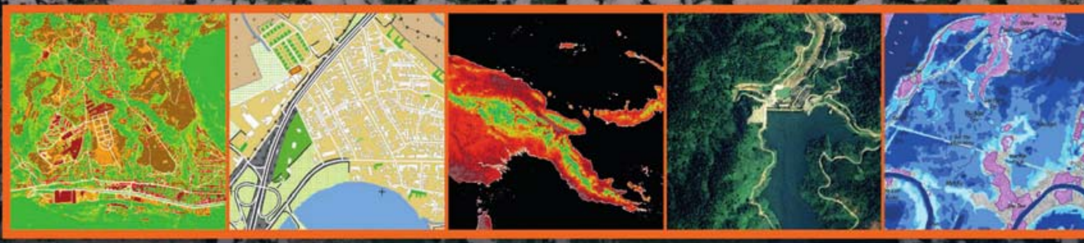
→ EARTH OBSERVATION FOR A TRANSFORMING ASIA AND PACIFIC

A portfolio of twelve Earth Observation projects supporting Asian Development Bank activities



Front cover
Manila Bay and the Metro Manila area on Luzon Island, the Philippines. The most populous region of the country is also home to the headquarters of the Asian Development Bank. The top half image was acquired on 8 October 2016. The composite image was created by allocating different radar polarisation channels for the red, green and blue colours of the image. The bottom half image is a natural colour rendering of Sentinel-2 data recorded on 8 May 2016.

Front cover inlays, from left to right:
Mapping of housing units near Tashkent, Uzbekistan (Project A). Credits: GAF AG.
Urban land cover mapping in Dilijan, Armenia (Project B). Credits: Starlab Ltd.
Land surface temperature over Papua New Guinea (Project F). Credits: GAP s.r.l / Planetek Italia s.r.l.
The Song Bung 4 dam in Viet Nam (Project I). SPOT 6 data © Airbus DS (2015).
Flood frequency mapping near Mandalay, Myanmar (Project K). Credits: Gisat s.r.o.

→ EARTH OBSERVATION FOR A TRANSFORMING ASIA AND PACIFIC

A portfolio of twelve Earth Observation support projects

Project		Page	Energy	Transport	Urban Development	Water	Agriculture and Food Security	Climate Change and Disaster Risk Management	Environment	Sustainable Development Goals
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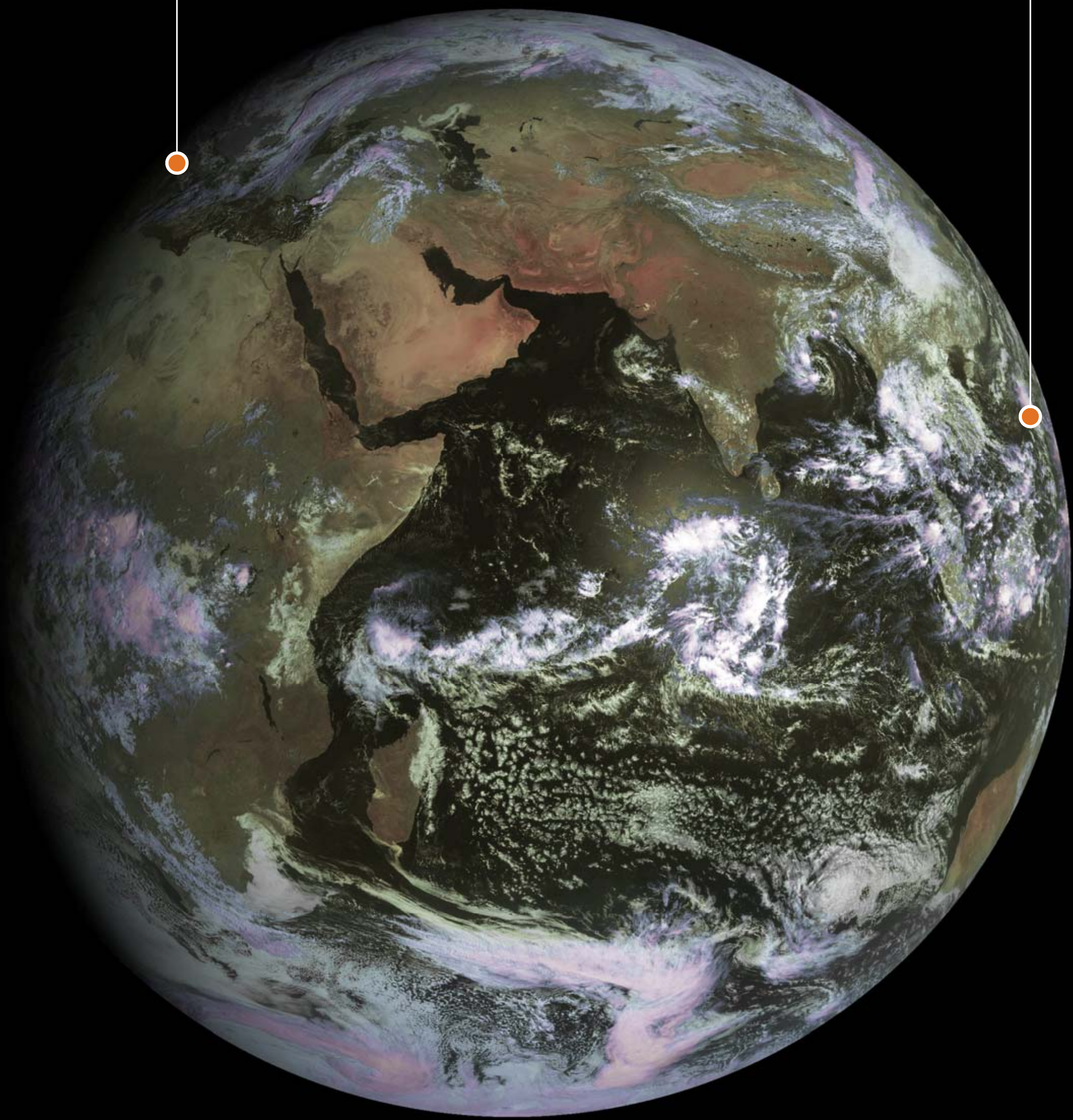
Project L	*Urban Environment and Climate Change Adaptation in Viet Nam*	p. 44			●	●		●	●	●

ESA ESRIN
Frascati
Italy

ADB Headquarters
Mandaluyong City, Metro Manila
Philippines



Meteosat-7 image acquired 2012 October 8

→ FOREWORD

This report summarises the main results of the initiative *Earth Observation for a Transforming Asia and Pacific* (EOTAP) that brought together our two institutions – the European Space Agency (ESA) and the Asian Development Bank (ADB) – to promote and demonstrate satellite Earth Observation (EO) in support of ADB's investments in its developing member countries (DMCs).

EOTAP supported twelve projects, carried out from 2014 until 2016. They were small-scale demonstrations of EO-based information products that addressed the specific needs of individual ADB projects, involving a wide range of ADB staff, programmes and initiatives, geographic regions and organisations in the concerned DMCs. The EO products were delivered by specialist providers in the European EO services sector under contract to the European Space Agency via an open procurement process that saw a large interest and highly-competitive response from the industry.

The use of satellite-based EO products has advanced significantly in the last decade for a broad range of environmental management and situation awareness applications. The particular advantage of satellites in this context is the non-intrusive, objective and consistent nature of the information, available both historically and into the future.

From the ESA perspective, increasing emphasis is being placed on putting EO technology to work in addressing today's grand societal challenges (e.g. population, food, water, energy, etc.). In this respect, the Copernicus programme (the cornerstone of the European Union's efforts to monitor the Earth and her many ecosystems) will play a significant role over the years to come. Copernicus marks the beginning of a new era in Earth Observation with the Sentinel satellites now being launched as the basis of operational environmental information services with the prospect of long-term continuity to 2030 and beyond.

From the ADB perspective, the overarching goal is to reduce poverty in Asia and the Pacific. ADB helps improve the quality of people's lives by providing loans, grants, technical assistance, and equity investments for a broad range of development activities. In ADB's context, satellite-based environmental information falls under innovative solutions that are finding new ways for ADB to serve and address development challenges. Through this initiative, ADB increases its cooperation with specialised technical agencies, leading to strengthened capacity among its staff and in its DMCs to better exploit the potential of satellite-based geo-information. ADB is committed in seeing the successful deployment of this technology replicated on a broader scale in the longer-term.

ESA is now scaling-up with larger, regional demonstrations over the period 2016–2019, and a more strategic approach focusing on ten high-priority thematic domains where EO can deliver key information. These are Urban Development, Agriculture and Rural Development, Water Resources Management, Marine Resources, Risk Management and Disaster Reduction, Energy, Forest Management, Ecosystems services, Fragile and Conflict States, and Climate Resilience and Proofing. First activities were initiated in 2016 in the first three domains, the remaining thematic areas planned for start during 2017/2018.

We look forward to a continued close collaboration and partnership between our organisations in co-designing and implementing these activities. This new phase represents an exciting development and a key milestone towards establishing EO-based products and services as 'best-practice' environmental information, planned into the working processes and financing of international development, and, ultimately, assisting developing countries with projects that create economic and development impact.

Ma. Carmela Locsin

Director General
Sustainable Development and Climate Change Department
Asian Development Bank

Josef Aschbacher

Director
Earth Observation Programmes
European Space Agency

Project A

→ INTEGRATED RURAL DEVELOPMENT IN UZBEKISTAN

Users

ADB Central and West Asia Department, Financial Sector, Public Financial Management and Trade Division (CWPF)

ADB Uzbekistan Resident Mission (URM)

Uzbekistan Ministry of Economy

Provided EO Services

High-resolution urban land cover / land use classification and its changes over time. Building footprint extraction and construction status determination

EO Service Provider

GAF AG (Germany)

Contacts

Matthew Hodge-Kopa – Economist, ADB CWPF
Elaine Glennie – Principal Public Management Specialist, ADB URM

Zoltan Bartalis – ESA, *Zoltan.Bartalis@esa.int*

Rainer Fockelmann – GAF AG, *Rainer.Fockelmann@gaf.de*

Analysis was performed in nineteen 2×2 km areas centred on HIRD housing complexes.

The project supported the HIRD (Housing for Integrated Rural Development Improvement) program, a large-scale, widely dispersed national residential construction program to erect 50,000 private homes using local construction contractors over a 5 year period (2011–2015). HIRD is a high-priority component of Uzbekistan's Welfare Improvement Strategy for achieving inclusive growth and greater diversification of the economy. By the end of 2013 over 33,000 houses have been completed, and 11,000 more targeted for 2014 and 2015. A second 5-year phase was proposed starting 2016. HIRD is creating opportunities for up to 1,000 small rural contractors and 100,000 rural construction jobs annually. Improved access to nearby schools and clinics is a key part of this program. More reliable electricity, gas, and water supply, combined with community designs that include space for retail shops and commercial services, are opening up opportunities for home-based businesses.

The EO-based service contributed to the program with so-called Essential Elements of Information (EEI), i.e. prior-to-construction site suitability verification (supported by classification maps), as well as construction progress verification and post-construction benefits and impact evaluation for the greater Tashkent area (supported by change maps). Presently, working practice involves input from the local stakeholders, including based on field missions, with little to no geospatial information available to ADB. The delivered products can support the project management team in tracking, verifying and reporting project progress and outcome using independent third-party information that can be made available near-real time, thereby reducing the need for extensive and frequent field visits.

The potential for improving transparency, accountability and strengthened governance was illustrated by sharing project outcomes with project stakeholders and key government agencies. The products can serve as a basis for designing the later phases of the project and advancing project monitoring approaches and methodologies even for other ADB infrastructure investment projects.

Land cover / land use classification and its changes over time

The service consisted of two types of products: classification maps and change maps. Based on high-resolution satellite imagery the classification maps contain land use information for artificial surfaces (urban fabric, industrial, commercial, public, military, sports and leisure, private residential units, roads and railways with their associated land, port areas, airports, mineral extraction and dump sites, construction sites, unused urban areas) and natural surfaces (urban greenery, agricultural land, forest, grassland, wetlands, bare land, water bodies). The maps also delineated infrastructure networks (road, rail) and provided footprints of individual buildings.

The change maps contained information on the status for each housing unit ("demolished", "unchanged", "new, completed", and "new, under construction"), and changes in land use types reflecting increased post-construction economic activity, social well-being and environmental impact (e.g. industrial to residential, grassland or bare soil to crops, etc.).

For each classification map, information was extracted from satellite imagery following a well-established processing sequence. Hereby, the delineation of features was performed systematically according to the geometry types and thematic relations between different classes. The workflow was based on two major mapping phases: (i) mapping of all objects except of the land cover area features, and (ii) delineation of all land cover area features. The geometry features (line or area) are extracted and attributed adhering strictly to explicit topology rules to ensure correct vector geometries in the final product.

The progress and change mapping was performed based on pairs of satellite imagery recorded at different times. The first point in time was provided by three SPOT 5 scenes (2.5 m resolution), covering most housing units in February 2010, and only two in February 2009. The recent situation was retrieved from nine Pléiades-1A and Pléiades-1B coverages ranging from February 2013 to April 2014. Each area of interest was analysed by an experienced interpreter towards changes compared to the older dataset. This effective mapping approach started with the most recent status and then worked backwards to retrieve past status by changing/deleting vector elements. Each housing complex was checked and analysed by semi-automatic GIS routines and manual interpretation following a multi-stage quality assessment procedure to ensure a consistent high product quality. Special thematic focus was put on the individual houses and their construction status. The result is a complex geodatabase with highly-detailed and high-precision vector data, ready for GIS import and further value adding. All produced metadata is conform to the European INSPIRE directive.

Additionally, a web-based map viewer was set up enabling the exploration of the mapping products in an interactive and user-friendly way. Apart from the customary map viewer functionality, specific INSPIRE-compatible metadata can be queried for each product. ■

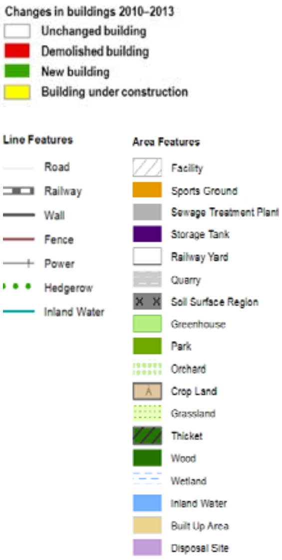
> *"Overall, this technology would be very useful for some projects. [...] As this project involved housing construction over all of Uzbekistan, we were able to view large tracts of construction in a quick and efficient manner."*
> **Matthew Hodge-Kopa**, ADB Economist

Examples of the input imagery over one of the housing sites northeast of Tashkent.
Left: detail of a SPOT 5 scene, 2.5 m resolution, from 2010 February 2.
Right: detail of a Pléiades 1A scene, 0.5 m resolution, 2013 February 13.
SPOT 5 and Pléiades data © CNES, distribution Airbus DS.

Example of how construction progress is observed in the satellite imagery.

Initial situation on 2010 February 2, showing unchanged buildings, and ones that were later demolished.

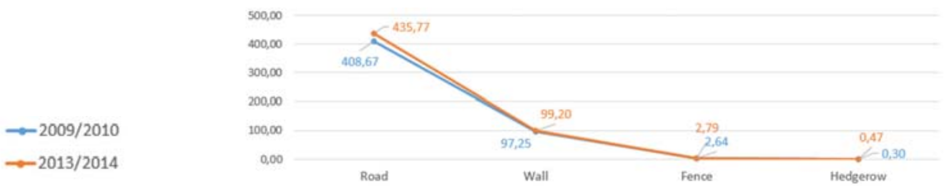
Situation on 2013 February 13, showing new completed buildings.



Situation on 2013 February 13, showing completed buildings and buildings under construction, but no longer the demolished ones.

The building footprints from the map to the left, overlaid onto the Pléiades imagery. Pléiades data © CNES (2013), distribution Airbus DS.

Example of statistics derived from the mapping product.
Top: Changes in land use areas (ha).
Bottom: Changes in linear feature lengths (km).
The values refer to the considered 2×2 km area centred on the housing site in question.



Project B

→ SECONDARY CITIES URBAN DEVELOPMENT IN ARMENIA

Users

ADB Central and West Asia Department, Urban Development and Water Division (CWUW), ADB Armenia Resident Mission

Ministry of Territorial Administration of Armenia
City council of Gyumri
City council of Dilijan, Geohazards Office, Urban Planning Office
IDeA (Initiatives for Development of Armenia) Charitable Foundation

Provided EO Services

1. High-resolution urban land cover / land use classification and its changes over time
2. Landslide risk assessment
3. Snow cover mapping

EO Service Providers

Starlab Ltd. (United Kingdom)

TRE ALTAMIRA s.r.l. (Italy)

Contacts

Cesar Llorens – Urban Development Specialist (Water, Sanitation and Transport), ADB CWUW; ADB Deputy Country Director for Armenia

Philippe Bally – ESA, *Philippe.Bally@esa.int*

Bahaa Alhaddad – Starlab Ltd., *bahaa.alhaddad@starlab-int.com*

Due to its peculiar location, landlocked between Georgia, Azerbaijan, Iran and Turkey, Armenia's economic development is strongly tied to the improvement of infrastructures that can facilitate the exchanges with other countries. Rapid growth of some cities and relocations of commercial and residential areas have produced important changes to the industrial and urban sectors, not always following sustainability criteria. As a result, many cities suffer from poor urban services management, traffic congestion, loss of green areas, poor air quality and noise.

To improve the economic and territorial development of the country, ADB, at the request of the Armenian government, prepares a policy and advisory technical assistance providing a series of city development plans (CDPs) and investment plans in the four cities of Gyumri, Vanadzor, Dilijan and Jermuk. These plans, spanning a 10-year period, focus on a series of actions to be taken in order to improve the urban sector and mitigate the unbalanced economic growth among regions.

The ESA support project contributed to the ADB efforts to create a priority list of urban investment projects by supplying urban land use / land cover classification and change mapping for the four cities, a landslide inventory and susceptibility map for Dilijan (including a Digital Elevation Model) and snow cover maps for the entire territory of Armenia.

To the largest extent possible, the best solutions were provided to comply with the requirements of ADB and local municipalities with respect to key features that can help characterise the status of the urban environment and its evolution in time, bringing improvements in environmental management and local situational awareness. The results were also presented at the *Gyumri Development Forum*, where key challenges and issues for economic, social and urban development of the city were discussed.

Land cover / land use classification and its changes over time

The service can be seen as an investment decision-making support tool able to monitor overall urban development processes, and the detailed spatial distribution and evolution of urban land use classes and features.

Location of the four secondary cities in Armenia, from west to east: Gyumri, Vanadzor, Dilijan, Jermuk.

A recent situation in the four cities was presented in so-called *baseline urban classification maps* (BUCs), based on Pléiades imagery acquired during 2014 (spatial resolution 0.5 m). These contain information on land use such as artificial surfaces, non-artificial surfaces and other natural and semi-natural areas. The broadest level of categorisation (Level I) distinguishes among broad land cover types: urban, agricultural, forest, water, irrigated lands, etc. For urban land, the second level of categorization (Level II) distinguishes among thematically detailed land uses, e.g. high- and medium-dense urban fabric, discontinuous urban fabric, main and secondary roads, and rail network. The methodology is based on semi-automatic pixel- and object-based image analysis with post-classification, including (especially for the Level II categorisation) analysis of textures, patterns, alignments and arrangements.

The land use change maps reflect a region's urban land use history, detecting major changes that occur in the urban land use classes, including the urban extent itself and major transportation networks. The change maps were based on a reference period (a combination of SPOT 4 and SPOT 5 imagery at 5 m resolution acquired during 2002–2004) and the BUC maps from 2014.

One possible type of analysis of the land use changes consisted in estimating the geometric city centre, after which the degree of physical continuity of urban settlements can be computed by summing up the area of artificial land use classes within concentric buffers of 100 metres centred on the geometric city centre. This calculation allows the identification of the central continuum of each city and of the artificialised land occupation, and helps to understand its structure. The land occupation change over time can help decision-makers take the appropriate decisions for future development.

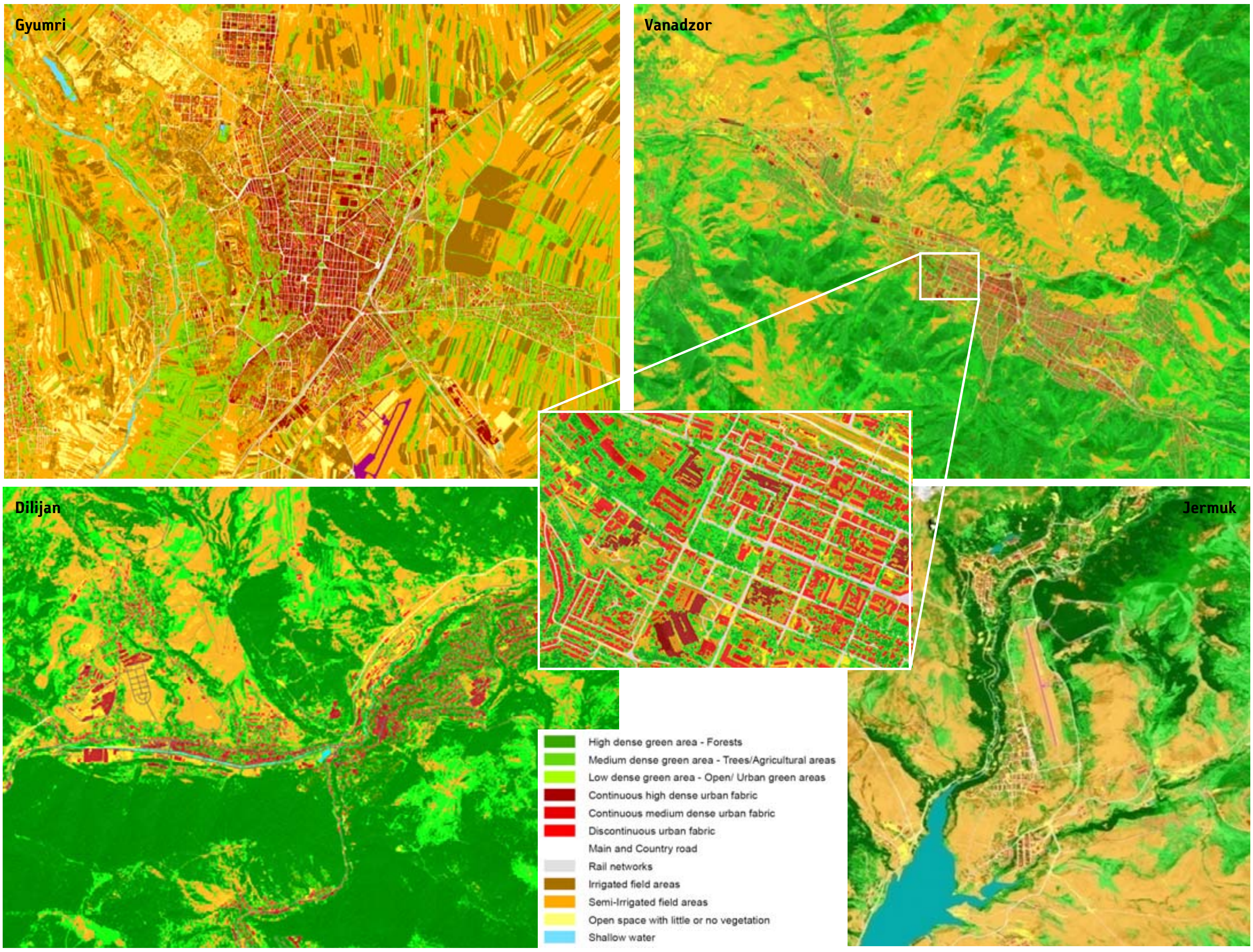
The land use maps allow also studying comparatively, in addition to the degree of land consumption, the morphology of the urbanisation of the defined cities. This can be done by studying the variation of entropy (or fragmentation). This indicator allows understanding the similarities and differences between city landscapes in different periods and characterising the typology of the urban sprawl process.

