USING SATELLITE DATA FOR IMPROVED URBAN DEVELOPMENT

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Abstract

Satellite Earth Observation (EO) technology has a major potential to inform and facilitate international development work in a globally consistent manner. Since 2008 the European Space Agency (ESA) has worked closely together with Multi-Lateral Development Banks (MDBs) and their client countries to harness the benefits of EO in their operations and resources management. A new initiative of ESA which started in May 2016, the EO for Sustainable Development (EO4SD) Urban project aims to mainstream the application of satellite data for urban development programs being implemented by the MDBs and their counterparts. The project implemented by a European Consortium is providing a variety of geo-spatial products from baseline land use/land cover data, urban green areas and slum mapping for the implementation of urban development projects in about 40 different cities globally. The products from EO4SD will illustrate the utility of EO based data to monitor spatial features and structures on the ground with the frequency needed to assess trends in spatial urban patterns. The project will provide information to the stakeholders on the technologies and methods behind the geo-spatial products for the improved understanding on what satellite data can offer for urban planning as well as associated costs.

Key Words: Earth Observation, Urban Planning
1.0 Introduction

Satellite Earth Observation (EO) technology has a major potential to inform and facilitate international development work in a globally consistent manner. The data has the unique ability to allow the evaluation of past and present spatial features and structures on the ground with frequent, detailed global coverage, allowing comprehensive analyses of the development and trends of spatial urban patterns.

The multi-lateral development co-operation Banks (MDBs) such as World Bank (WB), Asian Development Bank (ADB) as well as national development banks have as their core business poverty alleviation and sustainable development which also encompass a variety of themes both environmental and social. Most of the MDB programs have requirements for timely, regular and consistent non-spatial and spatial data and information for implementation of their strategies which are geared towards implementing international/national policy segments as well as the policies in developing countries. Thus, in international policies and strategies in areas such as food security, natural hazard assessment, water management and improved urban planning there is a place for geo-spatial data which can form the basis for both, monitoring and more analytical work required for planning. Whilst there is a general appreciation of the role of geo-spatial data for program implementation by the MDBs and counterpart developing countries and the potential wealth of utilization of the EO/Geographic Information Systems (GIS) technologies for improved environmental management, the application of these data by the Banks and governments has not yet been mainstreamed into the programs. The role of EO is relegated to components of their programs on a piecemeal basis and thus there is no sustainability of the systems.

Currently almost 54% of the world’s population live in urban areas and this is projected to increase between 2014 and 2050, to around 2.5 billion people or 66% of the global population (Floater and Rode, 2014). The challenges faced by governments to manage this staggering growth are multi-faceted as they have to provide certain basic requirements to the population in terms of infrastructure, access to clean water, electricity, sanitation as well as services to the inhabitants in order to avoid urban poverty which will have consequences on the overall development of the country. Urban planning, critical to improved management of these various challenges, involves many functions, scales, sectors, and stages, and include the themes of land use assessment for different activities (residential, industrial etc.); transportation systems; green areas; infrastructure and public facilities (power grids, sewer systems etc.). The need for geo-spatial data for the assessment and monitoring of these features is core to urban planning and design. However it is an under-utilised technology in the urban planning in developing countries; and the utilisation of for example EO for urban planning and development are reliant on critical factors: demand from the user community which
includes both the MDBs and the end users in the Client States (CS) as well as cost-benefits of overall production.

This paper will present an overview of a project initiated by the European Space Agency (ESA) to address the improved and sustainable uptake of EO-based applications in urban development programmes. The paper will provide some examples of the utility of geo-spatial data for addressing urban planning. The next Section will present the ESA project and its objectives. This is followed by Section 3 which will present the main programme activities and the portfolio of geo-spatial products that is available for international urban development programmes. The Section 4 will present 2 specific examples on the utility of the urban geo-spatial products and the paper will then conclude with a description of next steps, as well as lessons learned thus far.

2.0 EO4SD-Urban Project Objectives

Since 2008 the European Space Agency (ESA) has worked closely together with the MDBs and their client countries to harness the benefits of EO in their operations and resources management. Earth Observation for Sustainable Development (EO4SD) is a new ESA initiative, which aims to achieve an increase in the uptake of satellite based information in the MDBs regional and global programmes. The EO4SD-Urban project initiated in May 2016 (with a duration of 3 years) has the overall aim to integrate the application of satellite data for urban development programmes being implemented by the MDBs with the developing countries. The overall goal will be achieved via implementation of the following main objectives:

