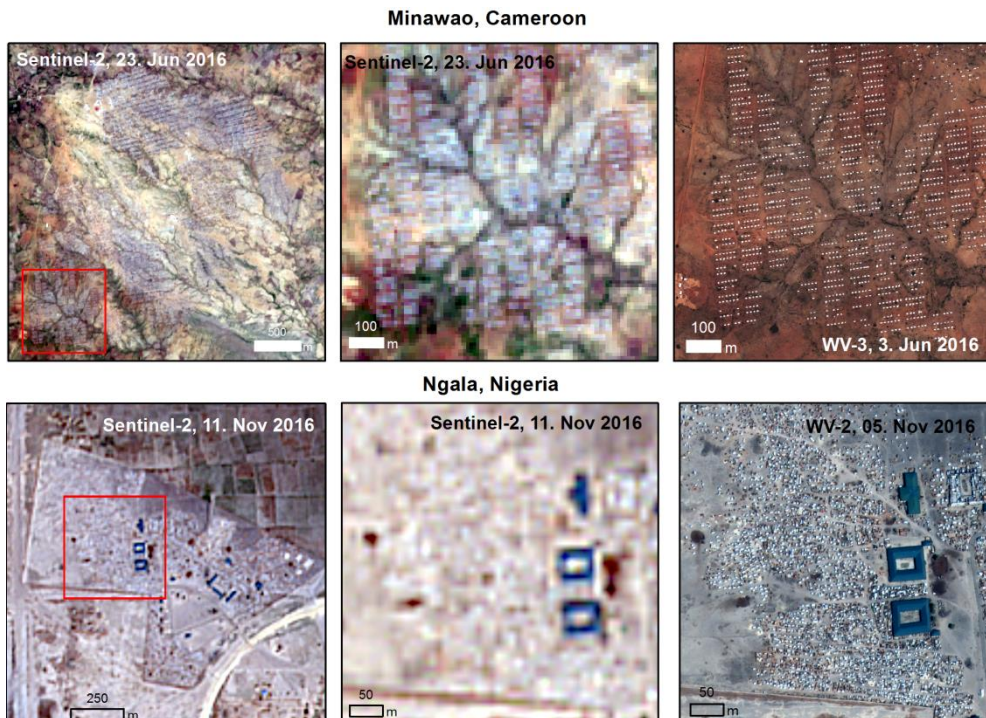


Figure 1: The Refugee/IDP camps of Minawao, Cameroon, and Ngala, Nigeria, as seen in Sentinel-2 images (left and centre) and in WorldView (2/3) images (right).

While it was clear that the ground resolution of 10m/pixel of Sentinel-2 images would not be spatially precise enough to extract single dwellings, it was unclear under which circumstances the Sentinel-2 images might be used effectively for the observation of refugee/IDP camps. In order to visually assess this, we compared VHR images of two camps with Sentinel-2 images of approximately the same time. The results are visualized in Figure 1. For Minawao, the figure shows a Sentinel-2 image taken on 23 June 2016 next to a VHR image acquired by WorldView-3 on 3 June 2016. Minawao is a refugee camp hosting people displaced by the conflict between Boko Haram and the Nigerian armed forces in the Lake Chad region. At the time of these images, the camp had a population of approximately 56,800 (UNHCR, 2017).

The comparison of Sentinel-2 images and VHR images is shown in Figure 1, displaying the natural colour bands (red, green, blue) stretched to the dynamic range present in the shown image subsets in order to maximize the contrast. In the example of Minawao, individual dwellings can hardly be discerned, but blocks of dwellings can be quite clearly seen. In the case of Ngala, an IDP camp in northern Nigeria, the comparison between the VHR image of WorldView-2 acquired on 5 November 2016 and the Sentinel-2 image of 10 November 2016, the distinction between areas covered by dwelling, and areas free of dwellings is limited due to the uniform spectral characteristics. Still, the appearing texture may be indicative for the overall extent of the camp. But here, while larger buildings can be clearly recognized, the Sentinel-2 image would not have provided enough detail even to locate the refugee/IDP settlement, had its location not been known beforehand. In this study, we compared various band combinations visually to test whether the camp area would be identifiable due to a distinct spectral signature. The test showed that for Minawao, the camp was best visible in the bands with the highest spatial resolution of 10m/pixel, and that the bands with lower spatial resolution were of little use for this task. In Ngala, the extent of the camp covered by dwellings could not be identified, either in the bands with the highest spatial resolution, or in the spectral bands outside the visible spectrum.