Landslide risk assessment

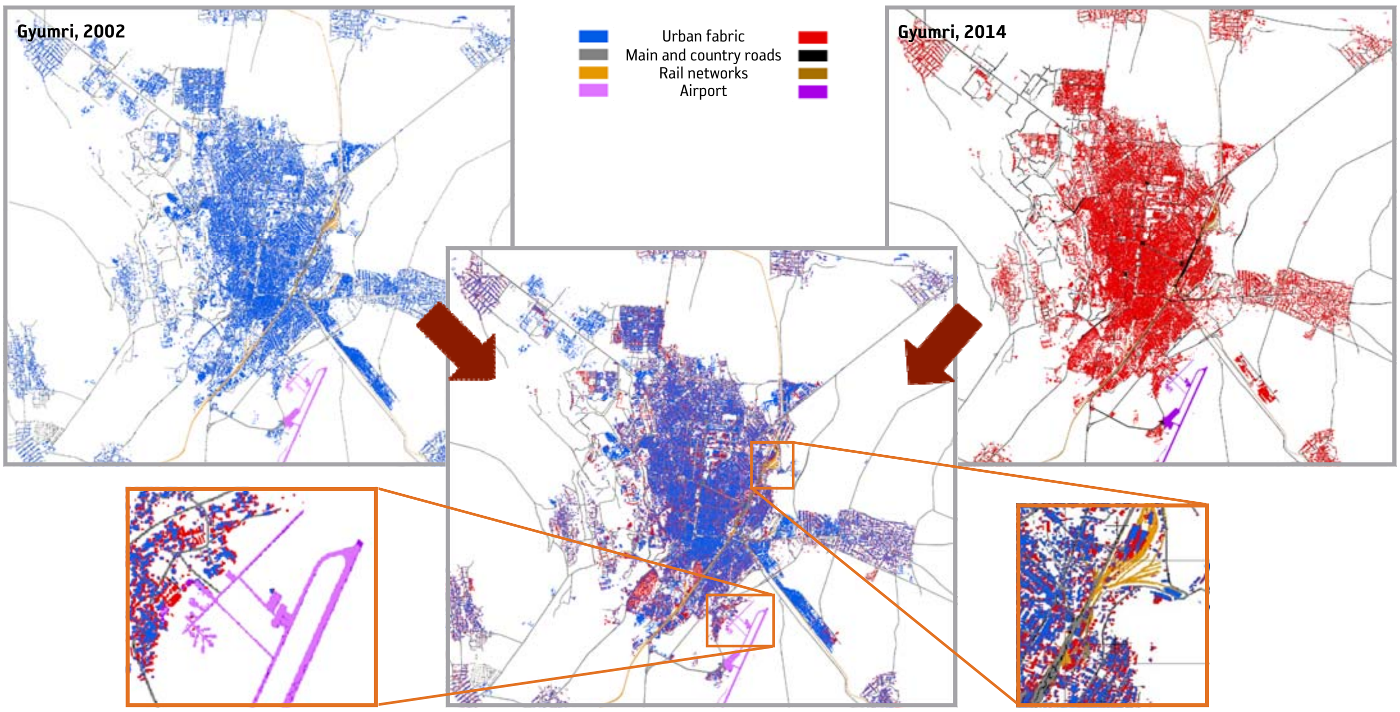
Being a mountainous country with a high occurrence of steep slopes, Armenia is one of the most affected countries in terms of landslides. This service helped characterise and delineate the areas subject to landslides by delivering the following products:

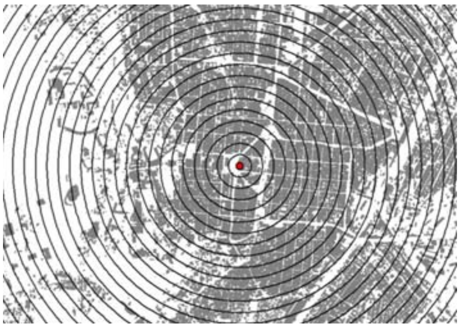
- Landslide Inventory Map (LIM),
- Digital Elevation Model (DEM),
- Landslide Susceptibility Map (LSM).

The LIM was produced for Dilijan using measurement of ground deformation derived from satellite-based SAR (Synthetic Aperture Radar) interferometric data together with visual interpretation of high-resolution optical imagery and morphological analysis of the DEM. The satellite sensors used were Envisat ASAR and ALOS PALSAR. The interferometric approach is exploited to measure, at specific points, ground deformations, and to construct time series of their displacement. The effectiveness of remote sensing techniques is particularly relevant for wide regions and inaccessible places, for which conventional (ground-based) analysis cannot compare in terms of timely update, Baseline urban classification maps for the four cities, based on 2014 Pléiades 0.5 m resolution imagery. Pléiades data © CNES (2014), distribution Airbus DS.

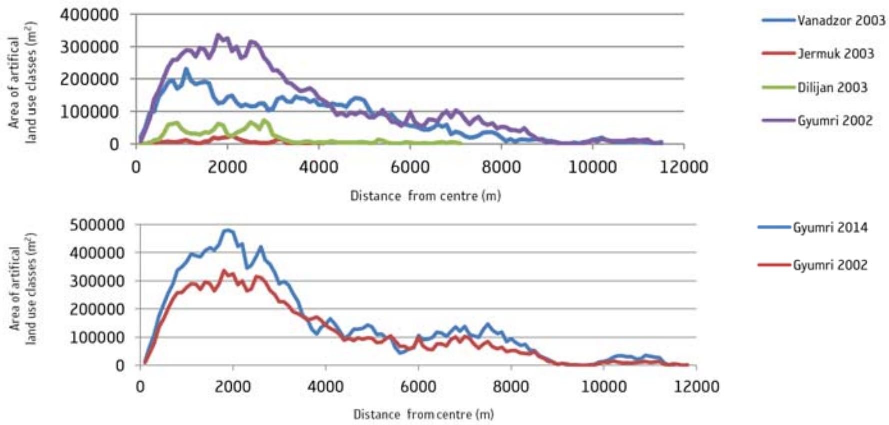


Example of land use change mapping for Gyumri.

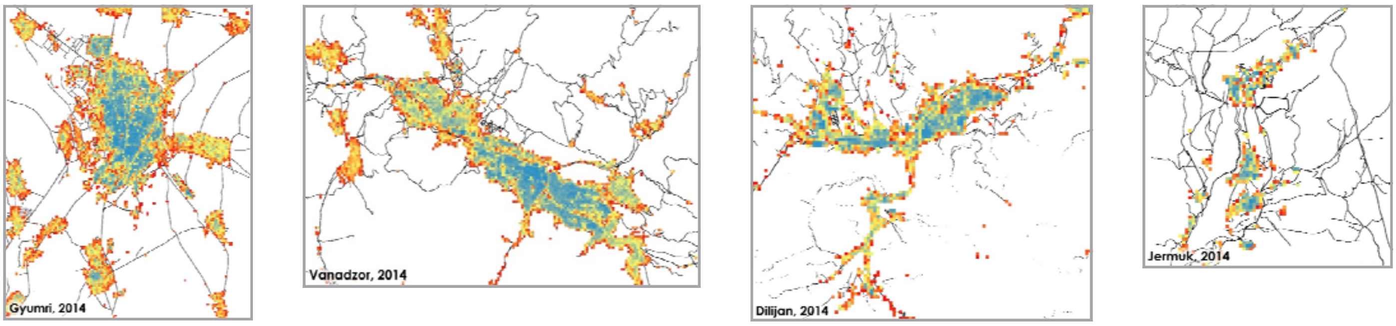




Geometric city centre of the city of Dilijan. The concentric buffer areas are at 100 m interval.



Continuity and discontinuity of the artificialised land area (occupation of urbanised land). *Top diagram:* the four cities compared, for the initial point in time. Few changes in land occupation have been detected in Jermuk, Dilijan and Vanadzor, while the city of Gyumri presents notable changes in most of areas (*bottom diagram*).



Urbanisation morphology. The entropy is computed using a grid cell dimension of 100 m². The spatial distribution of the entropy of artificialised land areas shows how there is a greater fragmentation of urbanisation in the periphery (red colour) while in urban centres and rural areas the entropy or complexity is lower (blue).

cost-efficiency, systematic coverage, accuracy and precision, due to the large extent of the investigated area.

For the city of Dilijan, the LIM was produced at basin scale. Detection (identification of features related to topographic surface movements) and mapping are mainly based on visual interpretation of different types of remote sensing products. A large number of instability phenomena were identified (totalling 204), thereby increasing the number and area of most of the already known landslides. The landslides are typically low-motion, with rates from a few mm/year to several cm/year. For each landslide, its boundary was drawn and the on-going motion described. Landslides were classified based on the prevalent type of movement, the estimated depth, and the relative age. Landslide types were also determined based on the local morphological characteristics. Pre-existing landslides are represented by flows, slides, and complex landslides. For a small group of landslides (about 15%) it was not possible to determine the landslide typology.

The most important phenomena were detected on the southern slope of the Dilijan valley, where several large landslides were recognised. These are probably complex landslides affected by partial reactivations. In this area, several other phenomena were mapped in the upper part of the valley (in the right tributaries of the Ahgstev River) where the vegetation cover is absent or minimal. Areas with superficial and channelised erosion affecting the surface deposits were classified with the label "superficial erosion", characterised by lack of soil and vegetation cover, with an ephemeral drainage.

The state of activity of most mapped phenomena can be considered as dormant or inactive by merely evaluating the so-called SqueeSAR™ line-of-sight (LOS) velocities. The active and most dangerous landslide is the one located in the Mets-Tala district, south of the Aghstev River. Also west of Little Maymech Mountain, an active complex landslide was observed, characterised by a velocity of –11 mm/year but its location does not threaten urban areas.

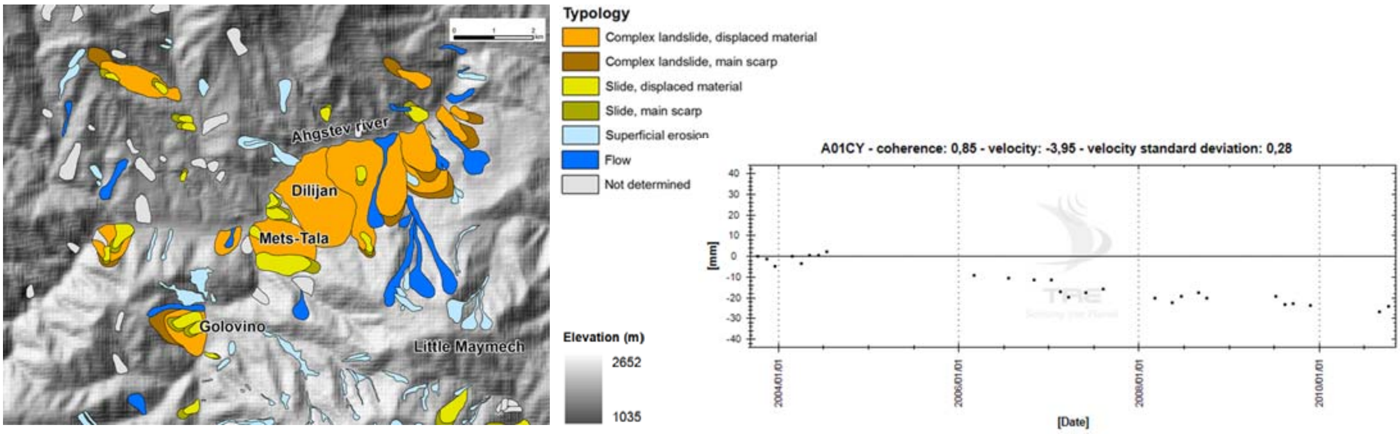
The Digital Elevation Model product covered the area of Dilijan and was meant to demonstrate the ability of high-resolution SAR satellite data (in this case COSMO-SkyMed) to enhance the freely-available SRTM DEM product by using the so-called DInSAR (Differential Interferometric SAR) technique. Pairs of acquisitions from satellites at slightly different times are combined resulting in a 15 m resolution elevation product with 7 m vertical accuracy, available wherever interferometric coherence is present. Roads, bare and rocky areas, and urban areas generally yield good results, while snow-covered or vegetated areas (with changes from one acquisition to the following) are not possible to map.

When dealing with landslide investigations, the ultimate aim is the estimation of the risk posed by existing and/or future slope failures to population or infrastructure. Landslide inventory mapping is typically one of the first workings steps toward a further hazard and risk assessment. The Landslide Susceptibility Map (LSM) of the Dilijan area was produced using a simple implementation of the Random Forest (RF) machine-learning algorithm performing a multivariate classification. The method considers numerous parameters in order to avoid the subjectivity in the choice of explanatory variables: elevation, slope, aspect, flow accumulation, land use from Service 1, etc. The analysis was performed on a grid resolution of 81 m.

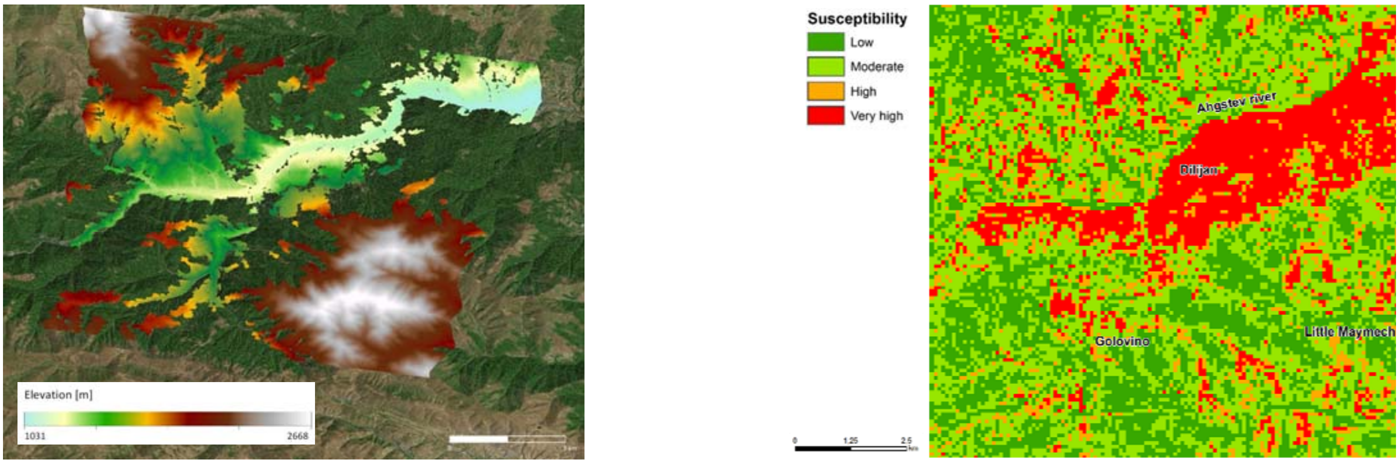
The obtained results highlight a large area, along the right bank of the Ahgstev River, characterised by very high susceptibility. Other very high or high-susceptibility zones are present in the Golovino area and in the lower part of the valleys of the right tributaries of the Ahgstev River.

"We found that the data the ESA project delivered to us was quite accurate. For example, when comparing with field data from Gyumri, the satellite-based data proved to be more complete and detailed. Especially the data on landslides was very accurate and allowed us to prioritise some projects above others. Given the overall high landslide risk in Armenia, we now plan to extend these services to other secondary cities in the country."

César Llorens, ADB Urban Development Specialist
(Water, Sanitation and Transport)



Left: landslide inventory for Dilijan. The landslides are projected on the DEM with a hill-shade effect. Background SRTM DEM © NASA/JPL. *Right:* example of line-of-sight (LOS) displacement time series for a point inside an area classified as landslide. Each dot in the diagram represents a satellite acquisition. In this case, over the seven studied years the average land motion velocity was approximately 4 mm/year in a direction pointing away from the satellite sensor.



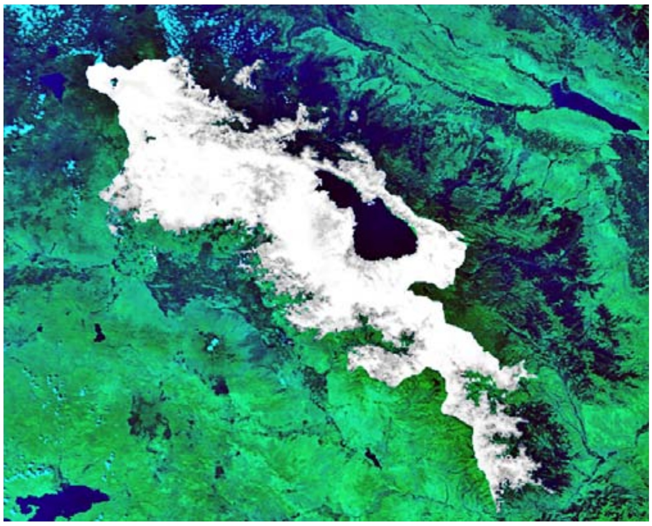
Left: satellite-derived Digital Elevation Model, Dilijan, based on descending pass COSMO-SkyMed acquisitions. *Right:* landslide susceptibility map, Dilijan. COSMO-SkyMed data © ASI.

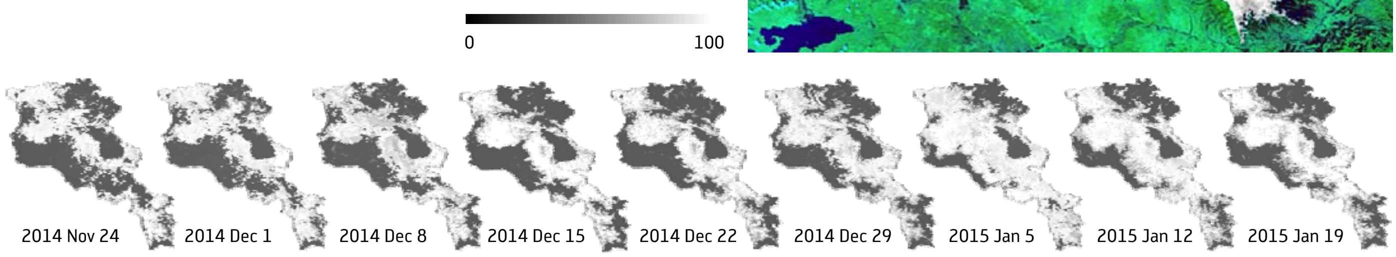
Snow cover mapping

Monitoring of snow cover (and, indirectly, the associated snowmelt) is a key parameter for the management of water resources and runoff modelling, as well as for planning and operation of winter tourism infrastructure. Remote sensing techniques are very useful for this purpose and have reached operational maturity.

The demonstrated snow cover map contains the fraction of snow cover within each pixel, and the time since the last update. The service was delivered on a weekly basis for the period December 2014 to January 2015, by merging daily cloud-free acquisitions from the MODIS sensor. The maps cover the entire Armenian territory at a spatial resolution of 500 m.

Fraction of snow cover for 2015 Jan 19–26. Background image: MODIS © NOAA.





Project C

→ CLIMATE-RESILIENT RURAL LIVELIHOODS IN MONGOLIA

Users

ADB East Asia Deparment, Environment, Natural Resources and Agriculture Division (EAER)

Mongolian Ministry of Food, Agriculture and Light Industry, Project Management Unit (PMU)
Mongolian National Remote Sensing Center (NRSC)

Provided EO Services

1. Land cover / land use classification and its changes over time
2. Drought monitoring

EO Service Provider

DEIMOS Engenharia SA (Portugal)

Contacts

Carey Yeager – Climate Change Specialist, ADB EAE
Markus Vorpahl – Senior Social Development Specialist, ADB EAER
Takeshi Ueda – Natural Resources Economist, ADB EAER

Zoltan Bartalis – ESA, *Zoltan.Bartalis@esa.int*
Mariangela Cataldo – SERCO SpA for ESA, *Mariangela.Cataldo@esa.int*

Antonio Gutiérrez – DEIMOS Engenharia SA,
antonio.gutierrez@deimos.com.pt

Location of the districts (*soums*) of Buutsagaan, Zag and Khüreemaral (Service 1, red) in the Mongolian province (*aimag*) of Bayankhongor (Service 2, blue).

For the last decades, grasslands in Mongolia are being degraded, with studies pointing to around 78% of national territory experiencing desertification and other forms of land degradation, resulting in decreased livestock productivity and lower incomes. Evidence seems to show that most of the degradation in Mongolian grassland steppes between 1988 and 2008 was due to climate change trends. In fact, during the last 20 years, 60% of the decrease in the vegetation indicators average values is correlated to precipitation and temperature trends, with the remaining part correlated to overgrazing and biomass burning.

Mitigation or adaptation to this reality requires optimising pasture management through e.g. a) rotational use of pastures; b) improving water supply; c) increasing hay harvest with irrigation and fertiliser; d) planting forage species. The ADB *Establishment of Climate-Resilient Rural Livelihoods* project carried out design and implementation of these type of actions within a collaborative pasture management framework in the territory of Buutsagaan, Khüreemaral and Zag districts (*soums*) of Bayankhongor province (aimag). To monitor pasture changes within these regions, studies were performed in various trial plots in 2013 and 2015. Positive changes were reported in vegetation structure, species compositions and yield as result of resting and rotational use of summer pasture. Results of the social surveys also highlighted the positive outputs of the use of collaborative management.

The ESA support project aimed to provide EO-based information to complement these results and demonstrate the usefulness of EO-based products to support establishing pasture management plans. The project also aimed at enriching the existing environmental database maintained by the National Remote Sensing Center (NRSC) and providing relevant EO traning and capacity building. In particular, EO-based products were planned to be feeding into the Mongolian Environmental Information Center (EIC), integrating several low- and medium-resolution EO products and geographical datasets on atmosphere, land, disaster risk, etc.

Land cover / land use classification and its changes over time

This service provided baseline land use and land cover (LULC) maps for September 2013 and September 2014 using Landsat-7 and Landsat-8 data as input (30 m resolution) for the soums of Buutsagaan, Zag and Khüreemaral. The classification focussed on pasture classes for both the summer and the winter seasons to be used as reference to measure the impact of the aforementioned ADB project. The month of September was chosen to minimise radiometric and seasonal variability and thus improve land classification accuracy and to avoid higher cloudiness during other months. Relevant land use changes between the two seasons were also mapped.

The classification followed as much as possible the classes used in the ADB project, even though the degree of pasture class discrimination proved too detailed to implement using only satellite imagery and few appropriate training datasets. Nevertheless, the produced mapping products clearly complemented Mongolia's map portfolio for the respective geographical areas, which already included the national LULC maps hosted by the EIC and the local/regional pasture maps provided by ADB-funded project. The delivered maps established a higher-resolution baseline, able to produce, for several spatial scales (national to local), accurate, consistent and continuous LULC information, with very little in-situ and ancillary data. The maps also provide valuable information regarding soil degradation trends, and livestock forage availability and trends (e.g. possible grasslands for grazing reserves) and can be used to assess the effectiveness of pasture management practices. For instance soil degradation can be indirectly monitored by identifying bare soils or loose of vegetation. Livestock forage can be retrieved by monitoring and mapping shrub and grassland areas.

At the level of the three districts, LULC changes for 2013–2014 revealed pasture gains of 4% (493 km^2) and pasture losses of 5% (610 km^2). Unfortunately high cloud cover hampered the derivation of a LULC map for 2012, the year most pasture management actions started as a result of the ADB project.

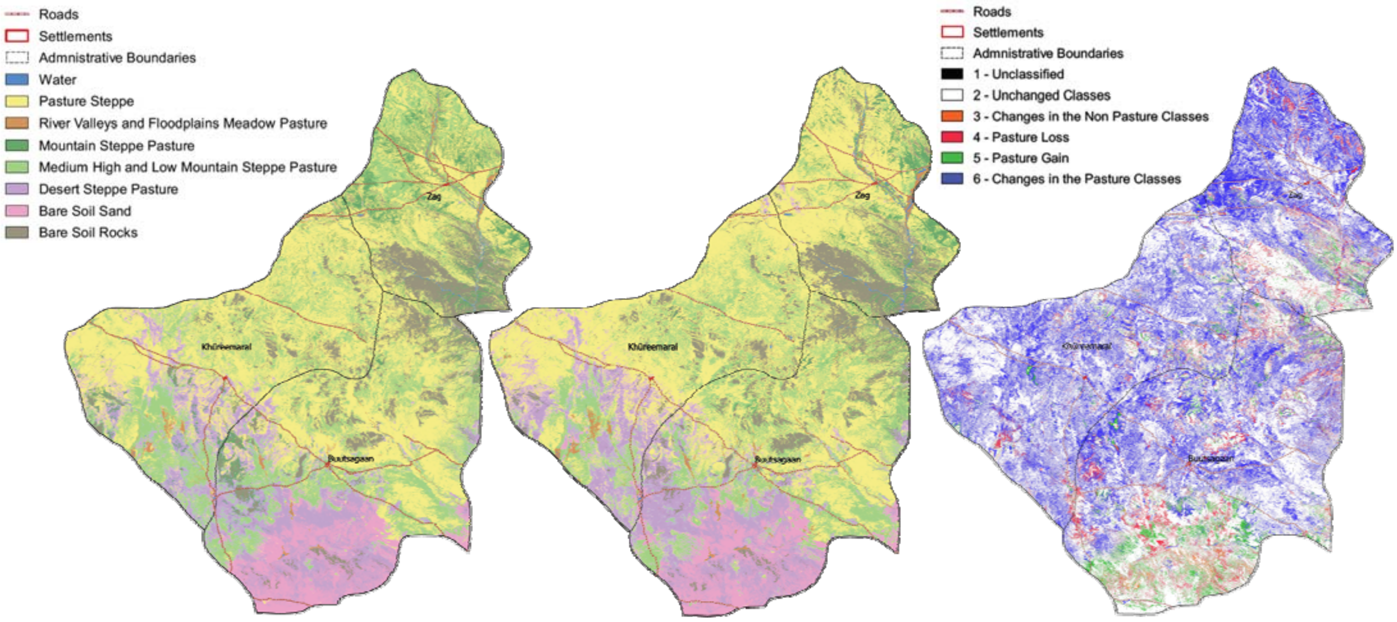
Users were satisfied with the delivered products and could clearly see the benefit of EO-based LULC products when compared to field surveys. Nevertheless they emphasized the importance of increasing pasture classification accuracy and discrimination.