- To provide the services on a regional basis (i.e. large geographical areas); in the context of the current proposal with a focus on S. Asia, SE Asia and Africa, for at least 35-40 cities.
- To ensure that the products and services are user-driven; i.e. priority products and services to be agreed on with the MDBs in relation to their regional programs and furthermore to implement the project with a strong stakeholder engagement especially in context with the validation of the products/services on their utility.
- To provide a service portfolio of primary and secondary urban-related products that have clear technical specifications, and are produced on an operational manner that are stringently quality controlled and validated by the user community.
- To provide a technology transfer component in the project via capacity building exercises in the different regions in close co-operation with the MDB programmes.
These objectives will be achieved via the demonstration of the application of a variety of geo-spatial products for various urban development programmes. This will be done in collaboration with the MDBs and several developing countries who have priority urban development programs. The project is being implemented by a Consortium of European EO/geo-spatial information Service Providers led by the company GAF AG in Germany. The Consortium has a well-established history of working in the provision of geo-spatial products for development co-operation programmes internationally. Chapter 3 will present the overall programme activities and the geo-spatial product portfolio which has been presented to stakeholders.

3.0 Project Applications and Activities

This Section will provide an overview of the main project activities planned as well as those undertaken thus far and the core EO-based products that can be used for urban planning/development. The distribution of the selected cities for collaboration in the project is also noted.

3.1 Program Activities

The program has as a first step the engagement with the stakeholders and assessment of their geo-spatial data needs for urban planning. These requirements assessed via guided semi-structured interviews provide the input for the provision of demonstration geo-spatial products for selected urban development programs in cities that are recipients of loans/grants from the MDBs. The products will have to be validated by the users and stakeholders before a roll-out of the products is provided in Phase 2; this Phase also includes a capacity building component which has the objective of training end users on the application of the geo-spatial products for urban planning cases. See Figure 1.
The main end users that have been contacted for the stakeholder engagement in Phase 1 are:

- MDBs which include World Bank (WB), the Asian Development Bank (ADB), and the Inter-American Development Bank (IADB).
- Client States and the related Urban Authorities which include Ministries, Municipalities, City Councils.
- City Associations such as International Council for Local Environmental Initiatives (ICLEI). Cities Alliance etc.
- The UN especially UN Habitat

The stakeholders were all introduced to the geo-spatial product portfolio and requested to select products with high utility for their respecting urban planning or urban development programmes. The Portfolio is described in the next Section.

3.2 EO4SD-Urban Product Portfolio

Based on the current available satellite sensors – both high resolution (30m spatial resolution such as Landsat data and the new ESA suite of Sentinel sensors) as well as Very High Resolution (VHR) data (with spatial resolution of 0.5-10 m with sensors such as Quickbird and Pleiades data) and initial discussions with stakeholders, the project prepared a Product and Service portfolio. A Primary set of products is considered to be the basis for urban planning and consists of Urban Land Use and Urban Extent. Other products are
derived from these basic products. See Figure 2 which describes the entire product portfolio in a schematic manner. A set of Secondary products are provided for specific demonstration cases and not considered to be the main focus of the EO4SD project.

The following list summarises the main EO-based products and their definitions:

- **Urban and Peri-Urban Land Use/Land Cover**: Spatial explicit information on different land cover types with variable map classes for the urban context.
- **Urban Extent**: The product is a binary mask outlining areas that are above a specific threshold of sealed surfaces.
- **Urban Green Areas**: The product describes a precise mapping of different green areas in the city with differentiation of trees and other green features.
- **Extent and Type of Informal Settlements**: The product shows the spatial location and extent of building agglomerations that can be classified as informal settlement or low income areas.
- **Population Distribution and Density**: The information is obtained by spatial disaggregation of available coarse scale statistical information into spatial units of higher detail.
- **Waste Sites**: The product is especially designed for the detection and monitoring of waste sites in urban and peri-urban areas to enable mitigation measures against illegal dumping.

- **Building Footprints and Types**: The spatial explicit representation of building footprints and their type is realised by visual interpretation and digitisation of Very High Resolution optical imagery.

- **Transport Infrastructure**: Mapping of linear features and their attribution in order to create a sufficient data set that is representing the road and railway network of an urban area.

Secondary Products are mainly related to environmental threats that have a direct impact on human health or could potentially affect human wellbeing in the future. The products are:

- **Air Quality**: The product comprises multi-temporal maps or time series of air pollutants.

- **Building Height, 3D Models**: Computation of Digital Surface Models, Digital Terrain Models and derivation of building heights from Very High Resolution (VHR) optical satellite imagery.

- **Flood History, Flood Risk and Associated Infrastructure Exposure**: This product informs on areas which are most likely being subject to losses due to their location in a flood exposed zone.

- **Landslide Inventory, Landslide Geotechnical Risk and Associated Infrastructure Exposure**: Risk assessment by integrating topographical parameters and analyses of historic landslide events.