3 Dwelling change monitoring

Sentinel-2A with its current revisit time of 10 days (at the equator) lends itself for the monitoring of the evolution of camps over time. This is the case for large, planned camps in particular, where newly constructed dwellings are fairly easy to recognize visually, and the spatial extent of the camp can be assumed to be strongly correlated with the population numbers. To test this, we compiled a time series for Minawao over a period of one year between October 2015 and November 2016, starting with the first Sentinel-2 image available for this area since the launch of the satellite. The time series consists of five VHR images analysed earlier for MSF, and 14 Sentinel-2 images. Over this time, the camp grew from approximately 46,000 to 60,000 inhabitants.

Two aspects were of particular interest: (1) How well can the built-up area be monitored and mapped? We considered as built-up areas only the camp blocks, meaning the dwellings and the roads and pathways between them, and not the larger open spaces between the individual camp blocks (see Figure 2). (2) How well can the spatial extent of the built-up area be used

as a proxy for the total number of dwellings? To test this, we used the numbers we had derived from the semi-automatic, object-based single-dwelling extractions that we had done for MSF as part of our operational service, using the VHR images. We calculated the overall dwelling density by mapping the built-up areas visually in the VHR images. We then mapped the extent of the built-up area in the Sentinel-2 images visually. To aid the distinction of dwellings vs. bare soil, we stretched the radiometry of the images to the dynamic range present in the observed subset of the scene. We also experimented with image filters to enhance the contrast further.

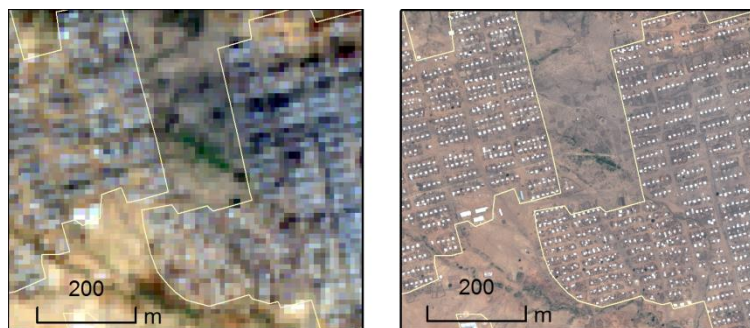


Figure 2: Left: detail of Minawao in Sentinel-2 image of 24 May 2016. Right: same location as seen in VHR image of 3 June 2016. Only the area covered with dwellings was mapped as the camp's built-up area; areas between camp blocks, devoid of dwellings, were excluded, if they were distinguishable in the Sentinel-2 images.

We then mapped the extent of the built-up camp areas visually. The extent mapped and derived from the Sentinel-2 images was used in conjunction with the dwelling density established in the VHR scenes to predict the dwelling numbers at the time of the Sentinel-2 image acquisitions. The methodology is very similar to area-based rapid population assessment methods such as the Quadrat method (Brown et al., 2001), which estimates the population of a camp or settlement by counting the population in a (limited) number of sample squares of 25m x 25m, which is then extrapolated to the entire camp extent. The method can be refined by stratifying the entire camp area into zones of similar expected population/dwelling density. An overview of mapping methods for refugee and IDP camps using EO data is provided by Kemper and Heinzl (2014).

In this test case, the underlying assumption was that the dwelling density remains constant, meaning that an increase in dwelling numbers (and population) is linearly correlated with the camp's built-up extent. The setup of a planned refugee camp often follows the widely accepted Sphere standards (The Sphere Project, 2017). These guidelines provide minimum standards for the space required per camp inhabitant, the minimum spacing between tents and so forth, and have also been adopted by the UNHCR (UNHCR Emergency Handbook, 2017). Therefore, it is reasonable to assume a strong correlation between camp size and dwelling number, in particular in camps that are not constrained by the surroundings, as in an urban setting. In contrast, non-planned or spontaneously emerging camps, such as many IDP camps, are often less structured, so that the density of dwellings is less uniform

throughout the camp and changes over time, making a dwelling/population estimation based on the camp extent less straightforward.