Drought monitoring

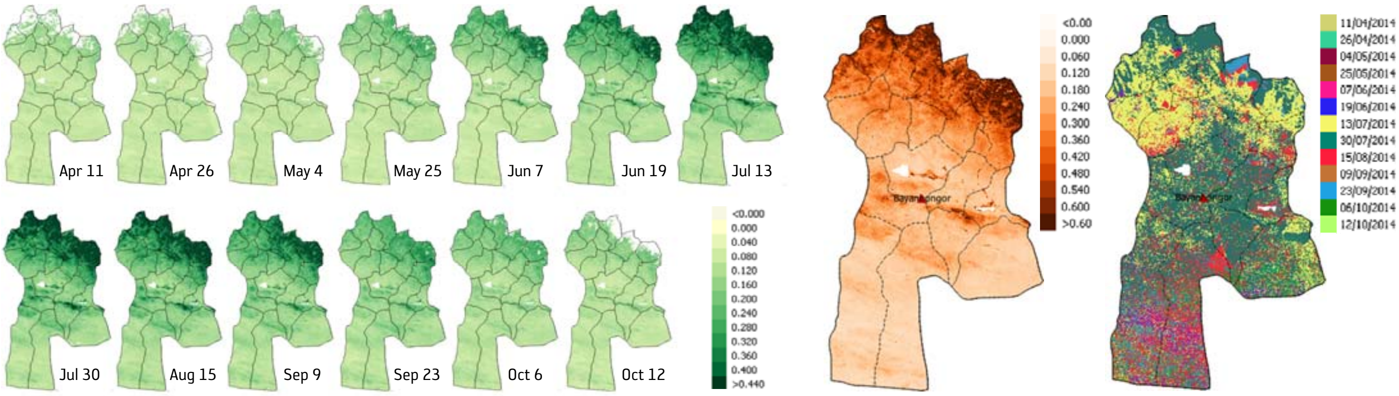
The drought monitoring service aimed at enhancing the current NRSC monitoring scheme based on MODIS data, by introducing higher-resolution data to monitor vegetation productivity and condition in the Bayankhongor province. The mapping products contain relative information on vegetation status and trends via NDVI and not absolute values of biomass or productivity variables. Nonetheless, these values are a good proxy for many of the biophysical features of grasslands and are not subject to the same error budget as maps providing absolute information.

The introduction of a 22 m resolution DEIMOS-1/DMCii NDVI time series (one image approximately every 15 days) and respective statistics for the year 2014 was an effective improvement of the currently-available information on pasture vegetation status and condition for a full growth cycle (April-October 2014). The dataset provided local users with a higher-resolution (22 m) characterisation of the pasture growth cycle, and consequently a more detailed differentiation of pasture growth regions and more detailed information to monitor the effect of pasture management actions. For instance, grazing reserves for the different stages of pasture growth could be defined more precisely.

Drought monitoring for 2014 was performed by calculating NDVI anomalies using monthly MODIS NDVI products from that year and their long-term



Land use and land cover (LULC) maps for Buutsagaan, Zag and Khüreemaral *soums* for September 2013 *(left)* and September 2014 *(middle)*. Right: LULC changes 2013–2014.



Left: NDVI evolution in the Bayankhongor province for the 2014 growing season. *Centre:* Maximum NDVI for the 2014 growing season. *Right:* The date of the maximum NDVI. The maps were produced based on DEIMOS-1/DMCii data (spatial resolution of 22 m).

averages (2001–2013). A sustained operational delivery of the higher-resolution NDVI maps could result in image time series that retrieve the normal (average) growing conditions, thereby identifying even more detailed growth anomalies related to droughts, diseases and human actions. By using the MODIS-based NDVI maps, although no effective improvement on drought monitoring resolution was made, an alternative methodology was introduced to monitor drought in the Mongolian territory, offering a less data intensive and more accurate and easily comparable option to the currently-used MODIS drought index. Results for 2014 showed that, although some regions within the Bayankhongor province presented both negative and positive anomalies, no significant and consistent drought signal was found. This was also confirmed by a correlation study done with satellite-based precipitation and land surface temperature estimates for the same period.

In the future, for both presented services, higher-resolution products derived from ESA's recently launched Sentinel-1 and Sentinel-2 data could be mainstreamed gradually into the current NRSC national information database that is now based on either low to medium resolution data from sensors like MODIS or AVHRR or extensive field surveys. The use of the Sentinel satellite series would allow the services to benefit from significant improvements in spatial and temporal resolution, as well as pasture class discrimination.

As an additional service, a comparative study of the trade-offs between image costs and information gain for similar products to the ones delivered for each of the previous services for three different resolutions (MODIS, Landsat/DEIMOS/DMCii and SPOT 5). The main impact of this analysis was visible during the Final User Workshop held in the Mongolian University of Life Sciences (MULS).

Project results are integrated in the web GIS portal available with user login at http://eotap.DEIMOS.com.pt.

Hands-on training on EO products during the knowledge-sharing workshop at the Mongolian University of Life Sciences in Ulaanbaatar, organised by ADB and the Mongolian Ministry of Agriculture and Small Industry, 29–30 October 2015.

Project D

→ INCREASING CLIMATE RESILIENCE IN TONGA

Users

ADB Pacific Department, South Pacific Subregional Office (SPSO)

Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR), Tonga
National Emergency Management Office (NEMO), Tonga
Tonga Meteorological Services

Provided EO Services

Coastal habitat (coral reef) oceanographic stressor mapping

EO Service Providers

ACRI-ST (France)
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente (Netherlands)

Contacts

Maria Paniagua – Unit Head, Project Administration Unit, ADB SPSO

Gordon Campbell – ESA, *Gordon.Campbell@esa.int*

Antoine Mangin – ACRI-ST, *antoine.mangin@acri-st.fr*

From 1991 to 2010, the global climate risk index ranked Tonga 19th of 179 countries in terms of observed average annual losses as a percentage of gross domestic product due to climate-related disasters and in terms of average of climate-related deaths per 100,000 people. In recent years Tonga experienced higher variability of rainfall causing localised flooding and droughts related to El Niño events. Increased ocean temperatures have caused coral bleaching and destruction of habitats for reef species. Sea level rise is contributing to coastal erosion and subsequent damage to infrastructure and property. Coral bleaching destroys natural coastal barriers and together with the increase in sea level rise puts coastal community livelihoods and infrastructure at risk, for example for tropical cyclones and storm surges.

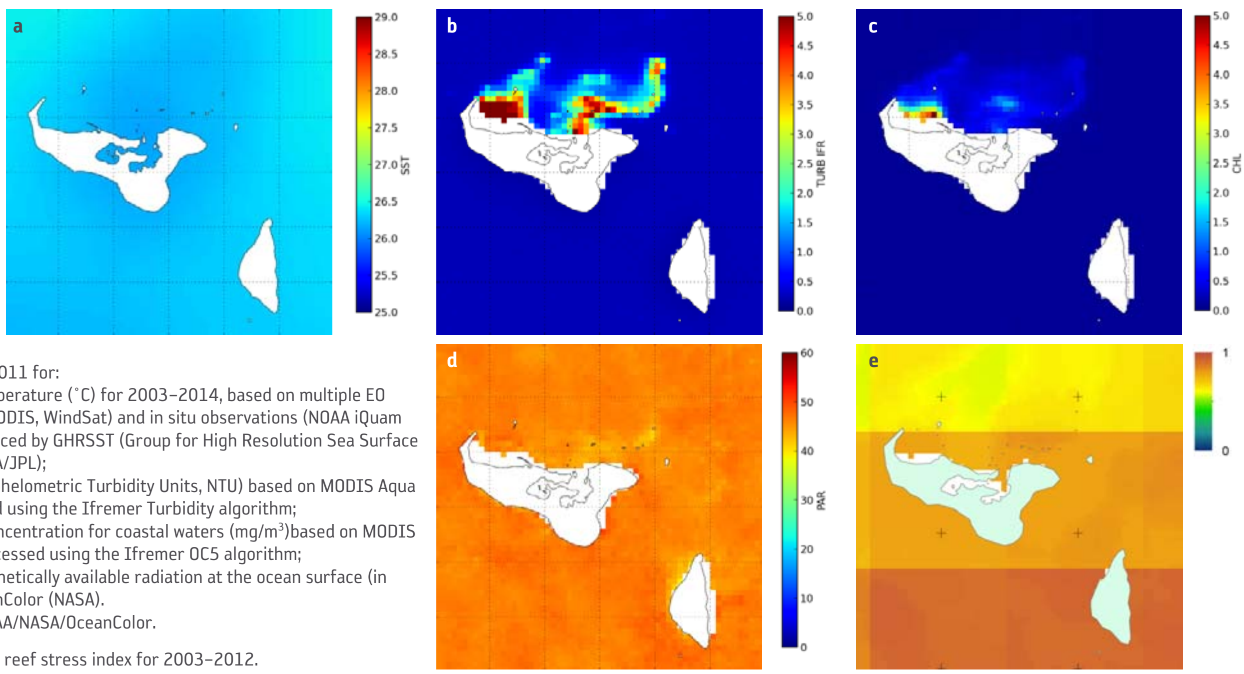
As part of the substantive investment required to help adapt to and manage these effects, the ADB *Climate Resilience Sector Project* is a five-year activity linked to enhancing climate resilience in Tonga. It is also part of the Pilot Program for Climate Resilience funded by the Climate Investment Fund.

The EO support project delivered regional statistics on marine parameters and specific coral habitat stressor maps, in an effort to improve the acknowledgement of Tongan climate in general, and to demonstrate the capabilities of satellite-based observations to complement existing data.

Coastal habitat (coral reef) oceanographic stressor mapping

This service provided a number of parameters relating to water and weather in the area surrounding Tongatapu and 'Eua islands, starting from 1990 to today. For each parameter, maps and time series were presented, including statistics based on monthly, seasonal and annual aggregate measurements (extreme values, mean values, P90 values, etc.) and temporal trends using linear regression. Additionally, anomalies and exceptional events were analysed. Where available, seasonal aggregation was calculated with two seasons: from April to November, and from December to March. The studied parameters were:

- *Sea surface height*: episodic but progressive changes will reduce or eliminate endemic terrestrial species. Coral reef ecosystems are likely to be affected by the mid-century as the upward growth rates of corals are expected to slow in response to rising sea levels.
- *Wave height and direction*: reefs dissipate wave energy, reducing routine erosion and lessening inundation and wave damage during storms.
- *Currents*: areas with strong currents and high mixing rates indicate a potential of cooling to counter increased sea surface temperature.
- *Sea surface temperature*: fluctuations of this important parameter are closely linked to, among others, coral proneness to stress during a heat wave.
- *Sediments concentration (turbidity)*: high sediment concentrations could signify poor water quality and pollution which reduces coral resistance.
- Sea surface salinity: fluctuation or especially a steep drop in salinity has already caused significant coral extinction.
- Chlorophyll-a: just like in the case of sediments, high concentrations could signify poor water quality and pollution which reduces coral resistance.



Yearly means for 2011 for:
a) sea surface temperature (°C) for 2003–2014, based on multiple EO inputs (AMSR-E, MODIS, WindSat) and in situ observations (NOAA iQuam project), and produced by GHRSST (Group for High Resolution Sea Surface Temperature, NASA/JPL);
b) Turbidity (in Nephelometric Turbidity Units, NTU) based on MODIS Aqua data and processed using the Ifremer Turbidity algorithm;
c) Chlorophyll-a concentration for coastal waters (mg/m^3)based on MODIS Aqua data and processed using the Ifremer OC5 algorithm;
d) Mean photosynthetically available radiation at the ocean surface (in E/m^2/d) from OceanColor (NASA).
MODIS data © NOAA/NASA/OceanColor.

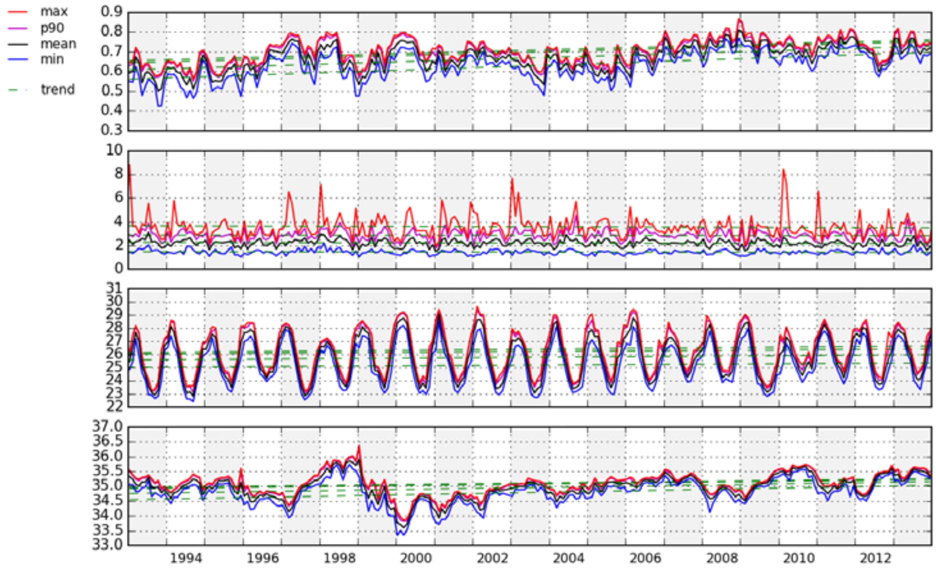
e) Cumulative coral reef stress index for 2003–2012.

- Photosynthetically Active Radiation (PAR): high solar irradiance at the water surface indicates a potential to heating and photochemical damage.
- Wind: high wind velocity enhances the water mixing and affects the air -water interface and thus solar radiation reach.
- UV radiation (ozone): high solar UV irradiance indicates a potential to heating and photochemical damage. decreased photosynthetic performance and altered community structure.

Ocean climate parameters listed in the previous section form the environment in which coral reefs have existed for millions of years, within specific limits of temperature, light, wave energy, etc. These key variables are also impacted by other atmospheric and ocean processes – for example wind velocity enhances the mixing of ocean water, with an overall effect of cooling. Similarly, strong currents could also have a cooling effect and at the same time affect the mechanical structure of the coral colonies. Chlorophyll and total suspended matter can be observed from satellites via changes in the optical properties of water. These variables can also be used as proxies of pollution from sediments and nutrients, which in turn can also be beneficial to corals as they create a 'shading effect', protecting corals from direct sunlight. Given that corals depend on light for photosynthesis, too much shading can prevent primary production.

Considering the above, the marine environment parameters were combined to estimate 'good' and 'bad' conditions as a gradient from 0 to 1, where 1 indicates high stress, and zero indicates relatively low or no stress to corals. Processing involved aggregating each of the parameters in time (2003–2011), establishing the effect of individual parameters on coral reef biological response, and finally, scaling the parameters to the established response behaviour.

EO-derived information provides a unique capability to cover the extended time periods and spatial extent required to ensure valid and comprehensive characterisation of climate change-driven trends and pressures on the Tongan coasts. Based on EO measurements, a wide range of climate-driven processes and their evolution over a 10-year were be generated in a consistent and comparable manner, enabling their combination to ensure a complete characterisation of climate-driven stress. These include the evolution of basic meteorological and oceanographic parameters (e.g. wind speed, ultraviolet radiation levels, sea surface temperature, ocean transparency/sediment load and surface wave height) as well as more complex information such as stress characterisation on the coral reefs surrounding Tonga. With the availability of data from satellites such as Sentinel-1, 2 and 3, continuous monitoring is ensured and small island states such as Tonga can access reliable and complete information on the changing environmental conditions in the surrounding area as well as the resulting changes in critical coastal habitats such as mangroves. As Tonga is typical of many Pacific Island states, we expect the capabilities demonstrated here to also be applicable to the other islands in the region.



From top to bottom: monthly means for
a) sea surface height (m) from Mercator Ocean GLORYS2V3 (Copernicus Marine Service). The observed trend corresponds to approx. +6 mm/year;
b) maximum significant wave height (m) from the WW3 numerical model (CERSAT/Ifremer);
c) sea surface temperature (°C) produced by GHRSST (Group for High Resolution Sea Surface Temperature, NASA/JPL);
d) sea surface salinity (in Practical Salinity Units, PSU) from Mercator Ocean GLORYS2V3 (Copernicus Marine Service).

This image acquired by Sentinel-2 on 23 May 2016 is one of the first higher-resolution satellite images showing the entire island of Tongatapu without cloud cover. Mangrove cover is clearly visible in several coastal areas including the extreme north east and north west of the island together with the edges of the lagoon area. Areas of coral can also be clearly delineated. Using images such as these to derive extent and status of mangrove and coral habitats represents a low-cost tool to rapidly obtain snapshots at different times.
© Copernicus Sentinel data (2016).

Project E

→ TRANSPORT SECTOR CLIMATE PROOFING IN TIMOR-LESTE

Users

ADB Pacific Department, Transport, Energy and Natural Resources Division (PATE)

ADB Pacific Department, Timor-Leste Resident Mission (TLRM)

Timor-Leste Ministry of Public Works, Department of the Environment

Provided EO Services

Climate data and climate statistics, Digital Elevation Model and hydrological features, land cover and land cover change, risk screening for floods and drought

Other Services

Hydrodynamic modelling, web-based viewer, capacity building

EO Service Provider

DHI GRAS A/S (Denmark)

Contacts

Hanna Uusimaa – Climate Change Specialist, ADB PATE
Richard S. Phelps – Principal Infrastructure Specialist, ADB TLRM

Pierre-Philippe Mathieu – ESA, *Pierre.Philippe.Mathieu@esa.int*

Mads Olander Rasmussen – DHI GRAS A/S, *mora@dhi-gras.com*

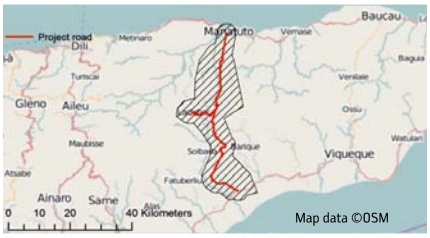
In recognition that an efficient and safe transport system is vital to secure economic and social development, ADB provides support for infrastructure upgrade and maintenance in Timor-Leste. This is done through the Road Network Development Sector Project, targeting general improvement of routine maintenance practices on existing national roads, and in particular focussing on the trans-island road from Manatuto to Natarbora in order to help improve national connectivity and support the government's petroleum and gas developments on the south coast.

The ADB project fits well into the ADB Long-Term Strategic Framework 2020, in which the bank explicitly commits to continue to integrate environment and climate change considerations into regional, national, and local development plans and actions. As Timor-Leste remains fragile due to years of conflicts, one of the initiatives identified in the operational plan is the development of a customized risk management framework to better address or mitigate four major risks: economic, political, state building and governance, as well as natural hazard.

Development and maintenance of infrastructure is very complex and expensive not at least in Timor-Leste, where inland roads are highly exposed to changed intensities and patterns of rainfall affecting landslides, floods, debris, scouring and rapid droughts after flooding. Therefore, developing and maintaining a complex infrastructure project is a challenge that has to be done in parallel with detailed hydrological analyses. The understanding of watersheds and its characteristics and the identification of climate risks will assure the sustainability of infrastructure projects and preservation of natural hydraulic conditions from surrounding catchments during the monsoon period.

ADB's project will upgrade the existing National road A9 between Manatuto and Natarbora, including the 10 km long spur extending to Laclubar. In order to make sure that the upgrading works comply with the ADB strategy on climate proofing of their projects, ADB would like to assess the current and future flood and drought risks associated with the road corridor. This is done mainly through the analysis of the expected change in precipitation, and associated overland flow, as this is the main source of risk for inland roads.

The EO support project helped to better quantify climate risks, especially from floods and droughts, and in particular on the road network in Timor-Leste. It also supported capacity building activities to raise awareness of the impact of climate and environmental changes. Focus was put on natural capital and road infrastructure, and the role of EO to support climate proofing and better watershed management.



Location of the Manatuto–Natarbora 81 km long road and its 10 km spur extending to Laclubar. More detailed analysis, including land cover mapping and hydrological modelling was carried out for the dashed area.

The EO support project demonstrated how many relevant EO-based datasets can replace traditional data sources and how these data can be applied for relevant analysis.

The following products and derived services were provided as part of the project:

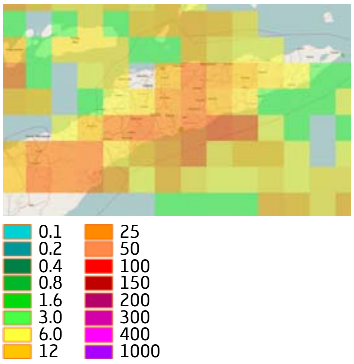
- Reliable and up-to-date climate data (based on the TRMM satellite, 3 h/daily rainfall),
- SPI (drought index) and rainfall statistics (IDF curves) based on the climate data,
- Digital Elevation Model (30 m resolution), hydrological catchments and rivers,
- Current land cover (2014) and recent land cover change (between 2007 and 2014),
- Hydrological modelling to support drainage design, 2D HD and 1D Design discharge,
- Risk screening maps for floods and drought.

Most of the above products as well as analysis of these were provided for browsing and further analysis in a web viewer specifically developed for the project available at http://timor.dhigroup.com.

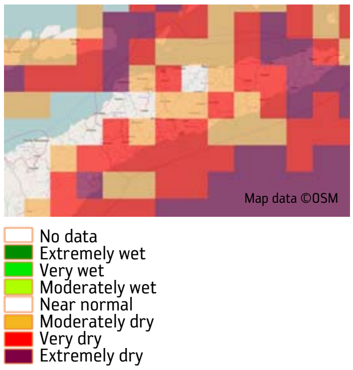
During the inception phase ADB representatives expressed special interest in 1) accessing and applying (in the hydrodynamic modelling) as detailed climate change scenario data as possible and 2) slope stability, as an essential part of a road engineering project. Both issues were investigated and implemented, noting that slope stability could only be considered on the coarse scale, as detailed studies of this would require much more detailed data than available.

The project clearly demonstrated the added value of providing access to long-term consistent data on local climate, allowing for derivation of IDF (Intensity-Duration-Frequency) curves describing the rainfall patterns in the area. IDF curves are essential (and used directly) for the correct dimensioning of road-structures like culverts and bridges. The original design of road structures were based on rainfall statistics from Darwin, Australia due to lack of reliable local data. Data from the TRMM and GPM satellites allowed for derivation of IDF curves at the scale of TRMM resolution (approximately 25×25 kilometres) and 3 hours temporal resolution which was further extrapolated down to 1 hour. Comparison between the IDF curves from Darwin and the EO-based, also considering climate change scenarios from IPCC showed that road structures have generally been over-dimensioned. Even for the RCP 8.5 scenario for 2090, the chosen design dimensioning should be sufficient. This is of course positive in that the road structures are likely to accommodate the expected rainfall for a long time, but over-dimensioning is likely to incur increased construction costs and maintenance. The main issue remains for similar projects–the lack of sufficient/reliable local data can lead to incorrect dimensioning.

