2.1 Why study human settlements using Earth Observation?

Population increase is unprecedented and so it is the growth of human settlements. Population estimates assembled by the United Nations Agencies (United Nations 2015b) report on the nearly tripling of world population in the lifespan of the authors, from the nearly 3 billion in 1960 to the nearly 7.5 billion at the moment of writing. Population growth is accompanied by the physical growth of settlements for which there is no corresponding global figure, only rough estimates (Seto, Güneralp, and Hutyra 2012). In fact, the physical size of villages, towns, cities, megacities remains unaccounted for. Questions such as: **How much of Earth Surface is covered by settlements? How much and how fast are settlements growing? Where are they growing most?** Where are settlements growing on an unsustainable path, remain open questions. That physical size and its growth impacts societal processes at all levels (resilience) and good settlement information are required to guide country development plans, issue legislation aiming at developing risk free and sustainable societies (United Nations, General Assembly 2015). Earth observation is the most promising measurement system to address the assessment of human settlements from local to national and global scale (Martino Pesaresi, Guo Huadong, et al. 2013).

Population are accounted through censuses that are carried out by country statistical departments but not all countries keep up with the updates and most censuses do not account for physical size of settlements. Population censuses address the location, temporal dynamics, age structure, social wellbeing of population among many other characteristics. Censuses provides also information on the use dwellings like the average living space per person or the proportion of rural and urban population as reported by each country. However, **censuses do not report on physical variables that can provide an understanding of the spatial size of towns, villages or cities, or their physical characteristics**. In addition, the delays in carrying out the censuses and delays in reporting the findings leave many countries with no updated figures on population. These shortcomings are often addressed through global statistical models using physical spatial settlement information derived from satellite imagery to estimate current population spatial distribution (Freire Sergio, MacManus, Kytt, et al. 2016).

Settlements increase as a result of population growth within settlements and also as a result of urbanization. Urbanization is intended herein as the socio-economic process that moves people from low density-agricultural based environment to high-density-service sector based economy in large cities and settlements. Urbanization dynamics are complex and vary from continent to continent. The processes may be different but results may be similarly described as an increase of population that migrate to larger settlements in search for better livelihood that all require shelter, working environments, and facilities. That growth expands the physical size of settlements and with it the management challenges of larger functional bodies that require energy, resources, defence to natural hazards.

Human settlements are referred to as urban when of high population densities – as in cities – and as rural when related to low population densities – as in villages or hamlets. The urban-rural dichotomy that is the basis for census statistical accounting worldwide may not be adequate to fully describe urbanization patters and settlement growth today (Morrill 2004). In fact, the increase in settlement physical size as well as in population is not only associated with cities and megacities but also with that of smaller settlements. While the measurement of larger cities and megacities is relatively well documented, the location and growth of smaller settlements is largely unaccounted for and thus limiting our understanding of the new challenges of urbanization (Tony Champion and Graeme Hugo 2003) and the associated demographic processes that are at its core (Montgomery 2008) .

The need for global settlement information goes beyond scientific enquiries and has practical implication related to local and global sustainability. **Information on location**

and size of human settlement are used to model access (to services, market, industrial infrastructure, food, water, land), **exposure** (to natural / man-made hazards, disasters, pollution), and **impact** (of human activity on land and water ecosystems). In fact, global human settlement information are in demand by a number of institutions operating globally including the European Commission Services for Development and Humanitarian Aid[10], the United Nations agencies and programs, the World Bank, as well as the donor countries that require quantitative variables to prioritize their humanitarian and development aid or their national investments.

Crisis management relies on information on the hazard, exposure and vulnerability. The physical size of human settlement is the main information source for physical exposure. In fact, satellite imagery is an important data source used to quantify the building stock (Daniele Ehrlich et al. 2010) and the lifeline that can be harmed by hazard impacts. Satellite imagery can be used to derive exposure at all scales (D. Ehrlich et al. 2013; Daniele Ehrlich and Tenerelli 2013; Martino Pesaresi, Guo Huadong, et al. 2013) and exposure at the global level is mainly derived from human settlement information such as that of GHSL (Martino Pesaresi and Freire 2014).The different phases of crisis management including risk assessment, alerting of disaster and emergency response all require exposure information and all at fine detail that is not available to the degree required. Global alert systems such as the Global Disaster Alert and Coordination System (GDACS)[11] rely on models with exposure and vulnerability as the weak link of the model. **The more precise the information the better will be the outcome of the alert**. Similarly, disaster risk models rely on same exposure variables with the difference that it may need to take into account also the expanding settlements in the coming age.