The time series for Minawao is shown in Figure 3. Although not ideally visible in this image due to the small size of the figure, the Sentinel-2 images allow mapping of the built-up area quite well. The growth of the camp by about 30%, mainly towards the south-east, is fairly visible in the Sentinel-2 images. Overall, the distinction of dwelling blocks is easiest when the contrast with the surroundings is high thanks to the presence of active (green) vegetation, but the white tents present in this camp are also fairly readily distinguishable from the surrounding bare earth during the dry season. However, the exact mapping of the built-up extent in the Sentinel-2 images is somewhat subjective, and not always clear. For example, two small parts of the camp were mapped as being built-up area, which a later VHR image showed to be bare earth.

The results of the dwelling extractions and predicted dwelling numbers are shown in Figure 4. The dwelling numbers extracted from the VHR images increase from 13,235 on 13 October 2015 to 18,206 on 1 April 2016 (Figure 4A). The extracted dwelling numbers then drop to 16,601 for the VHR image of 3 June 2016. Using the built-up area of the camp and the extracted dwelling numbers, the dwelling density can be calculated. Based on this, the development of the dwelling numbers can be predicted, using the camp extent mapped in Sentinel-2 images, resulting in five different curves (dotted and dashed lines in Figure 4A). The built-up area of the camp grew from 272.6 hectares on 13 October 2015 to 361.4 hectares on 20 November 2016 (Figure 4B). The camp population as recorded by the UNHCR grew in the same period from 46,571 to 59,469 inhabitants (Figure 4C). From the camp's built-up area (Figure 4B) and the camp population (Figure 4C), we calculate the mean built-up area per inhabitant (Figure 4D). This varies between $58.5\text{m}^2/\text{person}$ on 13 October 2015 and $63.8\text{m}^2/\text{person}$ on 19 November 2015, with a mean value of $61.5\text{m}^2/\text{person} \pm 2.1\%$. From the extracted dwelling numbers and the camp population recorded by the UNHCR, we can also calculate the number of persons per dwelling, for every dwelling extraction (Figure 4E). This number varies between 3.1 and 3.5 persons/dwelling, with an average of $3.28 \pm 4.88\%$.