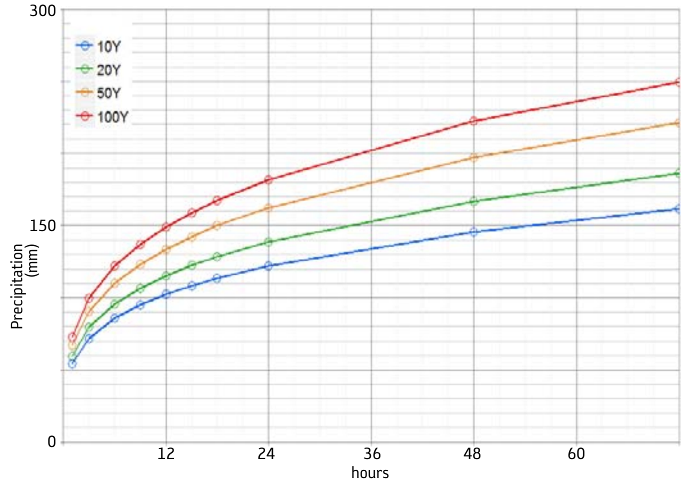
The project has also demonstrated how to apply the supplied EO information in hydrodynamic modelling with direct benefits for the road engineers in terms of the expected effects of climate change on runoff along the road corridor. This kind of analysis requires not only high quality data on topography, but also information on land cover as this influences the runoff. The



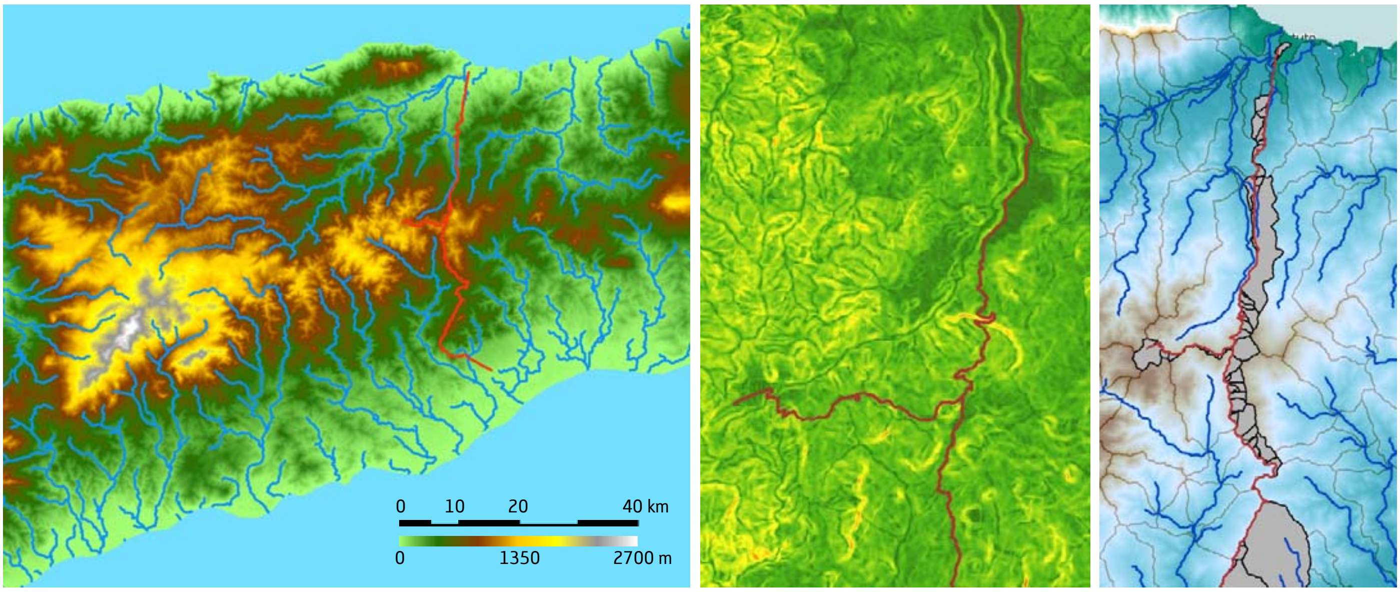
Example of 24 hour accumulated precipitation extracted from TRMM 3B42 product.



Example of SPI 12 months.



Example of IDF curves for a region in Timor-Leste.



Left: detail of the NEXTmap Digital Elevation Model (DEM) for Timor-Leste, overlaid with the derived catchments and river network. *Middle:* slope map derived from the DEM. *Right:* the derived hydrological catchments (light brown outlines), the river network (blue lines) and the and the road catchments (grey areas with black outlines) over a backdrop of the DEM. NEXTmap © InterMap/BlackBridge SARL.

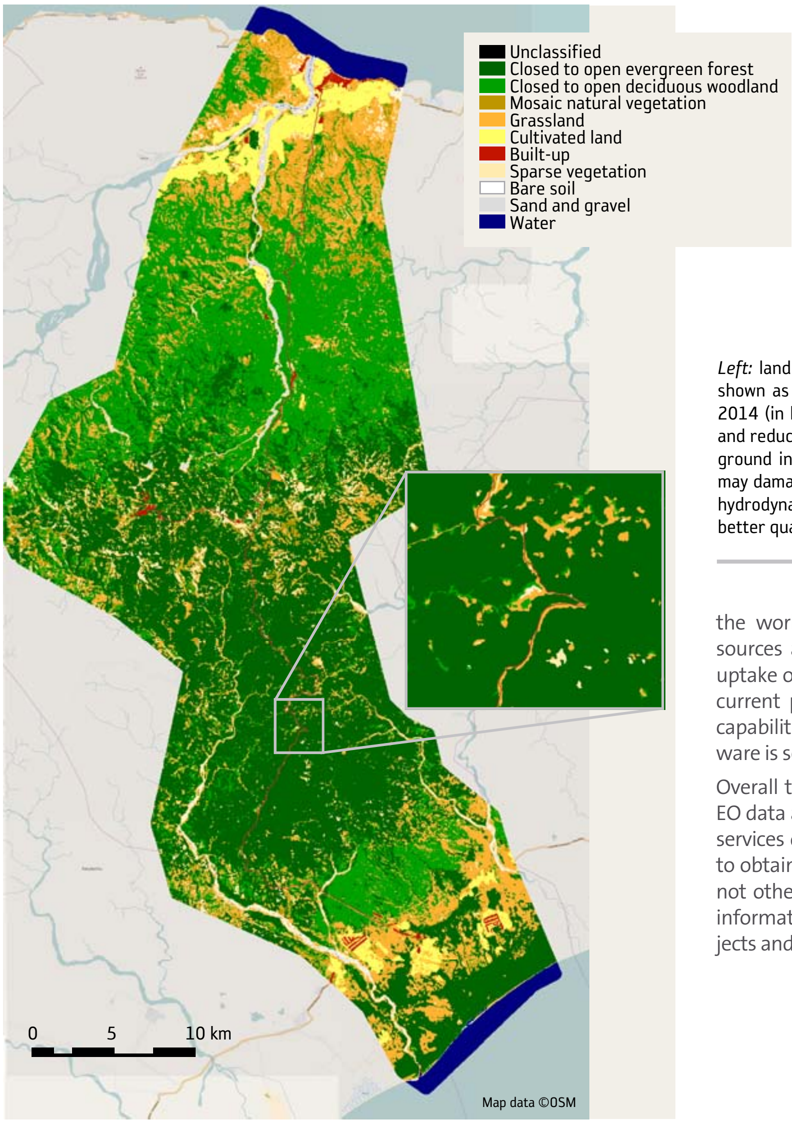
mapping of land cover and land cover change has shown a decline in forest cover during the period between 2007 and 2014. As the progression of forest into less vegetated land cover types is likely to increase the overland flow in case of heavy rains, the observed (and any similar future land use change) will increase the risk of flood damages to the road.

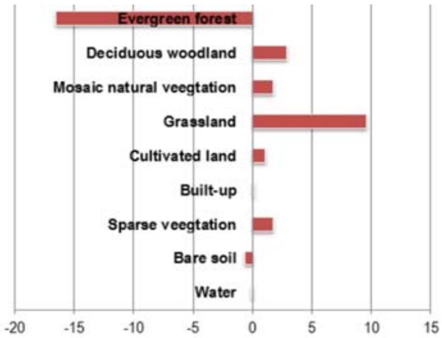
As part of the project, a two-day workshop/capacity building event was carried out at the ADB Resident Mission in Timor-Leste. The workshop had over 15 participants from government agencies (Ministry of Public Works, National Directorate for Water Resource Management, Institute of Petroleum and Geology), international organisations (ADB and various UNDP offices), NGOs and road engineers working on the road project. The project EO data and services were showcased by presenting how the data can be applied to a range of topics within climate change, infrastructure design and monitoring of land use and climate. All of the training sessions included local examples of the relevant data products, as well as demonstration on how and where these products were available in the project web viewer. Material was prepared for the course through the framework of *The Academy by DHI*, including and course presentations and project data distributed through the web viewer (requires login). In order to increase the uptake of the information locally in Timor-Leste and make the deliverables more accessible, ADB requested a number of “info sheets” explaining the value of delivered products for road projects and broader initiatives. As internet access is not widely available in rural areas in Timor-Leste and generally has very limited bandwidth, the info sheets were distributed also as paper versions.

The service utility assessment showed that there is great interest and potential for applying EO data and services within ADB projects, but currently significant, mainly institutional, constraints need to be overcome. In general, for road infrastructure projects, ADB presently only specifies the required outputs of feasibility and design studies and leaves it to the contractors to carry out

“The project helped ADB in better quantifying climate risks (in particular flood risks) to inform and validate the climate-proofing and watershed management activities. It also helped ADB to raise awareness about the impact of climate change and land-use changes in Timor-Leste, with focus on ecosystem services and road infrastructure. [...] Feasibility studies for larger projects could be facilitated using EO. Detailed drainage design, environmental mitigation, preliminary design could cut the time currently needed for ground based topographical survey – especially at the feasibility stage where the order of accuracy (particularly vertical) would be sufficient.”

Richard S. Phelps, ADB Principal Infrastructure Specialist



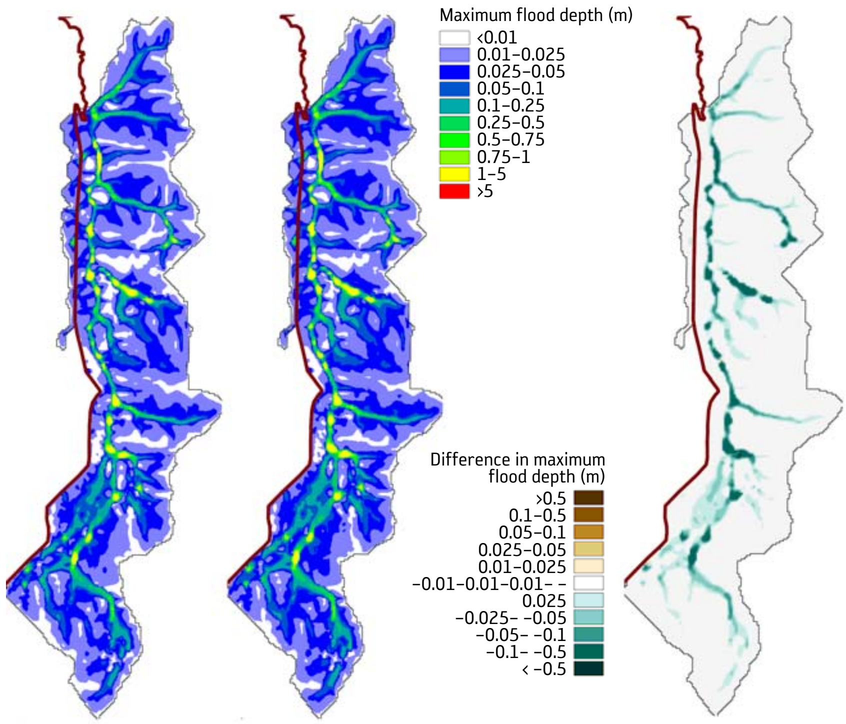


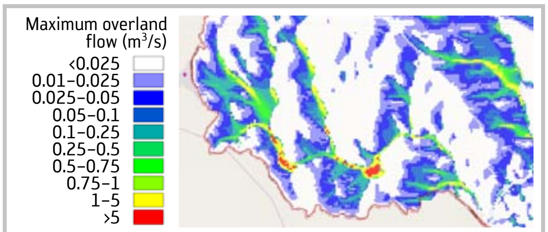
Left: land cover map for the Manatuto–Natarbora road corridor for 2014. The road is shown as a thin red line. *Top right:* associated land cover change statistics for 2007–2014 (in km^2). Vegetation is a major stabilizing component that protects soil and water and reduces floods and landslides. When the vegetation cover is removed or reduced, the ground instability increases and the area becomes more susceptible to landslides that may damage the road network. The land cover information was further used as input for hydrodynamic modelling to simulate overland flow and assess slope stability and to better quantify risks on the road network induced by future land use change trajectories.

the work as desired. This effectively means that the methods and data sources are chosen not by ADB, but solely by the consultants, making the uptake of EO data and services quite arbitrary and not an integral part of the current practices. Furthermore, the lack of knowledge and training on EO capabilities, as well as potentially the cost of this training and required software is seen as factor currently limiting the uptake of EO data and services.

Overall the project concluded that there is great potential for application of EO data and services within ADB on projects with similar scope. The data and services delivered were found to be of better quality, better value and easier to obtain than traditional data sources. They also provide information that is not otherwise available. The main obstacles for further update of EO-based information is the current practices on the Terms-of-Reference for new projects and the lack of knowledge and training on EO capabilities.

Example of the output of the hydrodynamic modelling, showing the maximum water depth at present conditions *(left)*, the projected increase in water depths for a future climate change scenario (RCP 8.5 for 2090, *middle*) and the difference between the two (right), providing a valuable map of predicted changes.





Example of maximum overland flow simulated for a 20 year event in 2090 under RCP8.5 indicating road sections more susceptible to scouring and erosion due to lateral flows.

Flood risk screening – Indexing of flood-related risks

Nation-wide indexing of flood related hazards and risks

Remote sensing and crowd-sourced information coupled with advanced spatial modelling tools and techniques nowadays offer unique opportunities to screen for flood risks for different types of assets.

Making use of digital terrain information, flood hazard zones can be efficiently identified using state-of-the-art spatial analysis tools. Spatial datasets for different types of assets such as population, property or roads can be acquired or derived and merged with flood hazard information to produce qualitative flood risk maps over large areas.

Indexed risk maps communicate in a fast and efficient way risk level and distribution across a country or region. They can provide support for preliminary risk analysis and prioritize detailed investigation and investments.

The components of risk

Risk can be represented by two components – the probability of an event occurring (summarised in the hazard term) and the impact associated with that event. To evaluate potential impact it is then necessary to characterize receptors (exposure) and their susceptibility (vulnerability) to flood. While flood risk assessment can require resource consuming techniques to describe the different components of risk in quantitative terms, straightforward qualitative approaches can be proposed to rapidly screen flood risks over large scale and support investment planning.

Flood hazard indexing

An index for flood hazard is derived at the country scale through spatial analysis of the digital terrain and using the Height Above Nearest Drain (HAND) method. The index ranks the terrain model from 1 to 6 with the highest values corresponding to areas lying lower along streams, rivers and coastal zones and more susceptible to be flooded.

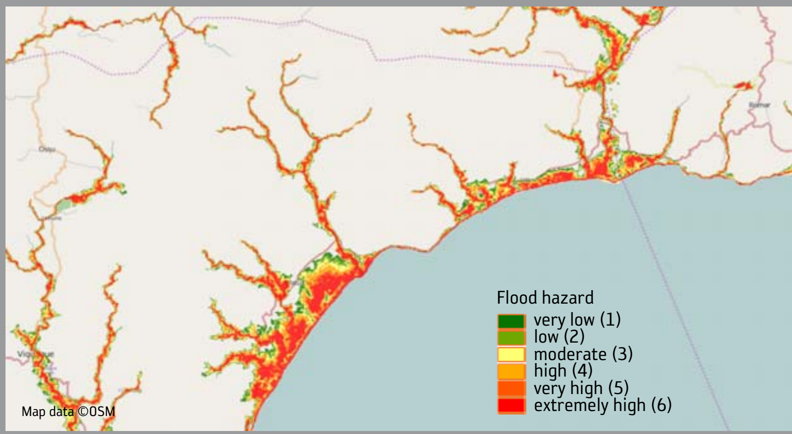
Population exposure

A population/property index is derived from the WorldPop gridded population dataset. The WorldPop dataset capture built-up areas and infrastructure through e.g. Landsat imagery and redistribute district level census to the raster grid produced. The WorldPop dataset is then reclassified to generate an Exposure Index with weighting increasing with the population density.

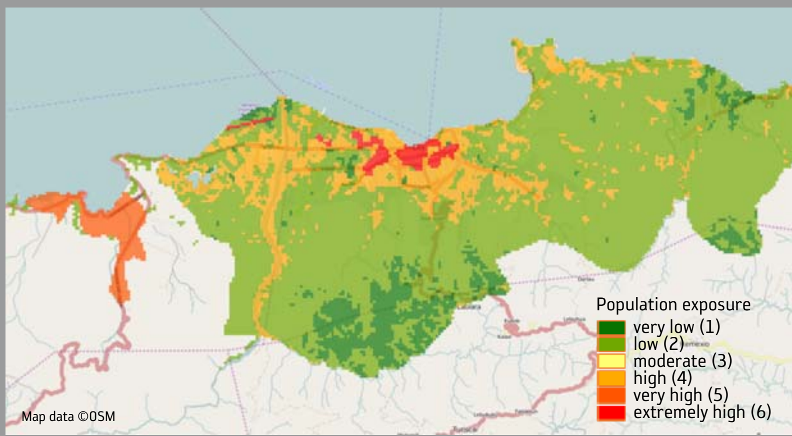
Flood risk indexing

The flood risk maps are generated from the hazard and exposure classification previously described for population and using Open Street Map road feature for roads. Risk indices are given at a 30 m resolution grid.

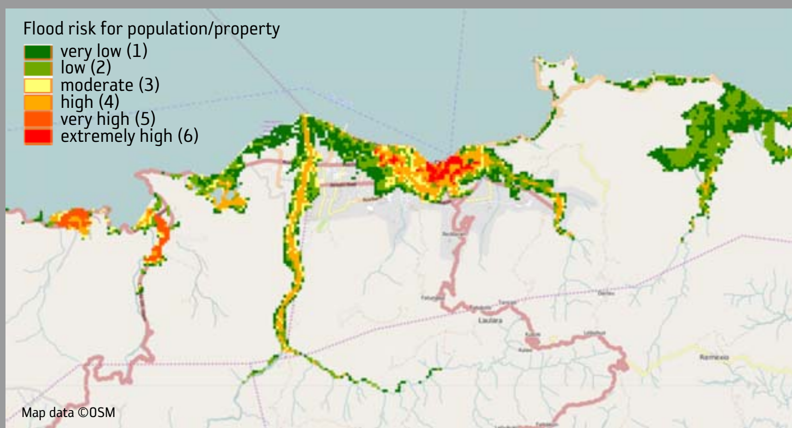
The index generated is a direct combination of the hazard and exposure layers without consideration of the susceptibility of the receptors. Being based on the spatially averaged elevation over the terrain model, the risk index do not capture exact road elevation and do not capture floods that might be associated with inadequate design of drainage structures along and across the roads. The flood risk maps for roads provides a nation-wide view of roads more susceptible to scouring or erosion/overtopping. It can help to identify the main risk zones and prioritize areas for detailed investigation and potential upgrading.



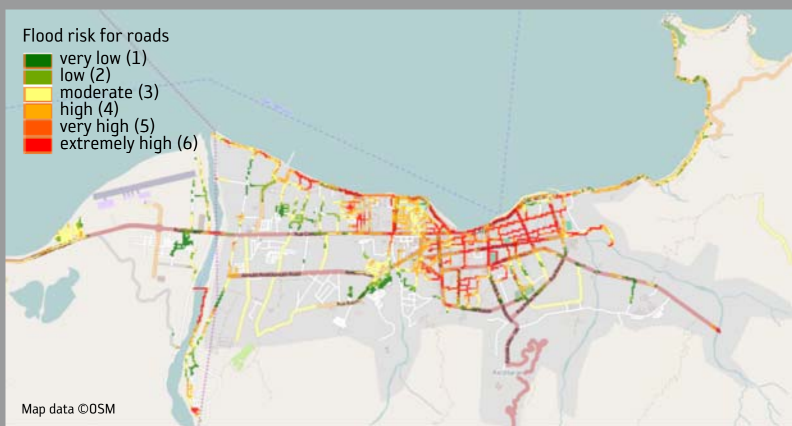
Flood hazard for the coastal area around Uaitame / Irabin Leteira.



Population exposure indexing in the Dili area.



Flood risk indexing for population in the Dili area.



Flood risk indexing for roads in the Dili area.

Project F

→ TRANSPORT INFRASTRUCTURE ASSESSMENT IN PAPUA NEW GUINEA

Users

ADB Pacific Department, Transport, Energy and Natural Resources Division (PATE)
ADB Pacific Department, Papua New Guinea Resident Mission (PNRM)

Papua New Guinea Department of Transport (DOT), Department of Works (DOW), Department of National Planning and Monitoring, and the National Department of Health
Papua New Guinea Office of Climate Change and Development (OCCD)
Papua New Guinea Department of Mineral Policy and Geohazards (DMG)

Provided EO Services

1. Main transport infrastructure inventory
2. Climate change-related products

EO Service Providers

G.A.P. s.r.l. (Italy)
Planetek Italia s.r.l. (Italy)

Contacts

Sarosh Khan – Senior Transport Specialist, ADB PATE
Aaron Batten – Country Economist, ADB PNRM

Zoltan Bartalis – ESA, *Zoltan.Bartalis@esa.int*
Mariangela Cataldo – SERCO SpA for ESA, *Mariangela.Cataldo@esa.int*

Raffaele Nutricato – G.A.P. s.r.l., *raffaele.nutricato@gapsrl.eu*

Location of the project area:
Hela and Southern Highlands provinces.

The Government of Papua New Guinea (PNG) recently launched its National Transport Strategy 2014–2030 (NTS) that highlights its goal to develop a well-integrated, multimodal, safe and financially and environmentally sustainable transport that efficiently serves its economy and people. ADB is supporting the NTS's strong focus on enhancing transport connectivity through four ongoing projects on land, aviation and maritime transport. Projects include the Highlands Region Road Improvement Investment Program, the Bridge Replacement Project, the Lae Port Project and the Civil Aviation Development Program aimed at rehabilitating 1400 km of roadway, 22 airports and one major seaport. In spite of significant ADB investments underway, major gaps remain throughout the country in connectivity and access to economic opportunities, trade, education and health facilities.

The goal of the four large ADB transport projects is based on a key element: the definition of rules for the development of infrastructure in the country. It is important to look at the various pieces of spatial information available but, even more, it is important to consider all of them together in order to prioritise actions and focus resources.

To this aim, geospatial information is required to provide the most consistent, quality-assured, up-to-date and high-detail picture of the transport infrastructure where the ADB projects are under implementation (mainly in the Southern Highlands and Hela provinces). The ESA support project contributed with an up-to-date picture of the transport infrastructure in central PNG, the information covering large areas via tailored validated services with short delivery time. Furthermore, considering ADB efforts to develop an approach for assessing climate risks and climate proofing of transportation investment projects, the project contributed to identifying vulnerable areas and and quantifying climate risks that the road network is exposed to (in particular floods and droughts), due to changes in climate and environmental conditions (e.g. rainfall patterns, vegetation, temperature, etc.). Additionally, products highlighting susceptibility to landslides, flooding and infrastructure instability were also of interest and delivered.

The covered area consists of the Southern Highlands and Hela provinces although some products are available for the entire PNG territory. The two services integrate both satellite radar and (high/medium resolution) optical data and are based on techniques that can be easily replicated for product updates or for the analysis of other areas of interest, especially in the light of the recently-launched European Sentinel satellite missions.

Although in-situ-based validation was generally preferable, often end users could not provide in-situ data for cross-comparison or these data were of poor quality or not well-distributed over the area of interest. There was an increasing need to identify alternative validation procedures which can be easily extended to other areas or time periods.

The products are available in typical GIS formats (ready to be opened in e.g. Google Earth) and a dedicated light web-based viewer was implemented in order to support the visualisation of the data. In addition, the solution includes a free Mobile MapWorks app for mobile platforms to enabling offline navigation and collection of geolocated annotations in the field. A number of datasets deemed useful by the ADB project team (SRTM Digital Elevation Model, World Database on Protected Areas, etc.) were also added to the produced GIS database.

Main transport infrastructure inventory

The service provides an up-to-date picture of the transport infrastructure over the two provinces through a land use map focussing on artificial structures and more specifically on transport infrastructure (road networks and associated land, port areas, airports, other artificial surfaces). For the road networks, linear features were also extracted into separate vector datasets. Additionally, various points of interest (bridges, airports) were also collected.