- **Urban Terrain/Infrastructure Motion**: Detection and Monitoring of subsidence and ground heaving in urban and peri-urban areas by radar data.

The stakeholder consultation to define the geo-spatial products was initiated in June 2016. In discussions with the MDBs and several developing countries, about 40 cities have been identified to collaborate with the Consortium for the project; the cities include both mega-cities as well as small to medium sized cities. The cities have a wide geographic distribution and also support both internal Bank research programmes as well as projects (loans/grants) with the counterpart countries (see Figure 3). Thus, it is envisaged that with this representative selection the basis for better understanding the MDBs and the developing country requirements for the urban geo-spatial products is well covered.
Figure 3: Cities selected for collaboration on EO4SD-Urban Project

For each of the 40 cities the stakeholders were requested to confirm the Areas of Interest (AoIs) for the urban land area that require information; this constituted both a Core Urban area where VHR data would be used to provide geo-spatial products with higher spatial details than the Peri-Urban areas where higher resolution (and cost-free data) would be used. See Figure 4 for an example of the AoI agreed on with the city of Semarang participating in a World Bank City Planning Lab project.

Figure 4: Area of Interest (AoI) for Core and Peri-Urban areas for Semarang, Indonesia.
The areas provided as well as the costs of EO data and production of the geo-spatial products are factors that need to be included when preparing budgets for the production of the spatial information. These parameters are often unknown to the city stakeholder and the Banks and therefore it forms an important component of the current project in the provision of this information to the end users. The next Section will present two examples of the applications for the EO-based products that are already showing high-levels of utility for urban development programmes.

4.0 Applications of Geo-Spatial Data for Urban Planning

The Consortium are currently in the stage where production of about 500 geo-spatial products for about 40 Cities is underway. However some examples of the products and their utility can already be provided. One main application for the geo-spatial products is for a Global Environment Facility (GEF) funded program called the Global Platform for Sustainable Cities (GPSC). The GPSC was launched in March 2016 in Singapore (WB, 2016a), and up to $1.5 billion will be made available over the next five years for the GPSC knowledge sharing and program management, resulting in common tools and sustainability programs for urban planning and financing (GEF, 2016b); 23 cities have been selected in 11 developing countries in Asia, Africa and South and Latin America which will serve as role models for further cities in the future, where knowledge shall be distributed via city networks and partners for cities. A main focus of the programme is to support the cities implement the United Nations Sustainable Development Goals (UN SDGs). The following Section provides an example of how the geo-spatial data will be used in the current project to support the GPSC Programme.

4.1 Application of Geo-Spatial Data for UN Sustainable Development Goal 11-Indicators

One of the key Urban policy frameworks that Governments have committed to implement is the SDG 11 “Make cities and human settlements inclusive, safe, resilient and sustainable”; the GPSC program and the current project are collaborating to assist Cities with the assessment of Indicators and their methodologies for achieving this Goal 11. In this context a main component of Goal 11 is Target 11.1 “By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.” Most urban centres in developing countries have very little current/accurate data available on the location, extent and the dynamics of informal settlements. Satellite data can provide spatially disaggregated information with high temporal consistency. Especially since the availability of VHR satellite data, this technique is of increasing importance for global slum mapping. An example of detection of informal settlements is seen in Figure 5, where types of slums (“pocket” slums or large slum areas) could be detected.
The detection of informal settlements and their expansion is a key geo-spatial product required by most of the 40 Cities that are participating in the current project; therefore the overall utility of the product for supporting countries with SDG Target 11.1 will be assessed in 2017 with further stakeholder engagement. The potential for a roll-out of the products to larger areas will be discussed with the stakeholders.

4.2 Provision of EO-based Building Height Data: Kigali

Another example of a product that has a high level of utility both by the MDBs and counterpart countries is the building height datasets as this is useful for a variety of purposes from urban planning and design, to assessment of property taxes, as well as floor-area-ratios (part of the legal zoning framework in countries for the building/construction sector). The production of the building height datasets is a complex and relatively costly exercise which relies on the use of a Digital Surface Models (DSMs) and Digital Terrain Models (DTMs). The methodology uses both automatic and semi-automatic processes to generate high accuracy DSMs which are the basis for creating also the DTMs needed for the building height product. The DTM represents all objects occurring on the surface terrain and thus for the urban applications there is the
need to have only the buildings extracted which is achieved by a filtering process. The building heights are then calculated by subtracting the DTM values from DSM values for each pixel (see Figure 6). The result of this subtraction is a normalized DSM (nDSM) which contains only the objects occurring on the terrain with their normalized height values (height above ground).