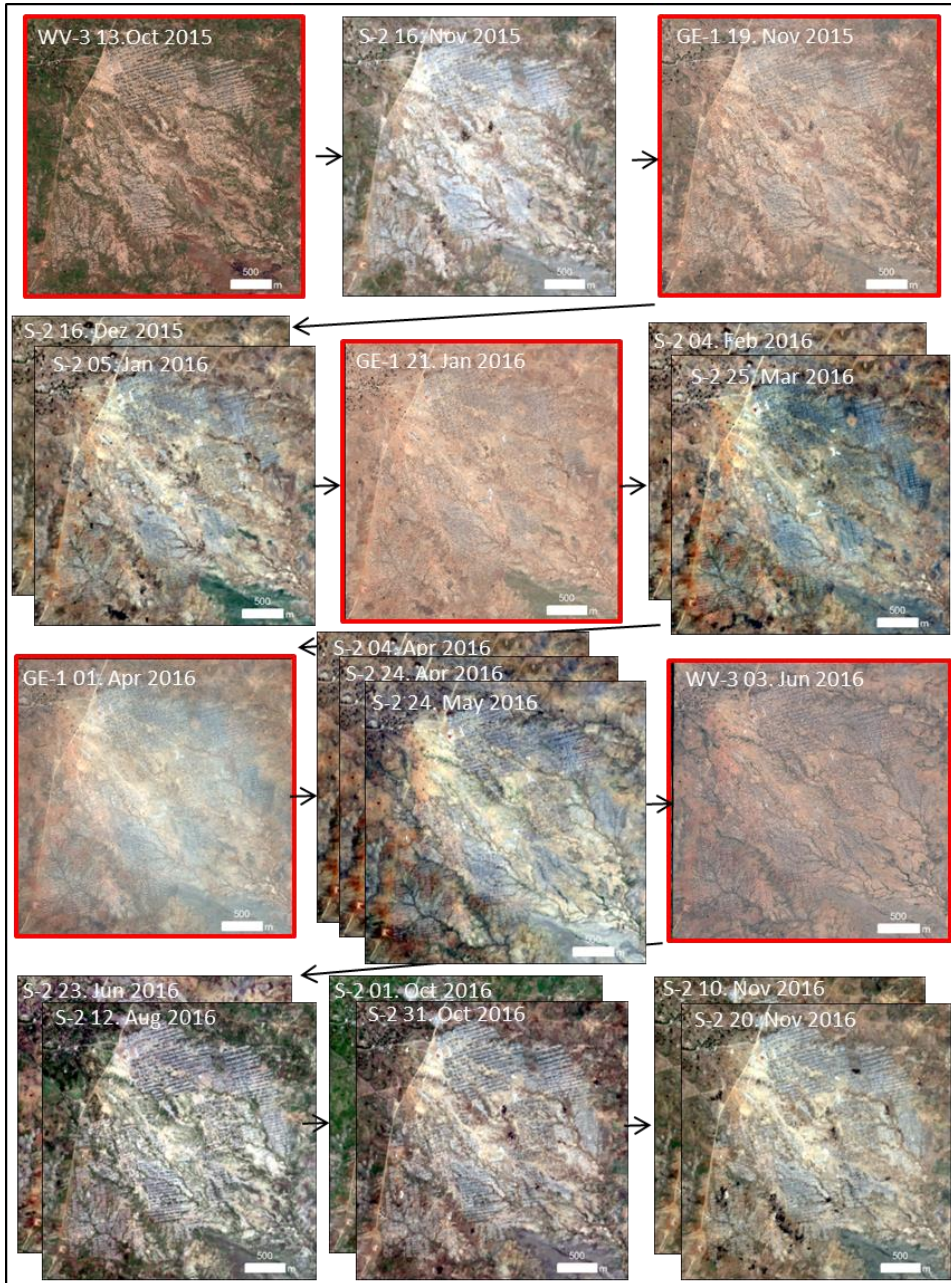


Figure 3: Time series of the refugee/IDP Minawao camp, Cameroon, near the border with Nigeria, comprising five VHR images (red frames) and 14 Sentinel-2 images, from October 2015 to November 2016.

4 Discussion

The numbers of the extracted dwellings from the VHR images show a strong increase between 13 October 2015 and 1 April 2016. This is in line with an increase in the camp's built-up area and the growth of the camp population recorded by the UNHCR. The apparent fall in dwelling numbers observed in the VHR image of 3 June 2016 is remarkable, as this drop is not underpinned by a decrease of the camp's built-up area or its population: both continue to grow. Further investigations are necessary to understand the actual situation. Potential but as yet unconfirmed reasons could be a difference in image quality, such that either individual dwellings have not been recognized in the latest VHR image, or several attached dwellings have been identified as one larger dwelling, resulting in lower overall numbers. Using the dwelling density calculated from one VHR image to predict the number of dwellings in later Sentinel-2 or VHR images always resulted in an underestimation of the dwelling numbers. The difference between extracted and predicted dwelling numbers was up to 7%, not taking into account the latest VHR image of 3 June 2016. This figure is in line with assessments of similar rapid population estimations performed by Grais et al. (2006) and Checchi et al. (2013), which report deviations from reference population numbers in the order of 5 to 10%.

The difference between extracted and predicted dwelling numbers can be explained by an increase of the dwelling density between the first four VHR image acquisitions. The reason for this might be that the camp inhabitants had erected further self-made structures on their compounds in addition to the tent they originally inhabited. These additional structures, identified as dwellings, could be storage rooms, kitchen huts or latrines, for example. Thus, the dwelling numbers might increase without an increase of camp inhabitant numbers. Another explanation for the observed drop in extracted dwellings might be that some of these additional structures are not permanent, and therefore might be present only for a particular time or in a particular season.

In this camp, the initially erected dwellings are various types of white tents. One mitigation strategy to avoid problems caused by the additional structures could be to count only these white tents, disregarding dwellings with any other appearance. However, thorough analysis is necessary before doing so, as experience from many mapped camps has shown that the inhabitants tend to replace the initially erected tents by other dwelling types, such as tukuls. These inhabitants would not be accounted for if these dwelling types were omitted from calculations.