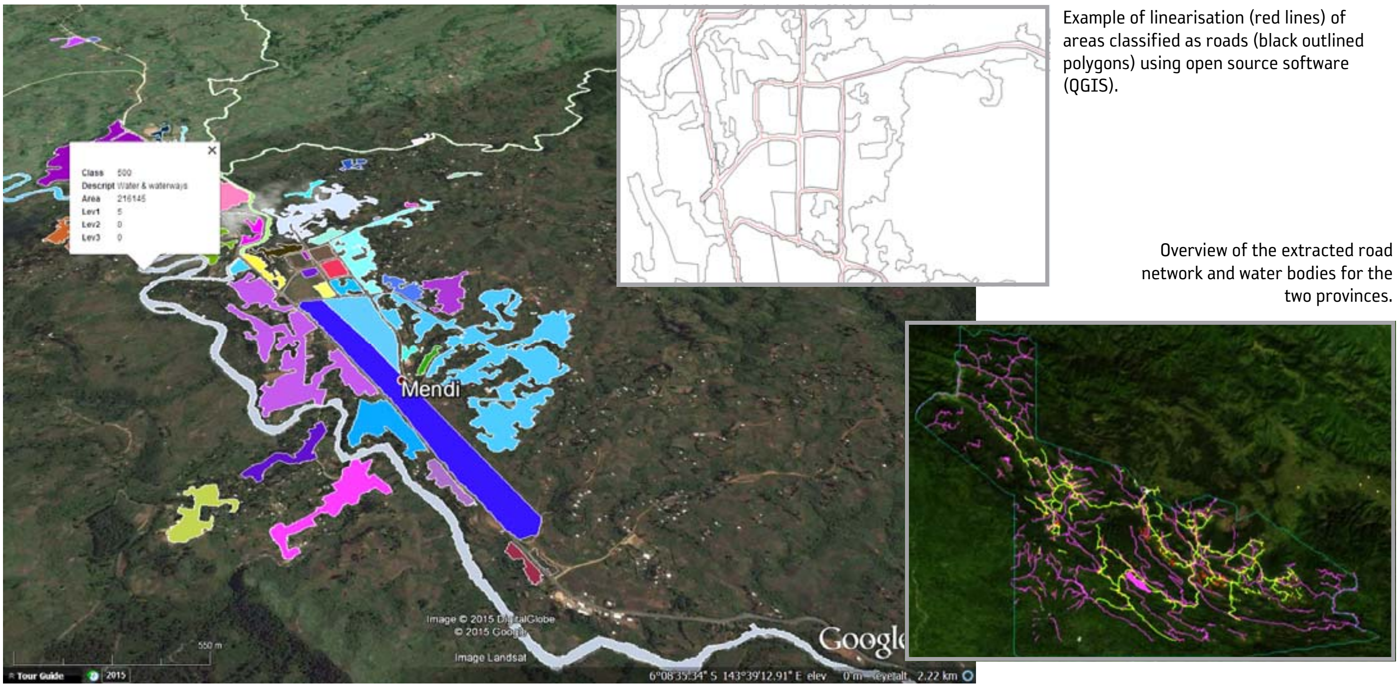
The service is based mainly on optical RapidEye imagery. The pixel size of 5 m prevented the detection of small roads, however, for some smaller areas very high-resolution imagery (Pléiades) was available and has been used to locally improve the results. Whenever the optical data was affected by cloud cover, the process was complemented by RADARSAT-2 (radar, 3 m resolution) imagery. The imagery was also used to update the water bodies layer, especially rivers, which typically are dynamic and can change shape frequently.

The datasets fall in the period January 2011 to September 2015. The algorithm is based on a semiautomatic object-oriented classification of optical and radar data.

Climate change-related products

This service provided satellite-based information on environmental parameters concerning climate risks: rainfall, temperature and vegetation indices, as well as terrain instability.

The **climate datasets** consisted of a number of indices associated to anomalies of temperature, rainfall and vegetation. These are mainly based on MODIS and TRMM satellite data covering the whole PNG territory with kilometric spatial resolution. They are thus intended for large-scale analysis. The delivered datasets were: total and mean precipitation (monthly and annual), rainfall seasonality, minimum, maximum and mean temperature (monthly and annual), as well as a series of precipitation, temperature and vegetation anomaly indices (Standardized Precipitation Index, NDVI anomalies, Vegetation Condition Index, etc.). All products were generated following the same WorldClim and USGS methodologies that were also adopted by the *PNG*



Example of linearisation (red lines) of areas classified as roads (black outlined polygons) using open source software (QGIS).

Overview of the extracted road network and water bodies for the two provinces.

Example of the land use classification product for artificial surfaces (transport-related) and waterways, near the city of Mendi, displayed in Google Earth.

An example of synergistic use of optical and radar imagery. *Left:* the road layer (white polygons) extracted from RapidEye imagery and displayed in Google Earth. The blue area indicates the cloud cover that prevents the full extraction of two roads. Note how the Landsat image available from Google Earth (acquired in 2013) is not recent enough to show both roads. *Right:* the same area, as seen in a RADARSAT-2 image. The extraction of the missing roads (green polygons) is possible in the radar imagery. RADARSAT-2 data © MDA/CSA.

Resource Information System (PNGRIS) Handbook prepared by the University of Papua New Guinea for the Land Use Section of the Department of Agriculture and Livestock.

An updated landslide inventory is essential for the assessment of the impact of slope failures on the main transport infrastructure. The **terrain instability datasets** consisted of a landslide inventory and a map of terrain displacement measurements over the two provinces. Landslides were identified mainly based on the use of RapidEye imagery. The 5 m pixel size allowed the detection of medium to large sized landslides. A number of smaller slides were identified by using higher-resolution imagery (Pléiades and imagery available in Google Earth). In particular, on-screen visualisation and interpretation of Pléiades imagery represented the main approach to identify and delineate slope instability phenomena along some of the main roads of the study area. Thanks to the excellent resolution of the imagery, high detail of many landslides was obtained, in particular those present along the Spine Road. In some cases a number of smaller landslides within an area were identified where the coarser-resolution RapidEye imagery only showed a single larger landslide.

It is apparent that the construction of the Spine Road on a complex topography, with loose material often piled up along the road, has led to many debris slides and flows. This is suggested by the fact that some of the phenomena are visible on the Pléiades imagery, but not on the older RapidEye imagery.

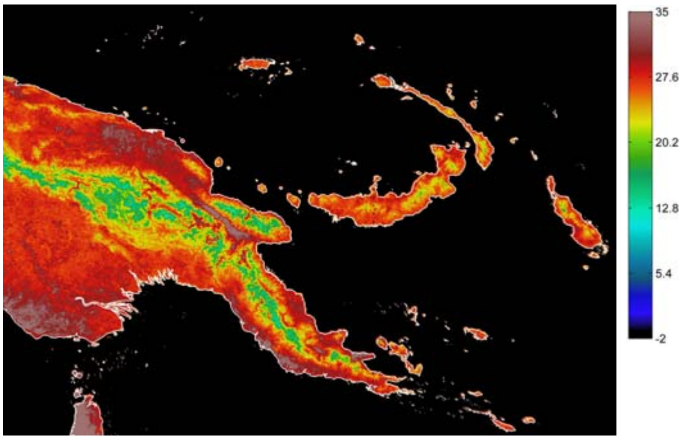
Terrain displacement measurements were obtained by using interferometric techniques on ERS SAR satellite data. This method provides terrain displacement estimates in the order of a few mm/year at a large number of (non-vegetated) points. The historical data covers the period 1992–2000), and are a good indication of what can be provided if the service would be based on the recently-launched Sentinel-1 satellite mission, acquiring more frequent and superior quality data on a regular basis over the entire PNG territory secured for operations for the next 20 years.

The very heavily vegetated character of the PNG provinces meant that the SAR interferometric method was able to produce reliable terrain motion estimates only at a relatively low number of points. Nevertheless, these points are often located on important man-made infrastructure, making it possible to study the evolution of e.g. road stability.

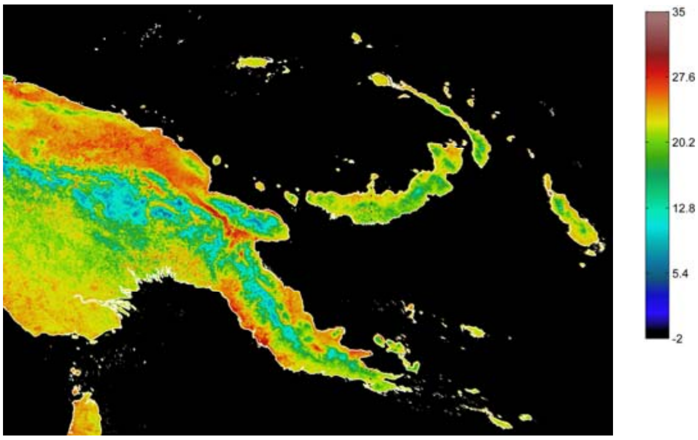
Compared to existing datasets (e.g. PNGRIS or the "GeoBooks", GIS-based planning tools created by the Remote Sensing Centre of the University of Papua New Guinea and expressly designed for use by the provincial governments), the delivered products make better use of satellite data, with some of the products showing a better spatial resolution and more recent information.

Having developed two QGIS projects for the data delivery was very much appreciated so that data could be transferred immediately to end users facilities. While consultation of WebGIS services remains a lower priority in PNG due to connectivity problems, the effort of putting the data online was evaluated positively by the project partners, especially in light of the intensive international cooperation in the area.

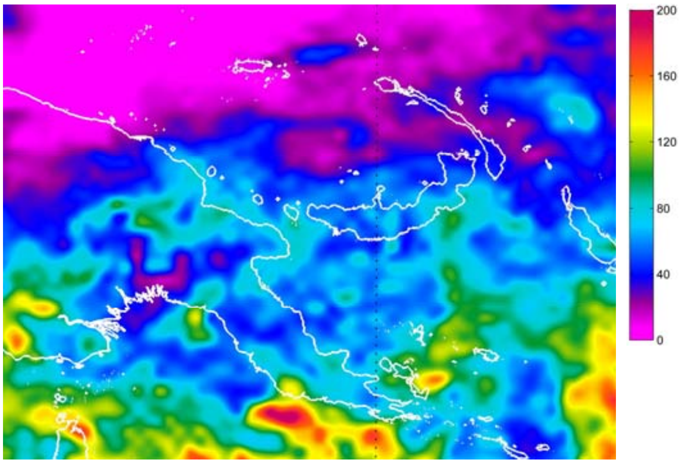
In November 2015 the EO service portfolio was also presented at the Adaptation Technical Working Meeting called by the Office for Climate Change and Development (OCCD) in Port Moresby. The meeting was attended by several PNG government offices and local NGOs and other stakeholders. The EO-



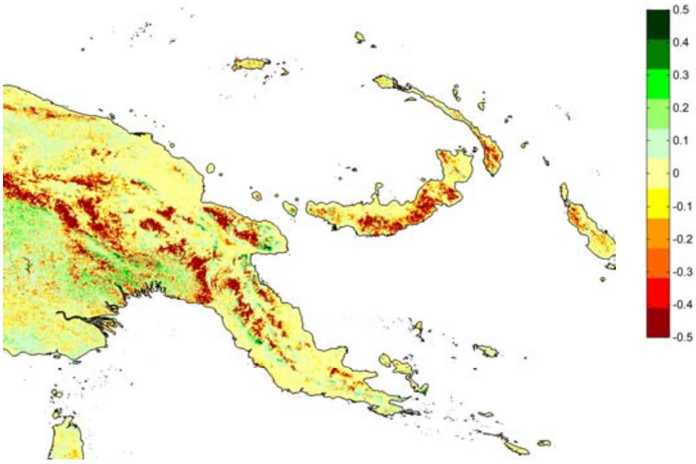
Maximum land surface temperature for 2013 (˚C).



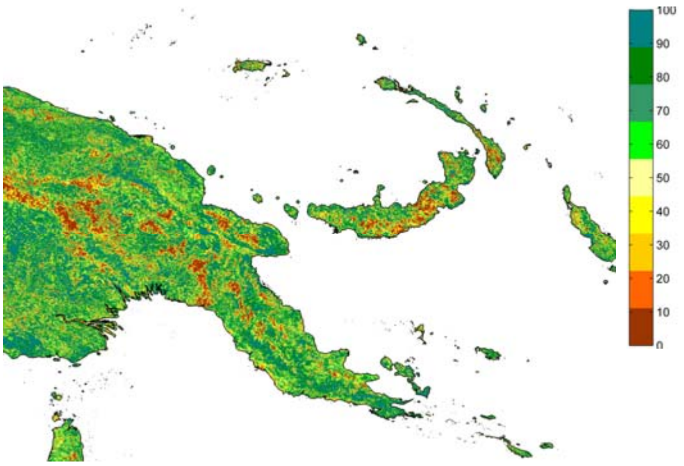
Mean land surface temperature for August 2013 (˚C).



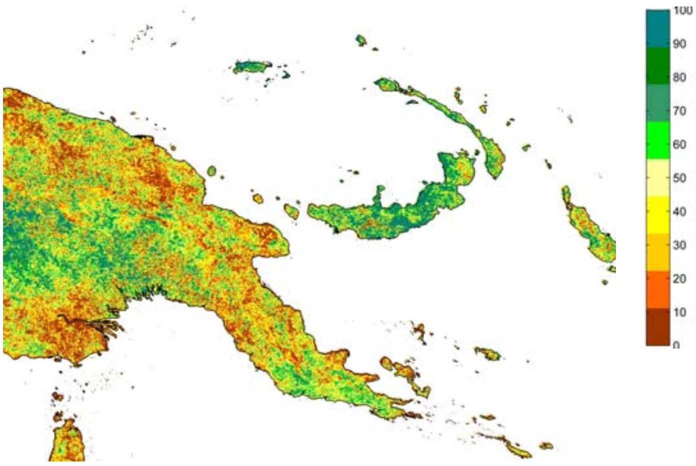
Mean monthly precipitation for August 2013 (mm)



NDVI anomaly for August 2013.



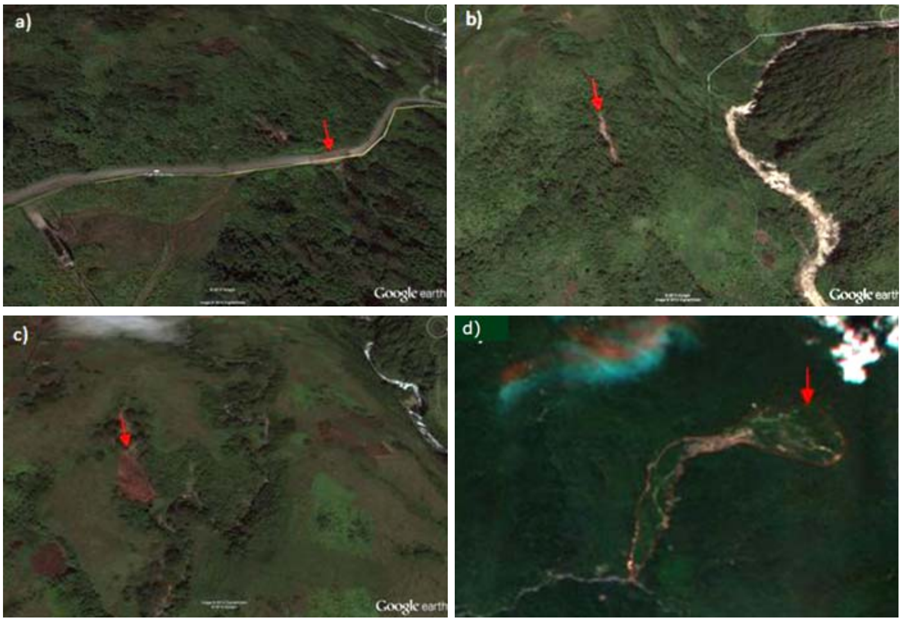
Vegetation Condition Index for August 2013.



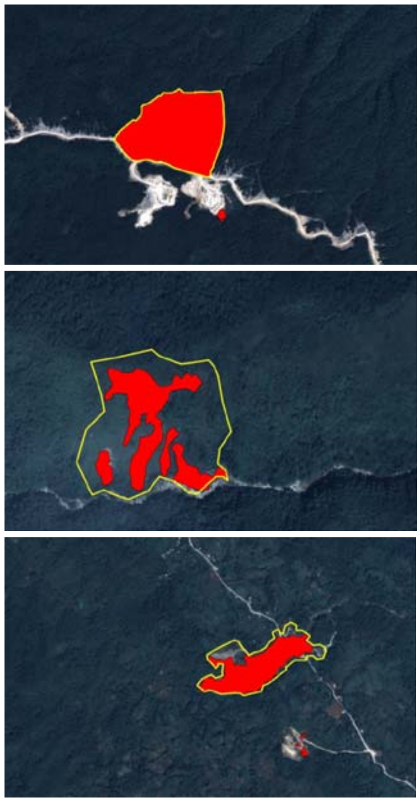
Temperature Condition Index for August 2013.

based solutions raised much interest in the OCCD group as well as in the PNG Department of Mineral Policy and Geohazards Management. Particular interest was shown for the landslide and terrain motion products, as there is little doubt that an adaptation to climate change should be inclusive of measures to mitigate the risk of geohazards. It was noted that subsidence is also a problem in coastal areas, also on other Pacific islands, where large swaths of land are at risk of submerging due to either sea level rise, subsidence, degradation of coral reefs or a combination thereof. Interest was also recorded for extending the study areas at least to coastal but also to cash crop areas (coconut industry). ■

> *"There are ongoing activities which produced maps on hazards and vulnerable areas. [The ESA support project] information will be used to supplement the data and information currently available. Information could also be used for developing management strategies."*
>
> **Luanne Losi Yawingu**, Project Manager,
> PNG Office of Climate Change and Development

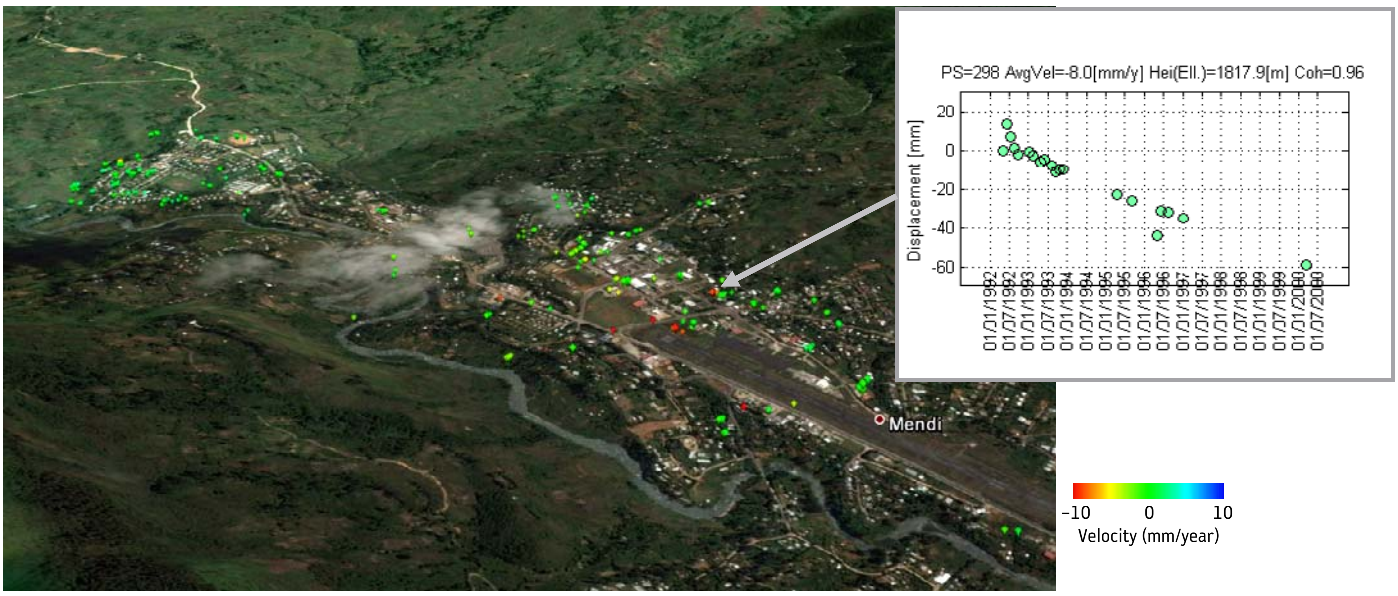


Examples of landslides extracted from satellite imagery and mapped over Google Earth (red arrows indicate the unstable areas): *a)* note a slope break above the road and a slight lowering of the slope below the road; *b)* and *c)* note the absence of vegetation within the perimeter of the landslide.



Detailed view of three landslides overlaid on a Pléiades 0.5 m resolution image. Yellow polygons indicate the landslides as detected in RapidEye 5 m imagery and red polygons as detected in the Pléiades image. Pléiades data © CNES.

Left: large landslide observed on RapidEye image (2012 September 30). *Right:* the same location on a pansharpened Pléiades image (2014 February 4), where more detailed geomorphic features (e.g. head scarp, drainage) are clearly visible. The images also indicate an apparent decrease of the landslide area that can be linked to the vegetation re-growth. RapidEye data © BlackBridge. Pléiades data © CNES.



Example of displacement map over the city of Mendi displayed in Google Earth. The colour of each point (so-called Persistent Scatterers) represents the estimated average terrain displacement velocity, according to the colour bar on the right. Average velocity is only a part of the information that can be retrieved for each point, since for each of them the full temporal displacement trend is actually measured, as indicated by the diagram on the top right. For that particular point, a mostly linear trend of −8 mm/year could be observed.

Project G

→ COLLECTING TRANSPORT INFRASTRUCTURE INTELLIGENCE IN ASIA AND THE PACIFIC

Users

ADB Sustainable Development and Climate Change Department, Sector Advisory Service Division (SDAS)

ADB Central and West Asia Department, Urban Development Division (CWUD)

ADB Pacific Department, Pacific Liaison and Coordination Office (PLCO)

Provided EO Services

1. Transport infrastructure inventory and its changes over time
2. Detailed land use mapping and population estimation
3. Maritime traffic statistics

EO Service Provider

e-GEOS S.p.A. (Italy)

Contacts

Katja Schechtner – Transport Specialist, ADB SDAS
David Margonsztern – Senior Urban Development Specialist (Transport), ADB CWUD
Sarosh Khan – Senior Transport Specialist, ADB PATE
David Ling – Senior Transport Specialist, ADB PLCO

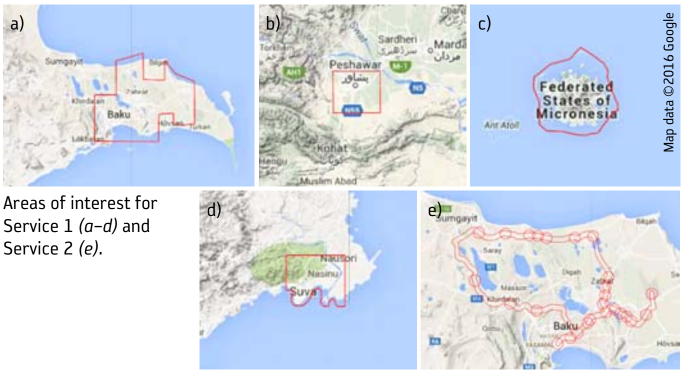
Zoltan Bartalis – ESA, *Zoltan.Bartalis@esa.int*

Domenico Grandoni – e-GEOS S.p.A., *domenico.grandoni@e-geos.it*

Current transport infrastructure data availability and quality often limit the development of sustainable transport policies, investment strategies and models of future transport needs. Data gaps also constrain the ability to evaluate impacts of such policies and investments. Detailed and updated knowledge about the spatial distribution of transportation assets is relevant also to disaster risk reduction (DRR) policies. ADB is interested in understanding how satellite-based data collection could be included in a standard set of data collection methods for an institutional data collection mechanism.

The EO support project supported the ADB *Global Transport Intelligence – Transport Outlook Asia* activity, a subproject of the *Implementation of Sustainable Transport in Asia and the Pacific* cluster CDTA (Capacity Development Technical Assistance). The CDTA targets three of the four key pillars of ADB's Sustainable Transport Initiative Operational Plan. (STI-OP) The subproject in question (Subproject D) aims to help increase the knowledge base on transport in Asia and the Pacific and its impact on environmental and social sustainability. The CDTA project works with the developing member countries also to build local capacity for regular transport data collection and reporting.