In the relation between settlement location and geographical setting, **especially slopes and elevation are relevant for the risks associated to a changing climate**. Coastal and delta areas are the most fertile and suitable regions for human economic activities. Water bodies are used for transport, access to fisheries, and river deltas are among the most fertile agricultural lands. Low-lying areas are also the most vulnerable to changing climate and the potential increase in sea level (Intergovernmental Panel on Climate Change 2015). The accurate mapping of settlements location in low lying areas and the emerging hazardous zone is essential to devise mitigation or adaptation strategies. **Gravity associated to settlements in steep slope is the main underlying root cause that is triggered by hydro meteorological hazards**. These include flash floods or landslides in mountains or along steep coastal areas. Similar risks are emerging in a number of fast developing cities of low income countries such as Lima and Caracas (Intergovernmental Panel on Climate Change 2015, chap. 12).

As highlighted during the Habitat III preparatory process, up-to-date information about land use and cover, cadastral systems and vulnerable areas should be incorporated in the planning process, especially at local level. "Open and easily accessible geospatial data can support monitoring in many aspects of development, from health care to natural resource management. They can be particularly effective especially in spatial analyses and outputs that can also be compared worldwide. Considering the challenge of handling large amounts of data (both in terms of know-how and costs), local and regional authorities can work together with national and international institutions and research centres to make the most effective use of open, easily accessible data." (Preparatory Committee for the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) 2016)

Human settlement information are also used for developing indicators for the four post-2015 international frame-works including 1) Sendai framework for Disaster Risk Reduction (DRR) (United Nations 2015a), 2) Sustainable Development Goals (SDG) with particular focus on Goal 11 (make cities and human settlements inclusive, safe, resilient, sustainable), 3) Paris Climate Agreements and 4) the New Urban Agenda (to be

[10] http://ec.europa.eu/europeaid/about-development-and-cooperation-europeaid_en
http://ec.europa.eu/echo/
[11] http://www.gdacs.org/

adopted in Quito, Ecuador in October 2016). In fact, to monitor the implementation of the SDGs, it will be important to improve the availability and access to data and statistics to ensure that no one is left behind in the information gaps.

The lack of consistency in global settlement information produced through census campaigns and released in aggregate form by **UN has promoted the science community to invest in extracting information from the available satellite remote sensing archives and plan to process future incoming imagery**. Satellite image archives provide globally-consistent measurement system of earth surface characteristics; it is updated regularly and frequently and with increased spatial resolution and still provides a synoptic overview that is considered objective.

2.2 Mapping and measuring human settlements from remote sensing

Remote sensing technology and information extraction techniques have improved steadily in the most recent years. The first attempts to map settlements globally relied on coarse scale resolution imagery. The outcomes have been used extensively for mapping mainly cities and megacities. In fact, global human settlements have mostly been mapped from low to moderate resolution (300m - 1000m spatial resolution) (Potere and Schneider 2007) and with estimates that varies significantly (Schneider, Friedl, and Potere 2010) .

Changes in the physical size of settlements have been measured from a combination of coarse and moderate resolution imagery as well as from medium resolution imagery. For example, DMSP/OLS night time lights and SPOT-VGT data were used to detect changes between 1998 and 2008 in India by (Srinivasan et al. 2013) . MODIS 500m resolution images were used by (Mertes et al. 2015) to map urban areas in East Asia from 2000 to 2010.

Landsat imagery have been also very often used to map of the built environment. Angel and his team (Angel et al. 2015) mapped 120 cities over 1990 and 2000. Taubenböck et al. (Taubenböck et al. 2012) conducted a systematic analysis of 27 current mega cities using multi-temporal Landsat data from 1975, 1990, 2000 and TerraSar-X data from 2010.

The availability and the processing of new generation of global medium resolution imagery have provided new opportunities to generate built-up information. The Terrasar-X was also used in the TanDEM-X mission to generate a Global Urban Footprint (GUF) for the years 2011-2013 by (Esch et al. 2013). Global finer scale built-up areas mapping from Landsat was delivered by the Monitoring of Global Land Cover (FROM-GLC) project for the year 2006 as reported in (Peng Gong et al. 2013) (P. Gong and Howarth 1992). In FROM-GLC, only one epoch (circa 2006) was processed, and the impervious surfaces resulted with not satisfactory classification accuracy as presented in (Ban, Gong, and Giri 2015) and (Peng Gong et al. 2013). Successive experimental activity tried to inject in FROM-GLC output the urban or impervious information derived from third-parts, low-resolution satellite-derived information. Finally, a 30m resolution global land cover (GlobeLand30) was produced in 2014 (Yu et al. 2014).

The GHSL builds on past experiences and on different resolution settlement products and reports on processing 40 years of Landsat imagery for mapping the global built-up areas from 1975 to 2014 (M Pesaresi et al. 2016). The section bellow summarises the methods, the results the limitations and the way forward.