EO-based environmental impact assessment of camps: a differentiated spatial view using multi-scale satellite imagery

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Rationale

This paper highlights the interplay between needs-oriented and technology-driven capacities of EO data analytics in the context of humanitarian action. It sketches existing and emerging technologies in the 'geohumanitarian' realm, illustrating in a few applied examples how geospatial tools can assist humanitarian aid in the nexus of forced migration and the environment. This view, intentionally synoptic, reflects personal experience in collaborating with humanitarian NGOs, in particular *Médicins Sans Frontières* (Doctors without Borders, MSF), and seeking ways to facilitate logistics and support mission planning in the field. More detailed and comprehensive background information are contained in the references provided.

EO-based evidence on environmental impact

Population displacement causes hardships to the affected people in need and poses challenges on the host communities. The latter depends on the magnitude of the influx, as a function of space and time, and the respective carrying capacity both in terms of societal and environmental systems. This may include, amongst other adverse effects, deforestation due to fuelwood collection, soil erosion and land degradation, (ground-)water abstraction and pollution. Such effects, in turn, may (re-)inforce tension and conflicts and evoke secondary reasons for migration in the course of deteriorating environmental conditions, increased population pressure, overuse of natural resources, decreasing soil fertility and competing usages of land.

Earth observation (EO) encompassing remotely sensed data (mainly via satellites) and ground measurements is nowadays widely used in the humanitarian application domain (Lang et al., 2019). It helps assess environmental impacts of forced migrations and allows monitoring them over time. Not all impacts, however, are as obvious and remotely assessable in an objective manner. For illustration, a few spotlights are shed on major refugee movements, purposely simplified in their portrayal. South Sudanese refugees entering into Uganda before 2016 were largely invited to integrate in existing village structures encouraged by a foreign-friendly welcome policy. However, when the influx exceeded a certain level, it triggered the erection of dedicated camps (e.g. Bidi Bidi) in northern Uganda. The forest close to the South Sudanese border transformed into a cultivated settlement area within a few months, with emerging dwelling structures including garden plots and crop fields. Pre- and post-imagery impressively demonstrate the growth of the (then) largest camp in the world. In Kutupalong in Bangladesh, nowadays the largest refugee camp complex in the world hosting more than 600,000 Rohingya refugees, the camp management since 2015 seeks permanently for expansion. Notably such widening often happens in a speed that Google Earth is not able to catch up. Immediate and intuitive impacts as these, clearly understood and readily measurable by spatial tools, are well suited for planning or any corrective measures – at least from a technical point of view. But sometimes, the environmental impact lies deeper behind obvious changes, when for example the potential contact of one of major elephant migration hampers expansion in this direction. In addition, the environmental impact may occur in a more subtle way. A larger share of the internally displaced population in Darfur, Sudan, resettled in 2004 around the village of Zam Zam, which over a short period grew into huge IDP camp with a large urbanised area hosting more than 200,000 inhabitants. In this case, the actual impact on the environment and its effect on the carrying capacity of this arid area is hard to determine. Such impact, manifesting over time, has implications to gradual depletion of natural resources in particular.

Multi-scale and multi-source assessments

Such multi-scale space-time phenomena to capture is a novel strength of satellite Earth observation. A series of different constellations (according to sensor type, resolution, frequency, etc.) and the increasing availability and accessibility of remotely sensed data, enables a differentiated spatial view on environmental impact.

What means multi-scale in this context? With the use of satellite data of different spatial (and temporal) resolutions, we gain insights on different geographical scale levels (a.k.a., scale of observation, such as local, regional, sub-continental, etc.), and its corresponding temporal dimensions. Despite the recent developments of microsatellites and swarm constellations, we may still consider the relationship between spatial and temporal resolution a 'reverse' one. Fine-scale observations (very-high spatial resolution, VHR, < 1m) are provided by commercial satellites (e.g., WorldView, Pleíades), acquired on-demand by tasking, whilst coarser scale observations (mid-to-high spatial resolution, MR, HR, 250m to 10m) deliver freely available in online repositories, highly reliable and standardized EO data sets (e.g., MODIS, Landsat, Sentinel-2). Once a specific scale of observation is determined, we are able to monitor in a quasi-static view, familiar from meteorological forecast geostationary satellite. Because EO satellites operate in orbital mode, the appropriate technological answer is data cubes, which allows queries and analyses over time. A semantic data cube for the Syrian-Turkish border region has been set up by to investigate vegetation dynamics, as well as crop and irrigation patterns (Augustin, Sudmanns, Tiede, Lang, & Baraldi, 2019) . Moving one-step ahead from image stacks to semantic information over time, this semantic data cube utilizes the potential to perform fully automatic low-level conversion of pixel values to information primitives. Using a space-time modelling language, this can be utilized for observations-based, yet user-driven, decision making (Sudmanns et al., 2019).

Another implication of the scale of observation in the context of EO-based environmental impact assessment is the availability of globally available reference data sets for the purpose of data assimilation. Assimilating satellite observations with other modelling results (e.g., from ground measurements or physical models or other global data sets) greatly increases the insights into complex phenomena. In particular, for monitoring purposes, the observing system needs to assure the actual status of the environmental parameter or object of interest is measured but not the divergence in observation. Advanced data integration techniques, including data fusion, resolution merge, ground referencing, calibrating & validating, play of their potential in multi-source data pools. Often such data assimilation, for practical reasons of data availability, may be done ad hoc and sort of asymmetrically: results from VHR data (fine-scaled, yet rare in time) are mapped against high-frequent data products e.g. from MODIS data (Kranz, Sachs, & Lang, 2015). Data products derived from satellite data are highly standardized early-stage information layers, residing between pre-processing and analysis and acting as information primitives. The normalised difference vegetation index (NDVI) and the enhanced vegetation index (EVI) belong to the twelve scientific data sets (SDS) of a MODIS VI product; they provide a vegetation (and water) mask, which helps monitor key aspects such as seasonal vegetation patterns. The MODIS 10-year aggregated product can be used as benchmark to report changes on and seeking for anomalies. These data also allow disaggregating climate data (e.g. precipitation, temperature), reported on national scale or other administrative units. The potential of deriving biophysical parameters from well-calibrated satellite sensors stresses the importance of physical-based models. The broader the scale, the more trust on capturing the typical systemic patterns and recursive regimes. The finer the scale, the more we seek for idiosyncrasies, anomalies, deviations. Clearly, such combination of fine-scale and coarse-scale observations is one of the assets of multi-scale assessments.