The satellite-based information contributed to the updated inventory of transport infrastructure (mainly roads, railroads, waterways, airports), and the identification of existing gaps, giving the most up-to-date picture of transport infrastructure, and of its evolution with respect to a previous date. Additionally, the activity also supported public transportation development projects both in the preliminary design and in the executive design phases, providing information supporting both the planning (e.g. population distribution around key points of interest such as train stations) and the detailed design activities (e.g. hyper-level of land use detail along a planned public transport corridor). The pilot areas of interest are Baku (Azerbaijan), Peshawar (Pakistan), Pohnpei (Federated States of Micronesia) and Suva (Fiji). A third service demonstrated the use of satellite-based information to deliver maritime traffic statistics based on integrating of coastal and satellite AIS



Areas of interest for Service 1 *(a–d)* and Service 2 *(e)*.

(Automatic Identification System) data with detected vessels from radar EO data. The selected test areas for this service lie in the area from the Andaman to the Celebes seas.

Transport infrastructure inventory and its changes over time

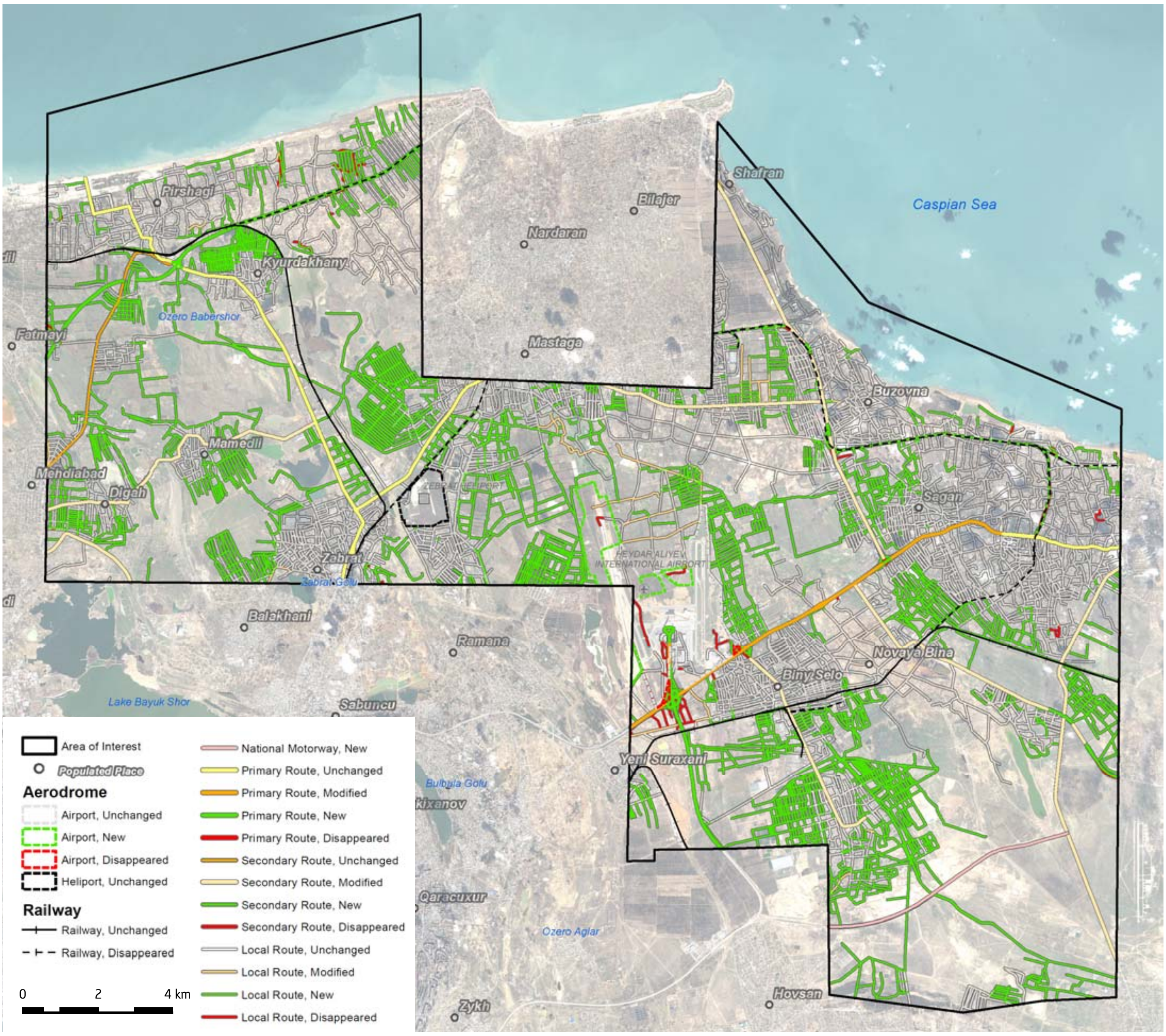
The knowledge of distribution and evolution over time of transport infrastructures is a key information for urban planning at local, regional and national level. The service demonstrating the detection of roads, railways, ports, airports and their associated areas, providing as much attributes as possible (e.g. surface type, number of lanes, construction status, etc.). The spatial resolution of the input satellite imagery proved crucial for the analysis level of detail. A higher resolution on the other hand lowers the possibility to cover large areas in a cost-effective way. To cope with such variability, imagery at different resolutions (from 0.5 m to 2.5 m) was tested on different. The tests showed that the highest resolution available is necessary to provide sufficiently accurate maps over relatively small urban areas, while for regional and national coverage a good compromise is to use 1.5 m resolution data. Naturally information could only be provided for above-ground assets and not always convincingly for the smallest elements such as footpaths and cycling lanes.

Historical data availability allowed comparing the map of visible transport infrastructures around the year 2005 with the status around 2012. A third map was generated highlighting the changes that occurred in the period. This information if particularly efficient in reflecting the results of public investments in the transport network and is at the same time an indicator of the urban expansion in the area (particularly relevant in the Baku). Additional indicators can be derived about the connectivity of different urban zones in order to prioritise interventions.

Detailed land use mapping and population estimation

When planning new Mass Rapid Transit (MRT) systems or adapting existing ones, it is essential to have precise and up-to-date knowledge of the situation in the field. In this context, and following discussions with ADB CWUD, two types of products were defined and prototyped for greater Baku, where currently there are several options under evaluation to rearrange the railway line connecting Baku city and the surrounding urban areas. The products were:

- Very detailed land use maps focussing on non-residential elements in a buffer area of 500 m width along the railway axis. This is basically an inventory of non-residential elements that may interfere with the planning of the adapted railway line. This product required a combined analysis of satellite images together with ancillary data from external sources to better characterise the use of the detected structures. The total length of the corridor was 80 km.
- Population estimation within 1 km from the planned MRT stations. This provided population information at the right level of detail and granu-



Change detection map showing changes in the transport infrastructure in parts of greater Baku. Changes are detected by comparing very high-resolution images from 2003/2005 (Quickbird and Ikonos) and 2012/2014 (SPOT 6 and SPOT 7 / Azersky, shown as background). SPOT 7 data © Airbus DS.

larity, aggregated at building block level. Census data is usually outdated or collected in an aggregated way e.g. at district level. Its combination residential land use classes as detected form satellites makes it possible to estimate the population distribution at the level of the single building block. This information is relevant as it allows transportation planners to get reliable data on potential user basins. Population distribution (and density) maps were generated for 26 different stations.

Maritime traffic statistics

Radar satellites have the capability to detect vessels over large swaths of seas, both close to ports and at open sea. Vessels are detected thanks to their contrasting radar signature with respect to the sea background and can be characterised in terms of both size and speed. The acquired maritime situation can be completed with vessel identification data (e.g. AIS, SatAIS) in order to identify vessels not transmitting their identity and which, therefore, are suspicious. Radar satellites also offer the possibility to monitor large areas systematically (several times per day), allowing the generation of a vessel database and further statistics elaboration. Vessel identification information can be made available in a very short time frame (20 minutes after capturing the image, if a receiving station covering the area is available), thus allowing operational actions to be undertaken by national or international institutions.

The service can be set up over any port area or to monitor specific areas (e.g. straits) or routes.

Impact, benefits, sustainability

Satellite-based products were demonstrated to be useful and effective in providing operational data to support the transportation planning process at different levels. The products are cost-effective when compared to other solutions for data collection and they guarantee systematic updates at the desired frequency (with a trade-off between resolution and frequent revisit) consistently over space and time.

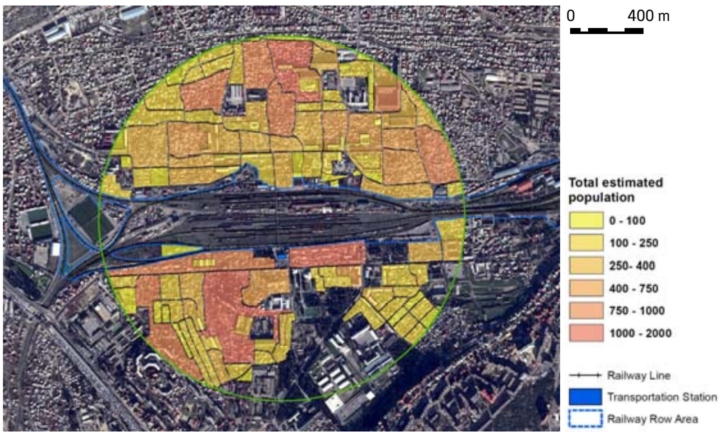
The services delivered to ADB had beneficial effect on the planning of large area transport infrastructure inventories, which were identified as highly relevant for future creation of harmonised transportation databases across multiple bank member countries. The satellite services can follow first surveys of currently available transport infrastructure databases and may be used as a gap fuller solution.

The detailed land use and population density products were extremely posi-

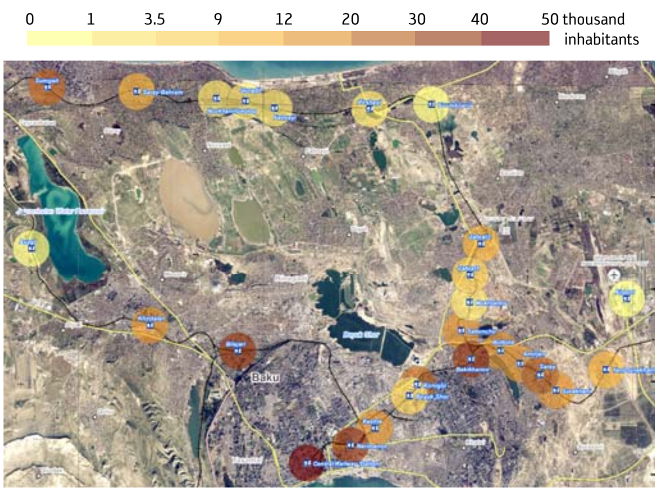
Examples of the detailed land use mapping in a 500 m corridor along an existing railway line in the Bilajari *(top)* and Surakhani *(bottom)* areas in Greater Baku. The mapping focuses on non-residential elements and is based on SPOT 7 / Azersky imagery with 1.6 m spatial resolution, acquired on 2014 December 14 (shown also as background). Not all legend items are necessarily present in the shown image. SPOT 7 data © Airbus DS.

Index of the detailed land use map sheets for greater Baku.

Population estimation within a 1 km radius from Bilajari station (Baku). The estimation is done by disaggregating most recent census data with residential building blocks as identified in the land use map. The total estimated population within the area was 31875 inhabitants (average density: 10151 inhabitants/km^2). Background: SPOT 7 / Azersky acquired on 2014 December 14. SPOT 7 data © Airbus DS.



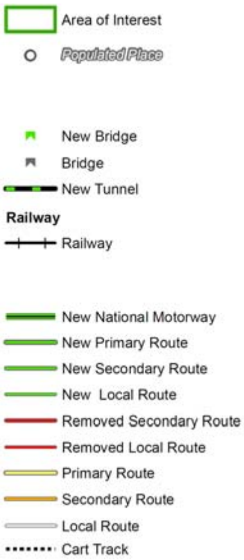
The obtained population estimates for each of the considered stations range from no inhabitants at all (Airport) and 334 inhabitants (Asagi) to 48995 inhabitants for Baku Central Railway Station. SPOT 7 data © Airbus DS.

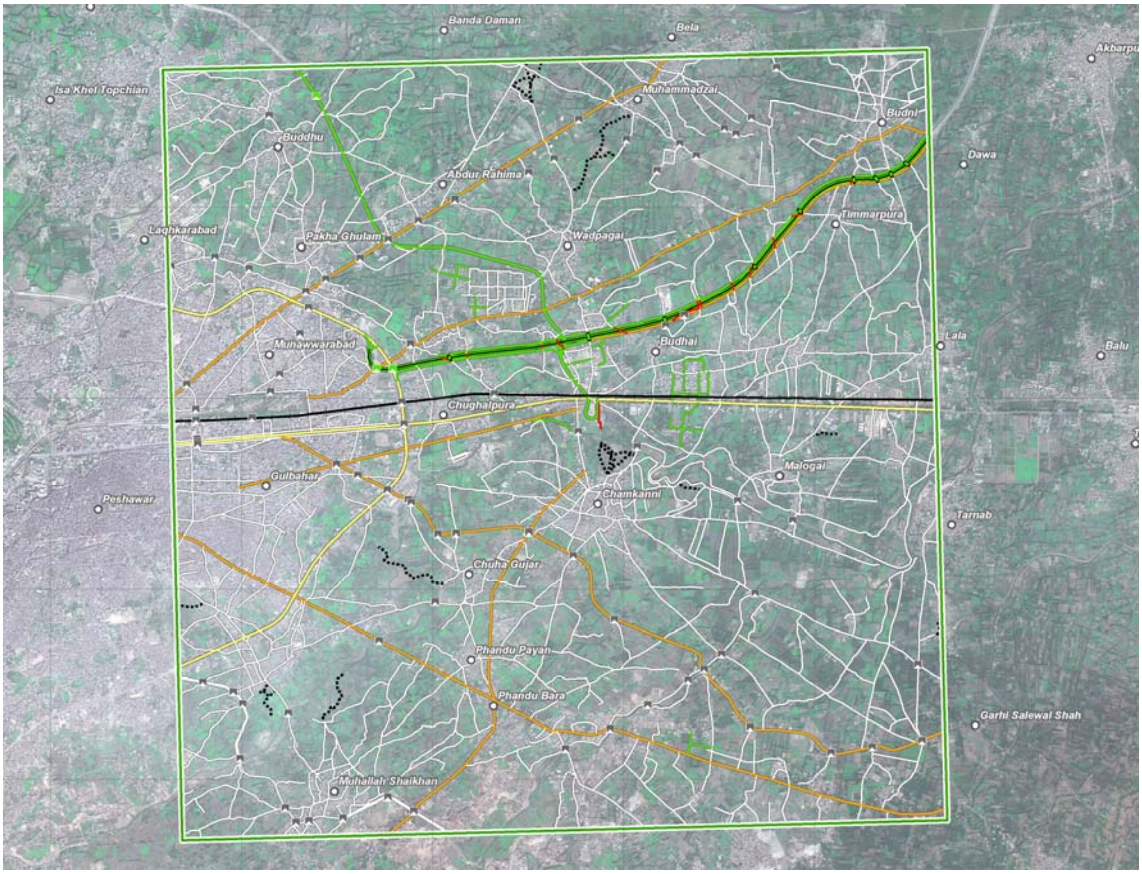


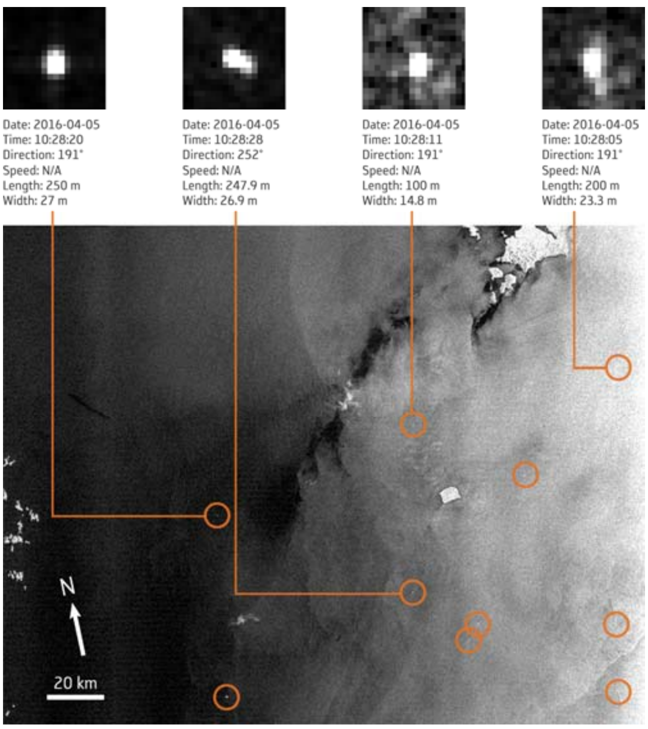
tive and ADB decided to further invest in the generation of such products to support other MRT feasibility studies in Peshawar and Karachi (Pakistan). One of the advantages of these products recognised by ADB staff is their independence of field surveys, especially in areas where field surveys may be difficult or impossible (e.g. for security reasons). Results from additional service provision over Karachi and Peshawar were considered positive, and steps are being taken to assess whether such products shall be considered as part of the standard methodology for new MRT feasibility studies.

Project results and relevant EO capabilities were also presented at the ADB Knowledge Sharing Event *How to Use Technology to Understand Urban Infrastructure and Human Mobility: A Hands-On Guide*, jointly organised by ADB's transport and urban sector groups at ADB Headquarters on 2015 September 17. There was general agreement that the introduction of geoinformation as a standard practice in the ADB urban and transport sector would be of great value, in particular for PPTAs (Project Preparatory Technical Assistance).

Change detection map showing changes in the transport infrastructure in parts of greater Peshawar. Changes are detected by comparing Quickbird imagery (2.4 m resolution, acquired 2005 July 31) with SPOT 5 imagery (2.5 m, acquired 2012 December 16, shown also as background). SPOT 5 data © CNES.







Left: Example of vessel detection based on COSMO-SkyMed imagery in the northern part of Riau Archipelago, Indonesia (Great Natuna Island is visible in the upper right corner of the image). COSMO-SkyMed image © ASI (2016).

"The benefits of using this technology for ADB is that we can plan and deliver our projects better, based on more reliable, better and more cost-effective information. For the same amount of money that we spent for planning previously, we can ask for more and better data, and deliver better services. That's especially important for public transport planning, like for corridors of Bus Rapid Transit systems or even when looking at informal transport."

Katja Schechtner,
ADB Transport Specialist

"One of the major opportunities we had by using satellite imagery analysis is obtaining the data we needed without going into the field. Satellite imagery allowed us to scan completely the corridor where we work, and to get all the data for the utilities, for the width of the corridor. Everything present in the corridor from one facade to the other was perfectly represented in the satellite imagery. It also allowed us to analyse the land use around the mass transit stations that we are planning. The outcome of the collaboration was very good."

David Margonsztern,
ADB Senior Urban Development Specialist (Transport)

Project H

→ DISASTER RISK ASSESSMENT IN BANGLADESH

Users

ADB South Asia Department, Public Management, Financial Sector and Trade Division (SAPF)

Provided EO Services

1. Land use / land cover maps and Digital Elevation Model (DEM)
2. Historical flood mapping
3. Disaster risk mapping

EO Service Providers

SarVision (Netherlands)
Nelen & Schuurmans B.V. (Netherlands)

Contacts

Mayumi Ozaki – Financial Sector Specialist (Rural and Microfinance), ADB SAPF

Gordon Campbell – ESA, *Gordon.Campbell@esa.int*

Niels Wielaard – SarVision, *wielaard@sarvision.nl*

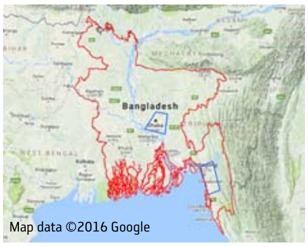
Bangladesh is a disaster-prone country, with floods being the most frequent and severe danger. Cyclones also constitute a major risk. Bangladesh is also susceptible to other dangers, including drought, earthquakes, river bank erosion, tsunamis, arsenic contamination of groundwater, soil salinity, and health pandemics. Because Bangladesh is a densely populated, low-income country, natural calamities cause disproportionate and adverse impacts to its population and economy. The government has made substantial efforts in disaster risk management and instituted national disaster management structures and legislation both nationally and sub-nationally. However, the application of financial protection in disaster risk management is still limited.

ADB has initiated a project concerning capacity building for Disaster Risk Finance (DRF) to enhance disaster risk preparedness of Bangladesh by developing public and private capacity for DRF solutions and fostering linkages between public and private sector in disaster risk mitigation. The project will develop a disaster risk model that requires geo-information as input and plans to use additional disaster risk information from other sources, such as in-situ data on physical data.

The EO support project linked to the ADB activity by providing datasets that support assessment of nature of disaster risk profiling: probability of occurrence, and the potential loss of, or impact on, life and physical capital. The delivered information included land use and land cover, a DEM, flood history as well as disaster risk data and maps for floods and cyclones (e.g. flood damage calculations based on land use, flood depths and duration). The areas of interest were mainly Dhaka and Chittagong.

Urban land cover mapping and flood occurrence monitoring represent two of the most common and useful applications of EO. Satellite-based land cover information when coupled with actual historical inundation and flooding detected by EO and hydrological models can help to analyse the existing situation as well as projected climate change, flood impacts, and developments to provide essential information for better decision making and planning of disaster response and finance projects. For example, such analysis can serve to highlight the areas at highest risk of floods and (riverbank) erosion, as well as key areas where critical urban assets (e.g. densely populated, commercial or transport) and infrastructure such as roads and bridges is at highest risk of being affected. Moreover, the EO-based information can help calculate scenarios with associated damage in financial terms. Finally, actual flooding can be mapped and monitored systematically to assess the impact and affected areas as floods happen.

Quantitative map accuracy assessment was applied using internationally accepted standard methods. Reference data was generated by means of expert visual interpretation of very high resolution satellite imagery (0.6—2.5 m spatial resolution) available from e.g. Google Earth. A minimum of 20 sample points were interpreted for each individual land cover class.



Location of the project areas: Dhaka and Chittagong (blue) and the entire territory of Bangladesh (red).

All products are visualised in an online geodata platform available at https://bangladesh.lizard.net.

Land use / land cover maps and Digital Elevation Model (DEM)

Land use / land cover maps were created for Dhaka and Chittagong at 15 m spatial resolution, based on a combination of imagery from the Landsat-8, Sentinel-1 and Sentinel-2 satellites, with SPOT 5 data being used as reference. The service meets the standard product specifications defined for the European Commission's *Urban Atlas*.

As other sources of very high resolution elevation data were not available over large areas during the project, the SRTM DEM dataset available for the entire country of Bangladesh at a resolution of 30 m was used for the assignment.

Historical flood mapping

Historical flood inundation maps of Bangladesh were derived from MODIS and Sentinel-1 satellite data period 2003–2015. The dataset is presented as weekly maps with a spatial resolution of 250 m. In each map, the pixel count represents the number of wet observations measured during that week (observations twice daily for MODIS for the entire period and). Flood occurrence has been mapped using long time series of MODIS (all twice daily observations between the entire period 2003-2015) and Sentinel-1 (observations at approximately 20 m made near-weekly not affected by clouds, between October 2015 and March 2016).

As an example of systematic flood monitoring, after 300 m of river embankment collapsed in the region of Bogra, radar satellite imagery could help to verify that over 100 villages were flooded and over 40,000 hectares of crops were affected. Reportedly, during this and other events in the region that left 3 people dead and 1 missing, more than 129,000 farmers had been affected and 1.7 million Euro in crop damage occurred.