![Figure 6: Extraction of Building Heights using both the DSM and DTM](image)

Due to the high spatial scale required for such a product the application of VHR EO data such as the Pléiades data set in tri-stereo provided by AIRBUS DS is used to create the DSMs (see Figure 7). The Pleiades satellite system has a spatial resolution in the panchromatic mode of 0.5m and in the multispectral mode 2 m resolution. The tri-stereo datasets with different viewing angles provides the optimum information for elevation models compared to single stereo acquisitions. Important to note is that the VHR tri-stereo data is commercially available and therefore the costs have to be considered for the production of these datasets as well as the fact that the coverage of the tri-stereo data globally is not always guaranteed.

![Figure 7: Illustration of tri-stereo satellite data acquisition required for DSMs. (source: Bärisch et al., 2017)](image)
A final step in the processing of the nDSM is the need to filter out trees in the image and this is done with the application of a Normalized Differenced Vegetation Index (NDVI). Special attention has to be given to the accuracy assessment of the building height datasets as there are several sources of error that have to be taken into account; examples include the presence of artefacts such as moving cars occurring between acquisitions of the VHR EO data as well as problems caused when there are high density urban areas occurring on steep slopes.

A specific application undertaken in the project was done for the World Bank Development Economics Data Group (DECDG) which is supporting the Rwandan Government to improve methods of land valuation. The objective of the pilot study - being implemented by DECDG for Kigali which is being conducted with the support of the building height data provided by the EO4SD-Urban project - is to assess methods for using actual land transaction data from the country with the land cadastral map and basic building height data (from the EO data) to simulate different property values and related tax rates. Such methodologies can support the country to move towards an electronic land transaction billing system, a relevant land taxation system and will also assist the country with improving the total revenues captured.

The Government of Rwanda has undertaken land registration where all properties are more or less registered and thus cadastral data for Kigali is available. A demonstration case was undertaken where the EO4SD-Urban geo-spatial building height data with 0.5m spatial resolution was provided to the DECDG team who could overlay it with the spatial cadastral data. See Figures 8 and 9. The results showed high levels of concurrence between the building height data and the cadastral data; thus the next steps for accuracy assessment have to be finalized. Furthermore, an enlarged area of mapping building height in Kigali will be provided to DECDG.
5.0 Conclusions

The overwhelming positive stakeholder engagement from both the Cities in developing countries as well as the MDBs which has resulted in 40 cities being confirmed for the project indicates a high level of interest in the utility of geo-spatial products for urban planning as well as using the products for implementing global policy frameworks such as the SDGs. The stakeholder engagement with the MDBs and the Cities have resulted in a comprehensive documentation of product requirements for both Core and Peri-Urban areas for these urban regions. The EO4SD-Urban Project represents an important and consolidated
approach to support cities in developing countries with the tools for improved urban planning and management. It has the objective to address the general lack of awareness on the technology behind the geo-spatial products as this is also critical for the improved understanding on what satellite data can offer for urban planning (in terms of timeliness for monitoring, spatial resolution and distinguishable features) and the costs involved. These factors are also important for the enhanced understanding of the MDBs. With an improved understanding of the technology and the utility of geo-spatial products it is envisaged that the satellite data and its products can be mainstreamed in urban development programs.

6.0 Acknowledgements

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7.0 References


8.0 Figures

Figure 1: Overview of EO4SD-Urban Programme Activities in Phase 1 and 2.

Figure 2: Overview and Relations between Primary Baseline and Derived Products as well as Secondary Products.

Figure 3: Cities selected for collaboration on EO4SD-Urban Project.

Figure 4: Area of Interest (AoI) for Core and peri-Urban areas for Semarang, Indonesia.

Figure 5: Mapping of slum areas using very high resolution satellite data in Surabaya, Indonesia (from PUMA Project© GISAT 2012, Image © WorldView, DigitalGlobe 2012).

Figure 6: Extraction of Building Heights using both the DSM and DTM.

Figure 7: Illustration of tri-stereo satellite data acquisition required for DSMs. (source: Bärisch et al., 2017).

Figure 8: Left image: Extent of the Area of Interest (AoI) for the generation of EO based urban products in Kigali. Right image: 2D representation of the Digital Surface Model (DSM) for Kigali city overlaid on Open Street Map (OSM) data set. The DSM was generated by GAF AG with software developed by DLR/IMF, 2016, and contains material distributed by Airbus DS, © 2016.

Figure 9: Examples of 3D views from western part of Kigali towards north (left image) and east-south (right image). Building heights were extracted and processed from Pléiades Tri-Stereo satellite imagery and combined with OSM building footprints (heights not true to scale for viewing purpose).