Having a methodological toolbox at stake, input data and areas of interested can be altered and adapted accordingly. The well-known limitations of optical data pleas for using synthetic aperture radar (SAR) data, both complementary or stand-alone (Braun, Lang, & Hochschild, 2016). The main advantage: data acquisition is widely independent from adverse weather conditions or seasonal effects; whilst the downside is a more complex handling of radar data in general. Again, Level-3 products can be used to determine changes, as shown by Braun, Fakhri, & Hochschild (2019) in the vicinity of the Kutupalong camp.

One tool hardly does it all, and one observation instrument can hardly measure everything. Another example of the interplay between different resolutions is the observation of camp growth and dynamics. Sentinel-2 is used to monitor the footprint of a camp (Wendt, Lang, & Rogenhofer, 2017) in relation to a reference outline, using semantic data cube technique as mentioned above. Thus, in regular time intervals (approx. 5-10 days), the geometrical changes of the footprint as compared to the previous one can be measured and systematically analysed. Trends can be derived and potential conflicts avoided. However, for a detailed understanding of the actual dynamics inside and within the immediate surroundings of the camp in terms of composition, newly erected housings, infrastructure, vegetation, burial fields, etc., we need VHR data. While increasingly drone data are used for this purpose, there is still a lot of implications in terms of access, permission, processing, repeatability, etc. With advanced expert- and machine-based classification routines applied to VHR satellite data, we are able to detect dwelling types and categories, the origin of tents, the ratio between traditional and additional dwellings, the distribution of latrines, the agricultural regime (gardens, fields, trees, etc.), etc. With advanced techniques of hybrid AI, i.e. merging knowledge-based and deep-learning approaches (Ghorbanzadeh, Tiede, Wendt, Sudmanns, & Lang, 2020; Tiede, Wendt, Schwendemann, Alobaidi, & Lang, 2021), we can utilize GPU processing power ingesting a solid understanding of camp structures gathered through numerous visual and semi-automated interpretation task. An often neglected advantage of satellite-based analysis is the capability to view camp growth retrospectively (Lang, Tiede, Hölbling, Füreder, & Zeil, 2010).

In sum, there is substantial progress made in rapidly providing detailed insights on the nature and inner structures of camps using ever improved image understanding techniques; notwithstanding however the notion, that with increasing detail, we gradually touch upon ethical issues as well.

Integration of expert evaluation

Another strategy of data assimilation is the combination of EO data and domain expertise using multi-criteria evaluation and expert weighting. In this approach, pixels are loaded with ‘values’ originating from expert judgements. This is how we advance the concept of impact from a pure biophysical assessment to an expert-based, multidisciplinary, evaluation. Thus, ‘impact’ becomes relative and, to some degree, subjective, reflecting various viewpoints and value systems. In doing so, we first decompose a complex concept such as 'impact' and then re-build an aggregated index taking into consideration different weightings of the measured land cover changes. When developing this methodology in assessing the potential impact on land degradation of the aforementioned IDP camp Zam Zam, we created a *Natural Depletion Index* emphasizing environmental and social aspects (Hagenlocher, Lang, & Tiede, 2012). For either aspect, we obtain a differentiated view on what the change of land cover classes actually means and what it implies. The general principle is, again, to combine observations with models, here: value systems. Transferring this approach to the refugee camp Dagahaley in Kenya (Braun, et al., 2016), we derived the land cover changes from SAR time series (Sentinel-1 and ERS-2) and applied an adapted weighting scheme and slight modification of the index calculation.

Outlook

Novel ways of data assimilation enhance the understanding of complex phenomena such as 'impact', and enables a comprehensive assessment beyond singular studies. Impact may no longer be seen as a simplified, unidimensional effect, but rather as an interplay of different aspects and factors, one can explore separately, and aggregate on demand. Geospatial data integration and multi-dimensional regionalisation techniques adopting e.g. the geon approach (Lang, Kienberger, Tiede, Hagenlocher, & Pernkopf, 2014) help model complex interdependencies in a spatial explicit way. Thereby we advance from classical per-pixel methods and generate homogenous units, which represent the variability of the phenomenon and its uniform spatial response, yet not confined to administrative units. A well-sorted mix of EO data sources increasingly match the requirements in terms of coverage vs. detail, and compensate for adverse atmospheric or seasonal effects, if needed. Future research shall focus on further advancing robust and transferable methods to integrate models and observations using hybrid AI approaches, merging deep learning and expert systems taking the best of either worlds (Lang et al., in prep). Trends in shifting the observation scale in both space and time beyond the (recent) limits direct towards daily coverages and ad-hoc sensor fusions of optical and SAR data, such as a PlanetScope and ICEYE (Braun et al., in prep).

We kindly invite everyone interested in following up these trends discussing further implications at our hybrid event on *Geohumanitarian Action*, taking place 8 July as a special forum of the Digital Earth 2021 conference hosted in Salzburg, Austria.

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