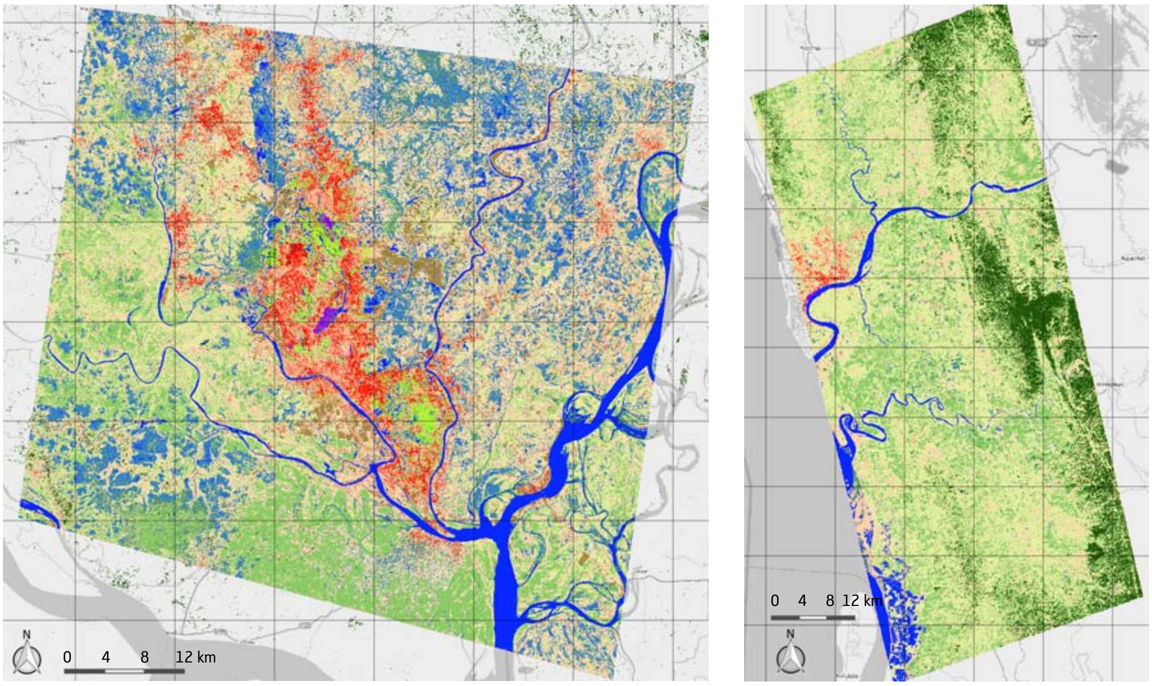
Disaster risk mapping

This service provided maps related to flood, cyclone and earthquake risk for the entire national territory of Bangladesh.

Maps of both EO-based actual inundation and 3D model-based flood risk were produced for areas around Dhaka and Chittagong. The result is a temporal stack of maps with water depths. With the calculated water depths and durations the potential damage (€/m²) was also calculated for the two cities. Graphs are available at any location and can be used to determine e.g. at what time the flood waters will reach the location, but also how fast the water depth increases or how the damage increases with depth.

Tropical cyclone tracks were acquired from the US National Centers for Environmental Information (NOAA NCEI, http://www.ncdc.noaa.gov). Earthquake data was used from USGS (http://earthquake.usgs.gov). One of the goals of the exercise was to translate the available information into easy-to-use statistics, with the ability to explore and aggregate data spatially and temporally in the simple online analysis tool. For instance, one can easily filter and extract the earthquakes that occurred in the year 2011.

Urban land use map for Dhaka *(left)* and Chittagong *(right)* as of 2015. Additional layers © GADM (2015), © OSM (2015).



Digital Elevation data from SRTM for Dhaka as delivered in the online geodata platform: example of on-the-fly height profile generation. Similarly, cumulative height distribution curves can be derived based on e.g. administrative units, providing information on the percentage of area that is above a certain height. This is important when considering flood risk. SRTM DEM © NASA/JPL (2004).

Limitations and constraints

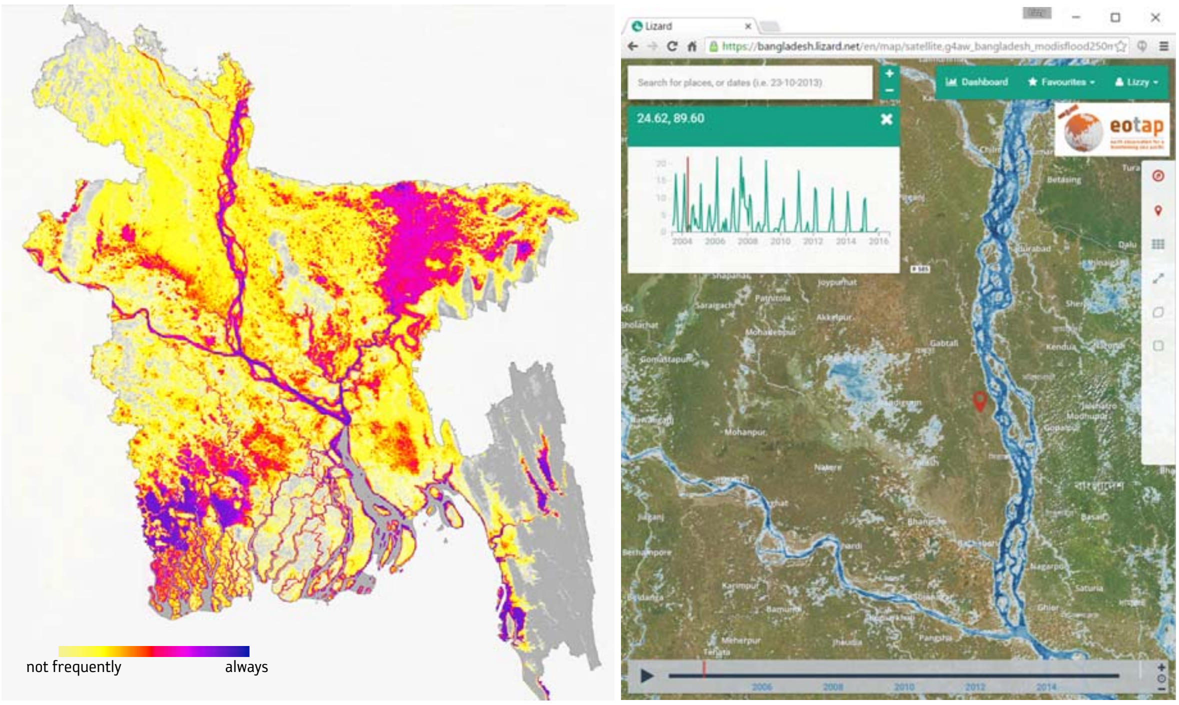
The urban land cover maps were produced at lower resolution due to non-availability of recent very high resolution data (2.5 m or better). Such information can be programmed in operational service provision scenarios.

The production of a spatially explicit historical flood occurrence database is limited by the availability and quality of existing satellite data. Due to gaps in time and space (no satellite overpass or observations in cloudy conditions) the historical flood event data should be used with caution. Especially the detection of (historical) flash floods with short duration remains problematic, such cases may likely not be recorded by the satellite data. Combining constellations of radar and optical satellites are able increasingly able to deal with this problem.

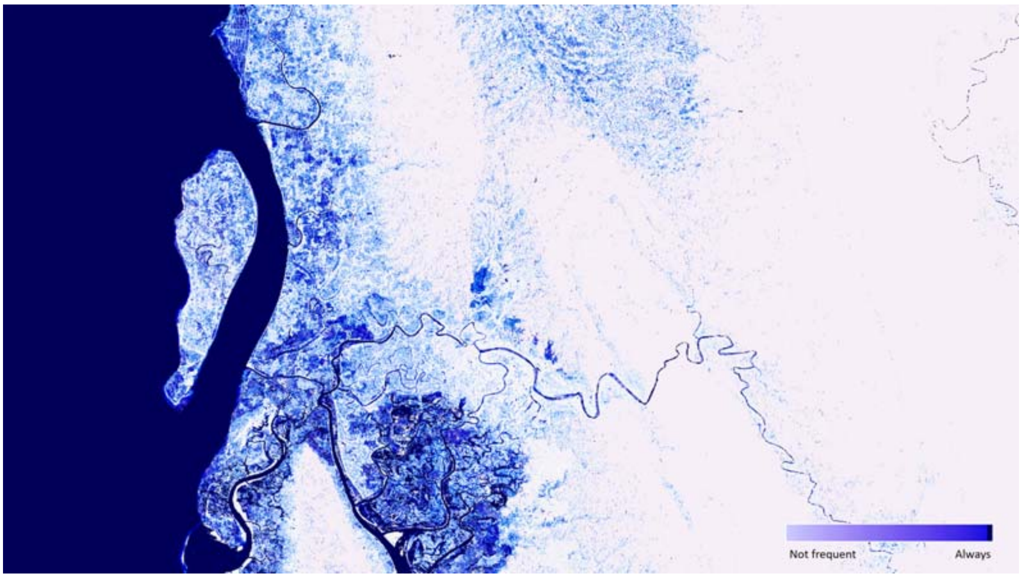
Moreover, further work is needed to separate flood occurrences into 'good' inundation (e.g. normal inundation of agricultural fields) from 'bad' inundation (e.g. disastrous flooding). For this reason, in an additional processing step, the nation-wide historical inundated areas map 2003–2015 should be interpreted by specialists.

The flood damage that was calculated for Dhaka and Chittagong could be created in much more detail. The more detailed the Digital Elevation Model and land cover map, the more precisely the damage can be calculated. At the time of project implementation very high resolution satellite (e.g. WorldDEM) or LiDAR datasets were not available.

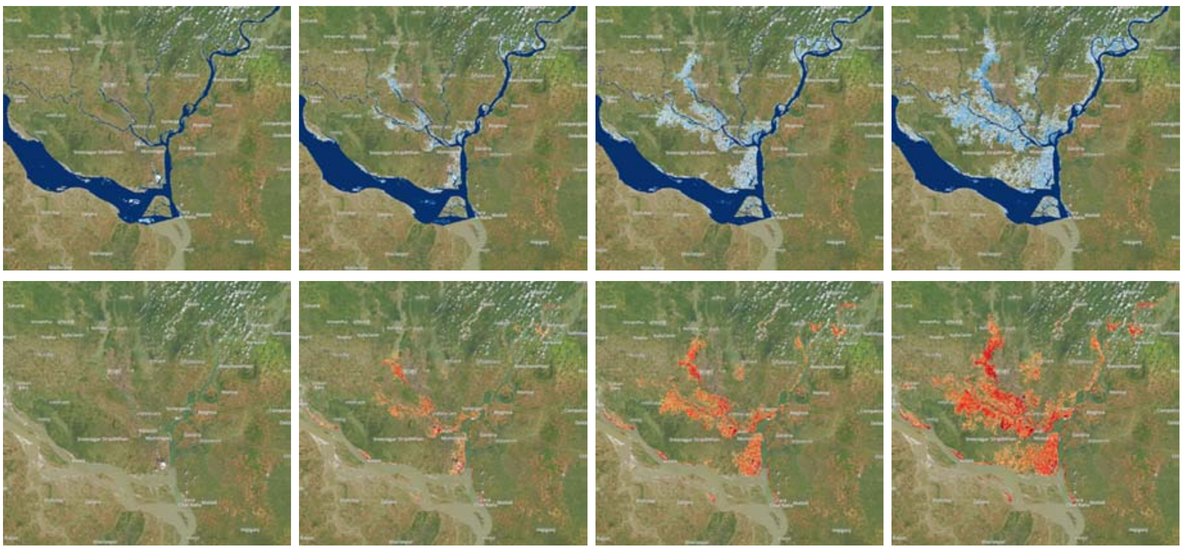
Effective characterisation of flood risk in Bangladesh requires the combination of a range of different datasets, including coastal conditions, river hydrology and urban development in a consistent manner. In addition, cost-effective monitoring of changes that impact on flood risk (e.g. movement of channels in the delta system, changes in mangrove cover, evolution in the urban land cover) can be achieved for the entire area only through the use of EO-derived information. The possibility of combining EO-derived flood risk information generated in the present project together with the cyclone-related risk characterisation performed by the ADB contractor and generated in cooperation with this project also represents an interesting possibility for providing a methodology for integrated risk assessment. Thanks to the long-term availability of data from the Sentinel-1 and Sentinel-2 satellite missions, the historic datasets generated here can be updated on a regular basis to ensure a robust, continuous assessment of the evolution in exposure to flood-related risk. In addition, this capability can be extended geographically to neighbouring India and Myanmar. Given the development investments planned for the region in relation to risk reduction, there is strong potential for wider use of this type of information in the near future.



Service 2 –
Left: Cumulative inundation frequency based on two observations of flood occurrence per day aggregated for the period 2003–2015 (the equivalent of 8760 satellite images) for the entire Bangladesh territory, where the consistently wettest areas can be clearly seen.
Right: All individual inundation maps are made available for browsing in the online viewer, with functionalities for displaying flood history at point locations.

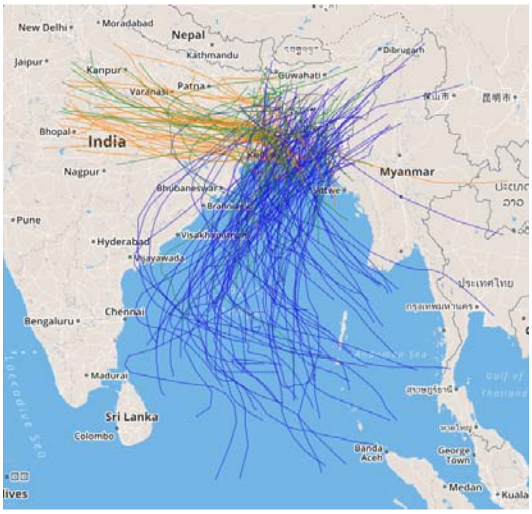


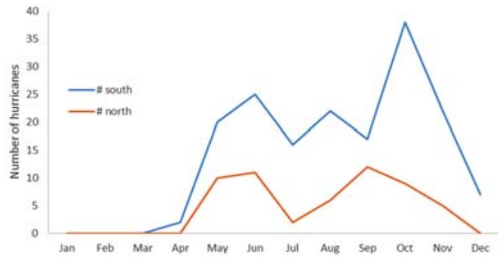
Service 2 –
Sentinel-1-based (20 m) cumulative inundation frequency south of Chittagong, using all observations (every 12–24 days) for October 2014 – March 2016. Areas inundated infrequently for rice production are shown in light blue while more frequently and permanently inundated ones such as aquaculture permanent water bodies are dark blue.
© Contains modified Copernicus Sentinel data (2016).



Service 3 –
Example of flood scenario evolution for the region of Dhaka *(top row)* and the associated estimated damage map *(bottom row)*.

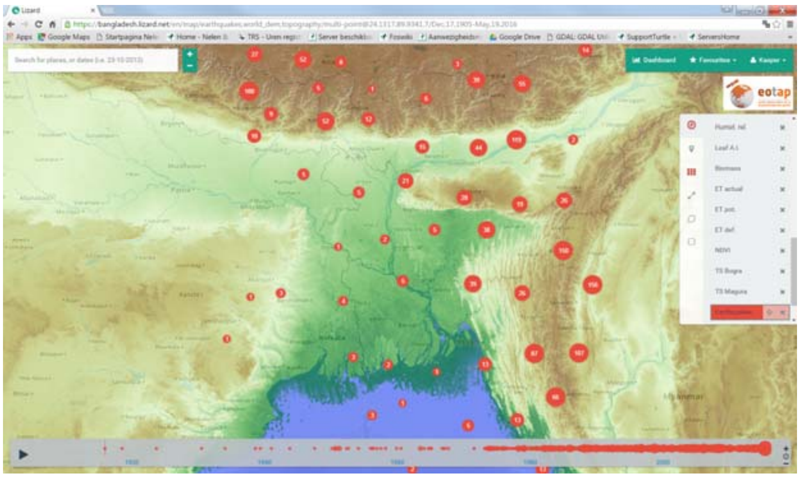
Service 3 –
Tropical cyclone tracks coloured by season. In the months of May, April, October, November and December the cyclones show a predominantly south-north trajectory (blue). In June and September the movement becomes more erratic (green), and in the months of July and August the movement is from east to west and most of Bangladesh does not take the full brunt of the weather events. (orange). The data used showed no records of hurricanes in the months of January, February and March.





Average number of hurricanes per month in the south and north of Bangladesh.

Service 3 –
Example of how earthquake data is visualised in the online tool by interactive aggregation both spatially and temporally. The time bar at the bottom of the screen shows the temporal distribution of earthquakes in time while the red circles aggregate the events in space. Seeing the location and frequency of events overlaid on the DEM provides additional insights on their relationship with the geographical features of the country. In the lowlands of Bangladesh there have only been a handful of earthquakes in the last century, with the vast majority occurring in the mountainous regions surrounding the country.



Chittagong in an image captured by Sentinel-2A on 5 January 2016.
© Copernicus Sentinel data (2016) / ESA.

Project I

→ SUPPORTING HYDROPOWER DEVELOPMENT IN VIET NAM

Users

ADB Southeast Asia Department, Energy Division (SEEN)

Provided EO Services

1. Land cover / land use classification and its changes over time
2. Digital Elevation Model (DEM)
3. Terrain deformation mapping

EO Service Providers

NEO B.V. (Netherlands)
SkyGeo Netherlands B.V. (Netherlands)

Contacts

Takafumi Kadono – Energy Specialist, ADB SEEN
Michiko Suga – Social Development/Resettlement Specialist, ADB SEEN
Zoltan Bartalis – ESA, *Zoltan.Bartalis@esa.int*
Corné van der Sande – NEO B.V., *corne.vandersande@neo.nl*

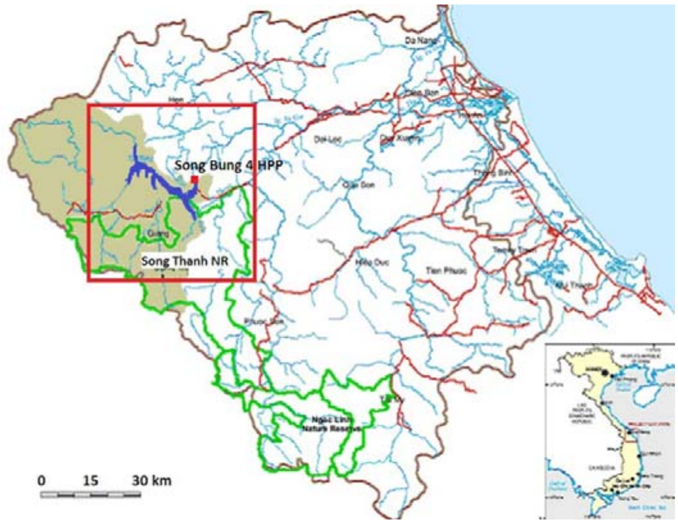
ADB is co-financing the construction of Song Bung 4, a hydropower plant in the Nam Giang District, Quang Nam Province, in compliance with ADB's safeguard requirements and the restoration and improvement of livelihoods of the affected population. The objective is to contribute to meet Viet Nam's increasing power demand in an environmentally sustainable and socially inclusive manner. The construction of the dam and the removal of trees in the reservoir area requires new transmission lines, new access roads into forests and improvement of the existing regional and local road network. This will increase access to the forested areas in the vicinity of the reservoir and potentially increase illegal logging. Special concern is expressed regarding the Song Thanh Nature Reserve (STNR), of which the reservoir inundates an area of about 37.5 ha. Access to it will increase significantly through the reservoir and the realigned highway 14D.

ADB is involved in proper management and mitigation of environmental issues, and Earth Observation (EO) is a likely tool for independent and effective monitoring. In this respect, the EO support project contributed with baseline and change maps to be used as reference after plant operation start, allowing measuring environmental changes due to encroachment of human activity around the dam and the reservoir. Additionally, precise ground and dam displacements in the order of a few mm/year during and after dam construction were delivered, to characterise the stress that the filled reservoir exerts on the dam and the ground in its vicinity. Information on illegal logging and other undesired and desired effects near the reservoir, the relocation sites and the nearby SNTR was also provided.

Land cover / land use classification and its changes over time

In order to monitor land use changes related to the development of the Song Bung 4 dam, a land use map for each of the following three periods was created: 2001–2003, 2005–2007 and 2012–2015. These three periods are key points in time for the development in the area.

Historic satellite imagery proved valuable to get insight in what happened over a period of almost 15 years. It was challenging to generate comparable output from the wide variety of used sensors. In total 16 satellite images from SPOT 5, SPOT 6, Pléiades, WorldView-2, Landsat 7 and Landsat 8 were used for the land use mapping, all with different spatial resolutions and spectral bands. The challenge was thus to translate this imagery into understandable and easy-to-use maps that can help monitor the impact of the development of the dam. An object-based classification approach was chosen, where similar groups of pixels are combined and classified as one land use type. For the end user this provided an easy tool to distinguish patterns and calculate for example the size of a village or agricultural field.



Location of the Song Bung 4 dam (red filled square), and the approximate extent of the reservoir (blue filled shape). The brown area is the drainage basin of the reservoir (incidentally, the Viet Nam/Lao PDR border coincides with parts of its western boundary). Natural reserves are delineated by green outlines.

The first study period represents the initial situation before development started. Some of the small villages along the Song Bung river were inundated after the reservoir filled up in the last period. The road network is rather limited in the entire study area.

During the second period saw mostly infrastructure development. The main construction of the dam started September 2010. The land use map of this period reflects this, with the appearance of roads to the dam site and the locations of the new settlement relocation areas. A clear decrease in natural vegetation was observed, mostly due to the development of infrastructure and agriculture.

The most recent period saw the dam being completed and the reservoir filled. Several villages were relocated to other areas as part of a complex resettlement and livelihood restoration process for indigenous and ethnic minorities.

The three land use maps of the different periods were combined into change maps. By combining certain land use classes detailed and meaningful information was provided about the location and type of occurresd changes. Good examples are the development of the relocation areas, or changes in natural vegetation, agriculture and the road network/infrastructure in the area. Based on the figures, the amount of natural vegetation has decreased, and the man-made areas have increased.

As change maps contain a large number of class combinations, these are still rather technical products, and not optimal for communicating change information. An additional number of products have therefore been produced aiming to present changes in such way that they provide direct meaning and value instead of just data. An example is the thematic map of deforestation, where the user gets direct insight where and into what natural vegetation has changed.

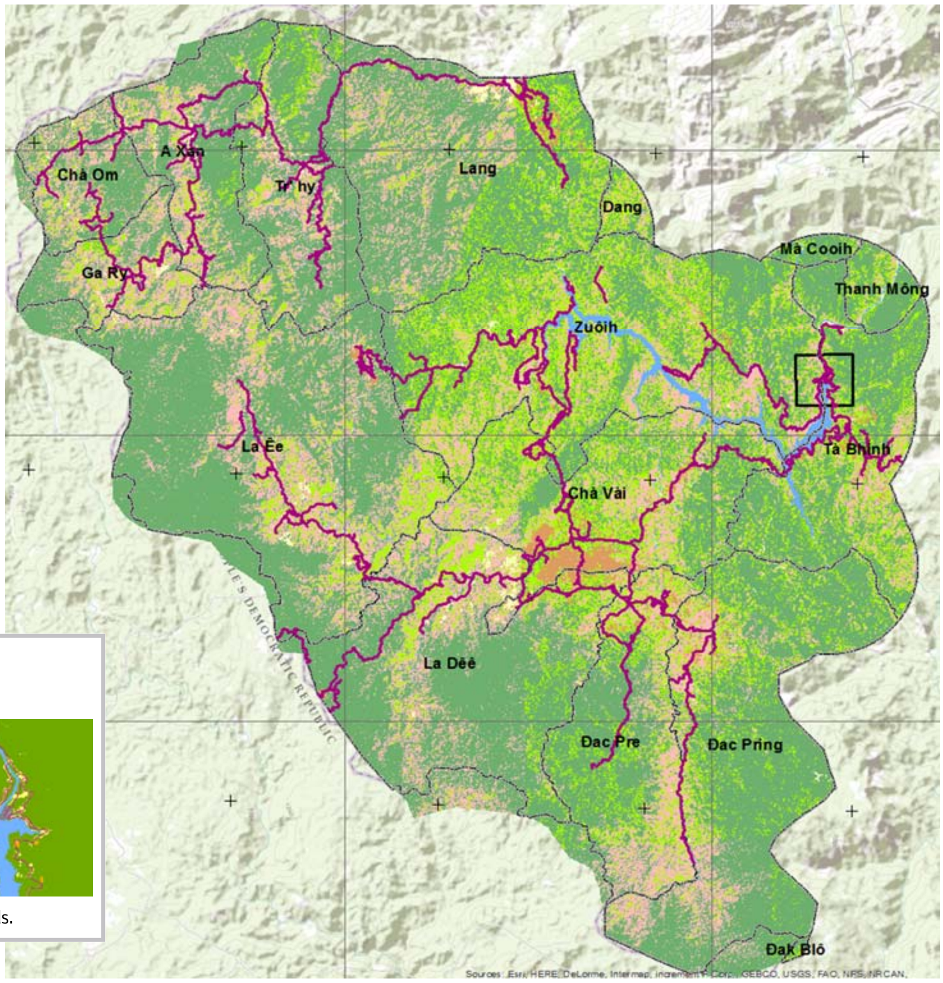
Digital Elevation Model (DEM)

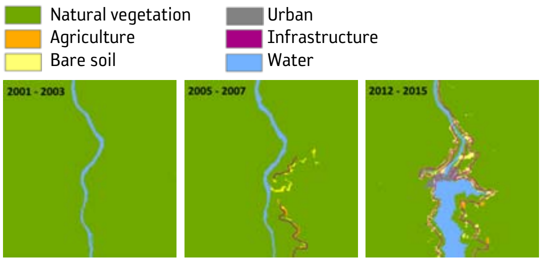
A DEM is a useful source of information for various applications. In this particular project it was used to orthorectify satellite imagery, derive locations of rivers and streams and generate slope maps that can be used for future erosion risk analyses.