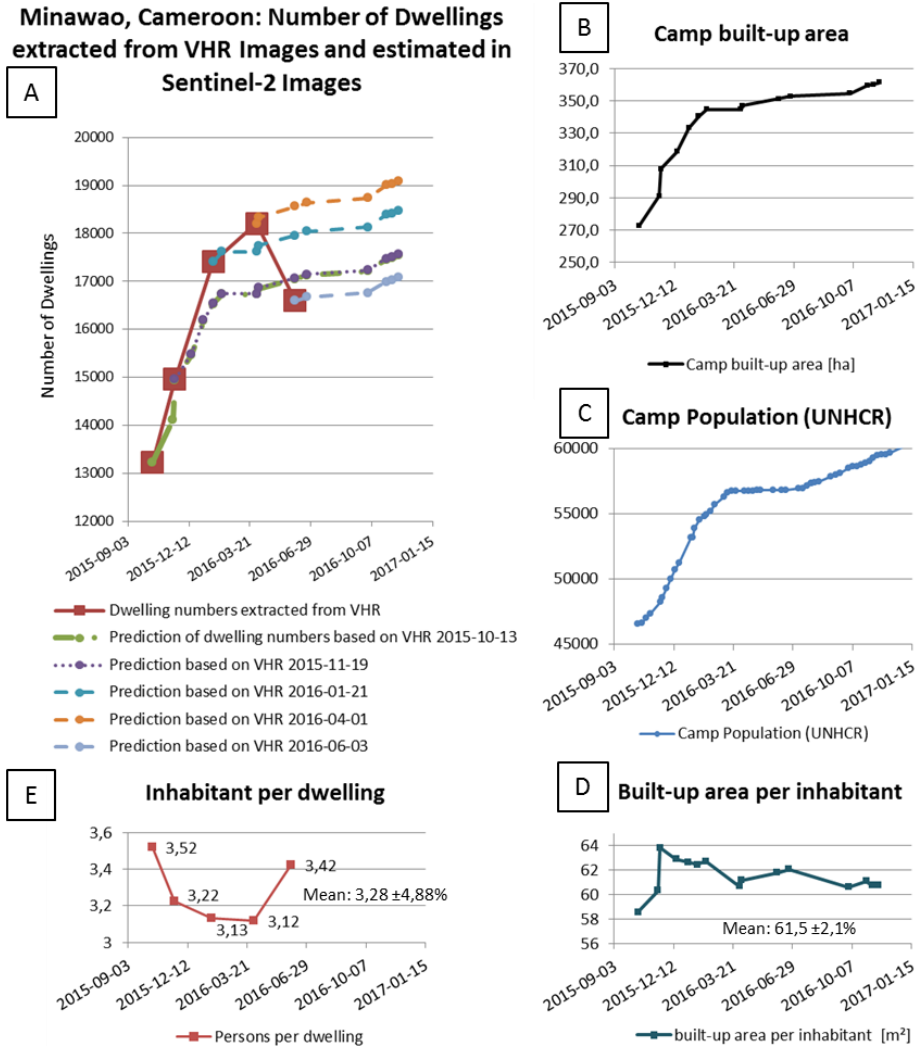


Figure 4: Dwelling numbers extracted from VHR images compared to dwelling numbers predicted from VHR images and population numbers from the UNHCR.

Using the UNHCR population numbers as reference, the average built-up area per inhabitant has a standard deviation of just 2% (Figure 4D), whereas the standard deviation of the occupancy rate per dwelling (Figure 4E) has a standard deviation of 4.9%. This suggests that the overall built-up area in this very regular camp appeared to be a better proxy for the camp population than the dwelling numbers. Further tests in less homogeneous camps, possibly employing different density zones as suggested by Brown et al. (2001), are planned as the next steps.

5 Conclusion

We tested the operational use of Sentinel-2 images for rapid situational awareness and the support of dwelling and population number estimations for the mapping of refugee and IDP camps. The free availability, global coverage and short repeat cycle of Sentinel-2 make this data type interesting for this application, despite its spatial resolution being at the limit of what is required for the task. The imagery can be used to plan the area of image capture (Area of Interest, AOI) and timing of more detailed but also more complex analyses of VHR images. The identification of dwellings depends on the camp structure and the contrast with the surrounding area (bare earth or vegetation), which is governed by the season. Individual dwellings were not recognizable, but the built-up area could be identified and used to estimate dwellings numbers, as the dwelling density had been established in a previous VHR analysis. For the planned and very regularly structured camp analysed here, the Sentinel-2 images underestimated the dwelling numbers by up to 7% as compared to those extracted from VHR images, because the dwelling density had increased since the VHR analysis. The ratio between overall built-up area as observed in Sentinel-2 and VHR images and the camp population was very stable, with a standard deviation of only 2%. Further tests on other camps will be performed before this analysis methodology will be considered for operational service.

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