The significant changes in topography, mainly due to the construction of the dam and associated reservoir, required the use of multiple DEMs. A 30 m horizontal resolution DEM provided commercially by Airbus DS was used for

Imagery of the dam area at different stages of the development, acquired by different satellite sensors . *Left:* Pléiades, 2013 June 7. *Middle:* SPOT 6, 2014 July 3. *Right:* SPOT 6, 2015 February 27. Pléiades data © CNES, distribution Airbus DS. SPOT 6 data © Airbus DS.

Land use map for Period 3 (2012–2015), after the completion of the dam and reservoir. Map background © Esri.





Land cover maps around the dam area for the three periods.

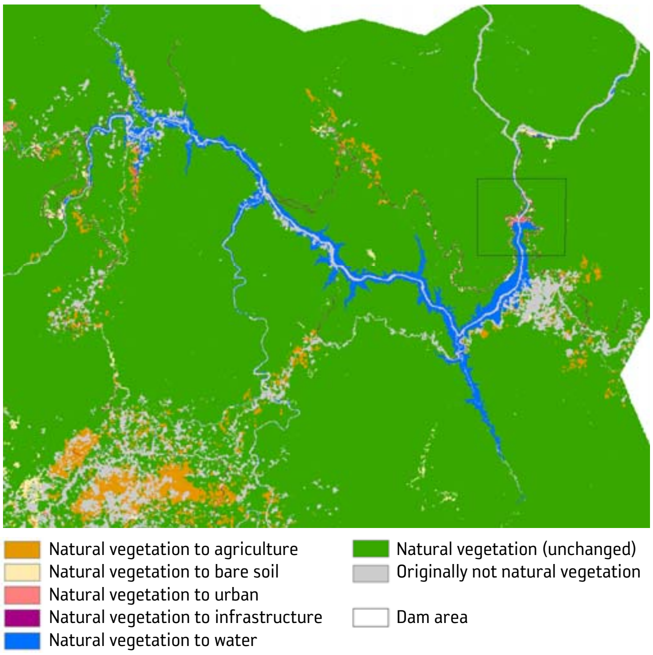
the entire study area, representing the situation from before the construction of the dam. Furthermore, a recent stereo pair of SPOT 6 images (February 2015) was acquired and used to generate a DEM covering the completed dam and fully inundated reservoir. The two DEMs were finally merged to be able to perform analysis for the entire study area based on the latest situation including the reservoir.

Terrain deformation mapping

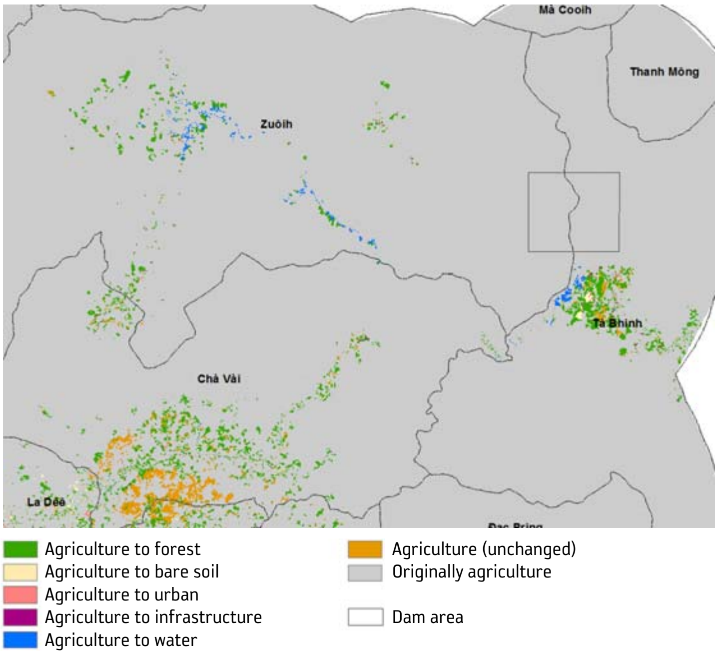
Deformations of the dam and its immediate vicinity have been mapped using interferometric techniques (so-called PS-InSAR) to infer precise ground or dam displacements in the order of a few mm/year. The period of interest for monitoring was from April 2014 to January 2015, using data from the (commercial) TerraSAR-X satellite. This offers the hydropower project stakeholders the possibility to study changes in the stress that the filled reservoir exerts on the dam and the ground in its vicinity, with monitoring extending beyond the timeframe of the present project.

The results showed indications of which sides of the reservoir are susceptible to deformation, with the westward slope of the eastern reservoir wall deforming at rates of up to 10 mm/year. Considering the size of SAR images, this clearly demonstrates the technique's possibility to regularly monitor large numbers of hydropower dams for reasons of safety, operational efficiency and/or quality of engineering execution after completion of construction.

Regarding the overall feasibilty of deformation mapping in these highly vegetated, mountainous and humid areas, a series of at least 25–30 images are necessary for optimal PS-InSAR analysis. The current results should be considered as a minimum result. Extensive analysis was also performed using ALOS PALSAR satellite data to extract deformation information for the period before dam construction, but the lower sensor resolution and the heavily forested nature of the area with only few rocky outcrops, lead to too much temporal decorrelation.



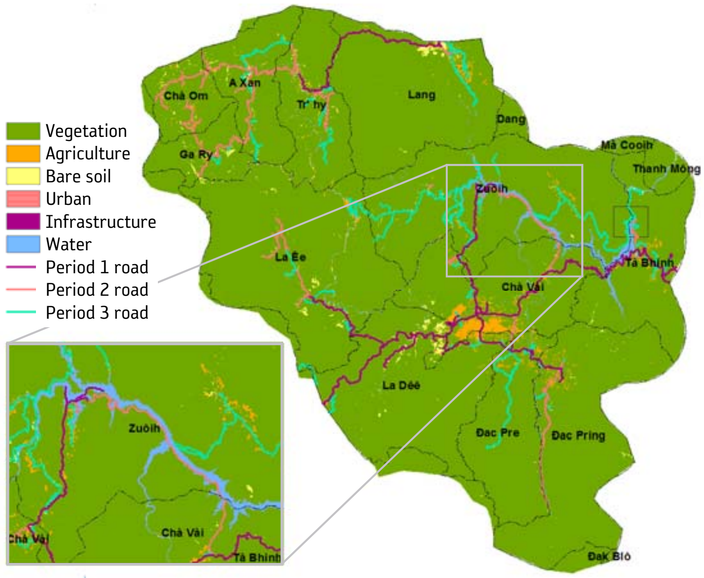
Example of change map between Period 1 and Period 3 (from 2001–2003 to 2012–2015). Different classes indicate where and into which land use type natural vegetation has changed. Practically what the map shows is deforestation.



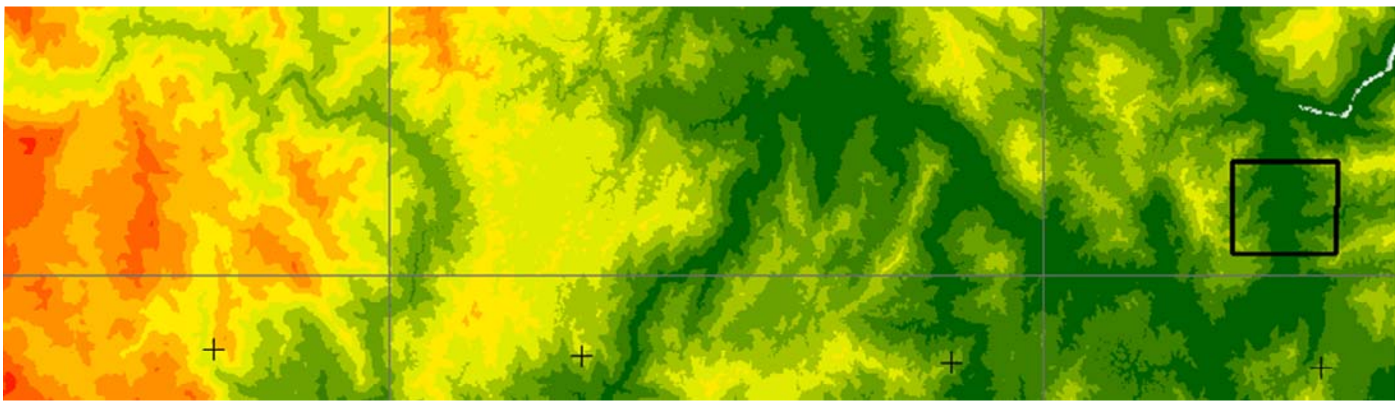
Example of change map between Period 1 and Period 3 (from 2001–2003 to 2012–2015). Different classes indicate where and into which land use type agriculture has changed.

Land Use	Period 1	Period 2	Period 3	Change (km²)
Natural vegetation	1626.10	1609.35	1602.30	**–23.80**
Agriculture	30.49	37.90	29.35	**–1.14**
Bare soil	6.79	12.60	16.70	**9.91**
Urban	0.64	1.59	2.03	**1.39**
Infrastructure	2.16	3.99	6.80	**4.64**
Water	10.58	11.70	20.29	**9.71**

Quantifying the land use areas and their changes.



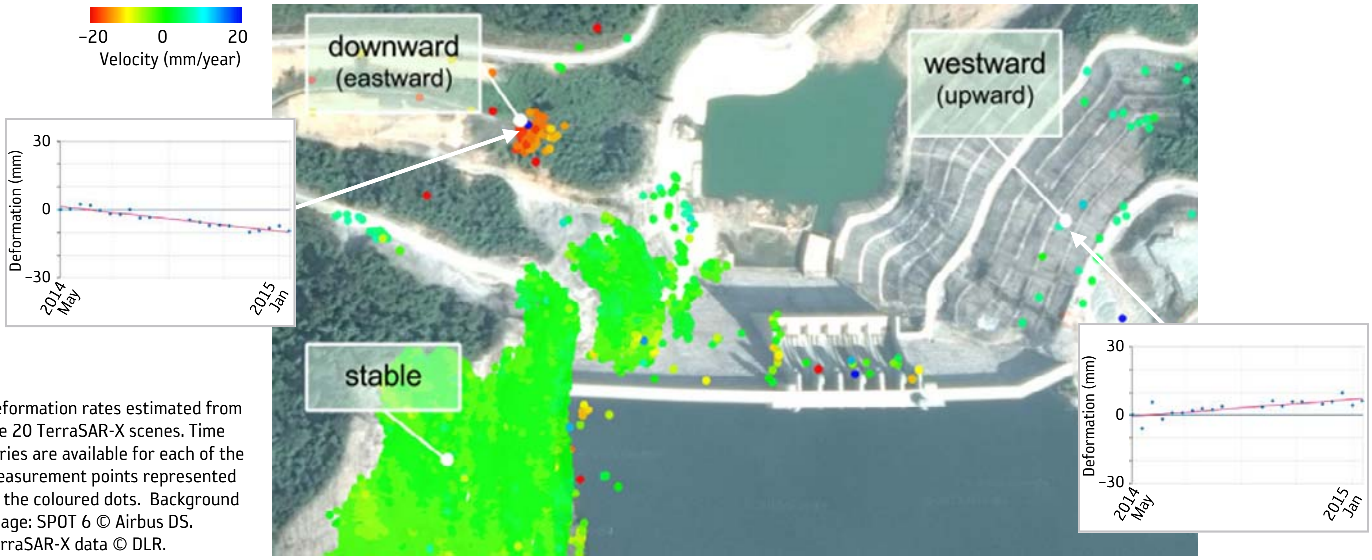
Road network expansion.



Combined DEM of Airbus DS (2009) and SPOT 6 Stereo (2016). Elevation30 © Airbus DS. SPOT data © CNES, distribution Airbus DS.

Old Parum B village as seen on 2006 April 6 (*left*, QuickBird), 2013 June 7 (*middle*, Pléiades) and 2015 February 27 (*right*, SPOT 6). QuickBird data © DigitalGlobe. Pléiades data © CNES, distribution Airbus DS. SPOT 6 data © Airbus DS.

The new (relocated) Parum B village as seen on 2001 March 16 (*left*, IKONOS), 2013 March 31 (*middle*, WorldView-2) and 2015 February 27 (*right*, SPOT 6). IKONOS and WorldView-2 data © DigitalGlobe. SPOT 6 data © Airbus DS.



Deformation rates estimated from the 20 TerraSAR-X scenes. Time series are available for each of the measurement points represented by the coloured dots. Background image: SPOT 6 © Airbus DS. TerraSAR-X data © DLR.

The current project demonstrates that EO is an effective tool to monitor land use changes over the period of the development. EO products can however also be valuable during earlier phases of a project such as the development of a future hydropower dam. In the planning phase, satellite im-agery derived land use maps could provide information about potentially affected settlements and natural environment. Combined with a DEM it could provide information about potential erosion risks caused by the development of a hydropower dam at proposed locations. It then becomes a de-cision support tool. Involvement from the very beginning of a project will furthermore deepen the understanding of the project.

EO products are especially valuable for remote areas where no or very limited geospatial infor-mation is available. Most of the potentially interesting areas for still to be developed hydropower dams are in remote areas.

Continuation of deformation mapping of the dam area and its vicinity would further improve the insights in ongoing deformations. The current stack of imagery was just sufficient for a reliable result, but more would optimise results significantly.

The outlook for the ADB is to use these maps as part of their primary process in monitoring & eval-uation of a bank project. With the case of Hydropower in Viet Nam several projects are implement-ed and more are to come. Land use maps are a valuable tool to monitor the land use changes. De-formation monitoring can be done continuously and reported with alert mode and as a twice yearly status update.

Project J

→ RIVER BASIN FLOOD MANAGEMENT IN INDONESIA

Users

ADB Southeast Asia Department, Indonesia Resident Mission (IRM)

Directorate General of Water Resources (DGWR), Government of Indonesia

Provided EO Services

1. Land use and land cover classification (basin-wide and for urban areas)
2. Digital Elevation Models

EO Service Provider

Hatfield Consultants (Canada)

Contacts

Eric Quincieu – Water Resources Specialist, ADB IRM

Ola Gråbak – ESA, *Ola.Grabak@esa.int*

Andy Dean – Hatfield Consultants, *adean@hatfieldgroup.com*

Location of the project areas (red outlines), from west to east: 3Cs RBT, Ambon Island and central Seram Island

The ADB activity *Flood Management in Selected River Basins Project* supports the Government of Indonesia (GoI) to better manage and mitigate flood risks. Past flood control projects emphasize controlling floods by structural measures such as confining floodwater between artificial embankments, which need to be continually built higher and stronger to protect growing cities on floodplains. Less focus has been given to manage watersheds, which have degraded over the years because of land cover conversion, such as forest to agricultural and other uses. Management of watersheds holistically consists of integrated environmental activities related to the use and modification of land and water of an entire watershed system, from the uplands to downstream, to floodplain wetlands and river channels, and must consider the economic costs/benefits, and the sustainability of the watershed ecosystem. People living in and around watersheds are the main subsystem of integrated watershed management. Improving watershed management includes promoting people's participation in decision making through social forestry programs carried out on publicly-owned forested land and community managed lands.

Many flood warning systems do not have proper communication links to the flood affected communities. Similarly, flood hazard maps do not exist for many flood-prone areas. Flood hazard maps are required to plan land use and develop early warning procedures to evacuate people living in these areas. Flood forecasting and warning systems, flood hazard mapping, and evacuation planning need to be closely linked for the management of entire watershed systems. The primary objective of the Flood Management in Selected River Basins Project is to support the GoI's transition to an integrated flood management approach and improve the preparedness of the government to manage and mitigate negative impacts of flooding in selected river basins. The goal of the ADB support is to transition from the existing project-oriented flood control centred on structural mitigation measures, to a process-oriented integrated flood risk management (IFRM) system that incorporates a mix of non-structural interventions, institutional and capacity building, and structural measures to mitigate the impacts of floods.

The objective of the EO support project was to develop EO-based information products that could be used to prepare flood risk management plans as well as flood forecasting and early-warning systems in support of IFRM. The selected river basins were the Ciujung, Cidurian, and Cidanau River Basin Territory (3Cs RBT) in Banten Province, the island of Ambon, Maluku Province, and Central Seram, Maluku Province. Basin-wide land use and land cover (LULC) and digital elevation models (DEM) were the primary EO products delivered.

The need for geospatial information

In formulating and updating river basin flood management plans, specific geospatial data sets are required to support 1) flood hazard mapping to determine the effects of flooding, and 2) two-dimensional floodplain hydrodynamic modelling. Indonesia's growing population have increased the demand for human settlements and expansion of urban areas resulting in increasing land conversion from forested to non-forested land. Furthermore, poverty and economic development result in improper land cultivation and the conversion of upload forest and wetlands to agricultural land. These incremental changes in land cover have led to soil erosion, watershed degradation, and the loss of valuable resources.

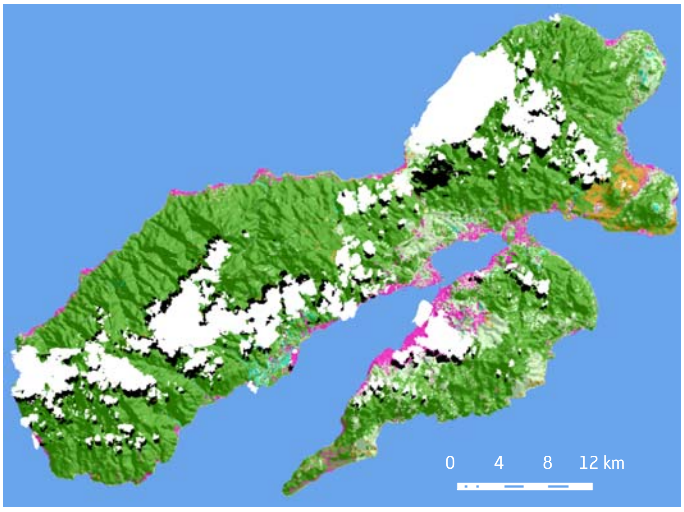
Identification of these critical lands and assessing the condition of the land cover within the selected river basins requires up-to-date LULC maps. However, completeness and vintage of LULC data varies greatly across Indonesia and up-to-date maps are not readily available for many areas.

Topographic data such as DEMs are also fundamental sources of geospatial information required for hydrodynamic modelling, accurate catchment delineation, and drainage mapping. Topographic data also help determine areas of erosion potential and areas prone to flooding by defining low lying areas, topographic depressions, and gradients. Collecting detailed and accurate elevation data for large areas using methods such as LiDAR or stereo-aerial photography is expensive. As a result, other sources of topographic information are used, such as digitised historical topographic maps or freely available global DEMs (e.g., Shuttle Radar Topographic Mission, SRTM, or Aster GDEM). These global data sets require extensive post-processing to convert Digital Surface Models (DSM) to Digital Terrain Models (DTM) and have insufficient detail to be used in hydrodynamic modelling. Other sources of DEMs may be too old to accurately reflect current topography. The EO support project identified a clear need for a more cost-effective source of up-to-date topographic data, with accuracy that is "fit for purpose" for flood hazard mapping and two-dimensional floodplain hydrodynamic modelling for large basins.

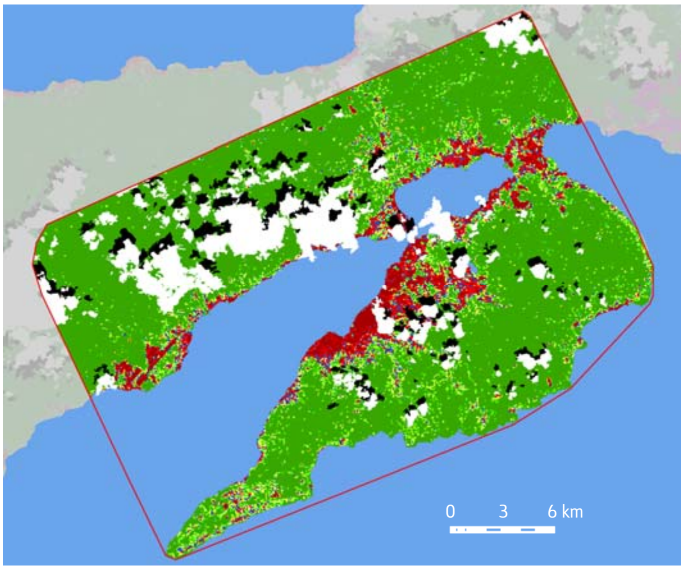
Basin-wide land use and land cover

Cost-effective high/resolution optical imagery (RapidEye and Pléiades) was used to produce the basin-wide and urban LULC products. Image compositing techniques to mitigate persistent cloud cover using additional imagery was successfully demonstrated. As a result of image compositing, the project was able to obtain an additional 1,000 km² (16%) of usable data across for all three study areas. However, due to specific restrictions on image collection dates and the availability of cloud-free images in the archives, complete removal of cloud covered areas was not possible.

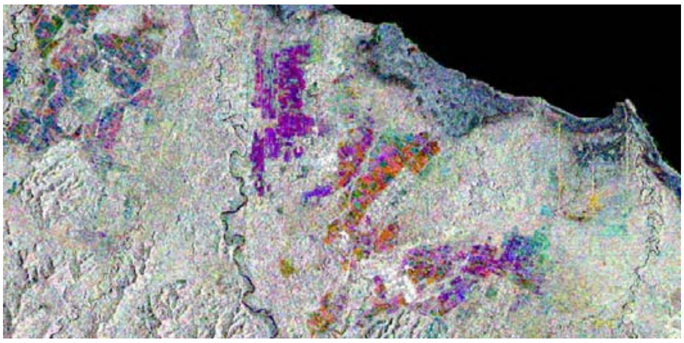
Basin-wide LULC classification was based on RapidEye data (5 m resolution) using an object-based methodology. All images were atmospherically corrected. During correction and removal of atmospheric affects, automated cloud and cloud shadow masks were generated allowing for more efficient image compositing. Additional datasets from the Sentinel-1 mission were used and co-registered to the RapidEye data. Given the distinctive radar response from agricultural land in radar imagery such as Sentinel-1, multi-temporal composite images were created to support the classification process. Classification rules incorporated additional information such as elevation, road networks, etc. Thematic information followed GoI's Bakosurtanal standard for land cover categories (Standar Nasional Indonesia SNI 7645:2010).



Sample basin-wide land use and land cover classification product for Ambon Island, derived from RapidEye, May 2014. RapidEye data © BlackBridge.



Urban Land Use product derived from 0.5 m Pléiades imagery for Kota Ambon, November–December 2014. Pléiades data © CNES (2014), distribution Airbus DS.



Detail of a Sentinel-1 temporal composite image acquired November 2014, January 2015, and May 2015 for the northern coast of Central Seram Island, clearly showing agricultural areas and potential paddy fields. © Copernicus Sentinel data.

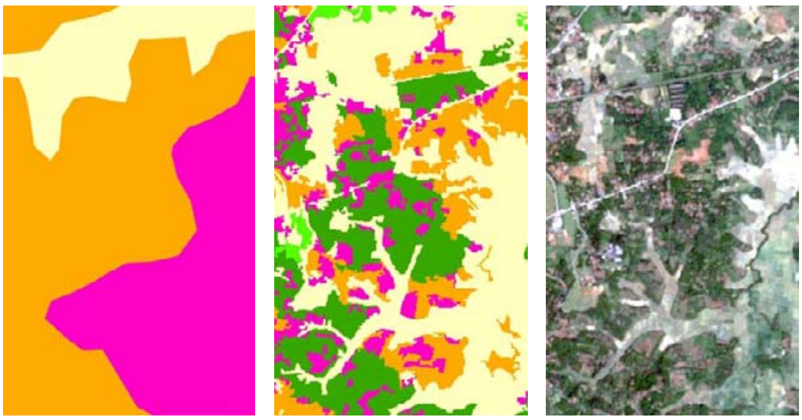
Urban density and land use

For the urban centre of Ambon Island (i.e. Kota Ambon), urban density and urban land use classification was based on 0.5 m Pléiades data, again using an object-based methodology. All images were processed in a similar fashion as the RapidEye data. Initial urban density was determined by a pixel-based assignment of artificial and natural surfaces within the study area. Subsequently, urban density was derived based on the local area proportion of artificial and natural surface within a given area (50×50 m). Density classes were then defined based on the categories presented in the European Commission's GMES *Urban Atlas* project. Additional urban land use classes were also identified via image segmentation and classification, e.g. settlements, natural vegetation, urban greenery and agricultural areas. Urban density and urban land use classes were then merged to produce the final product.

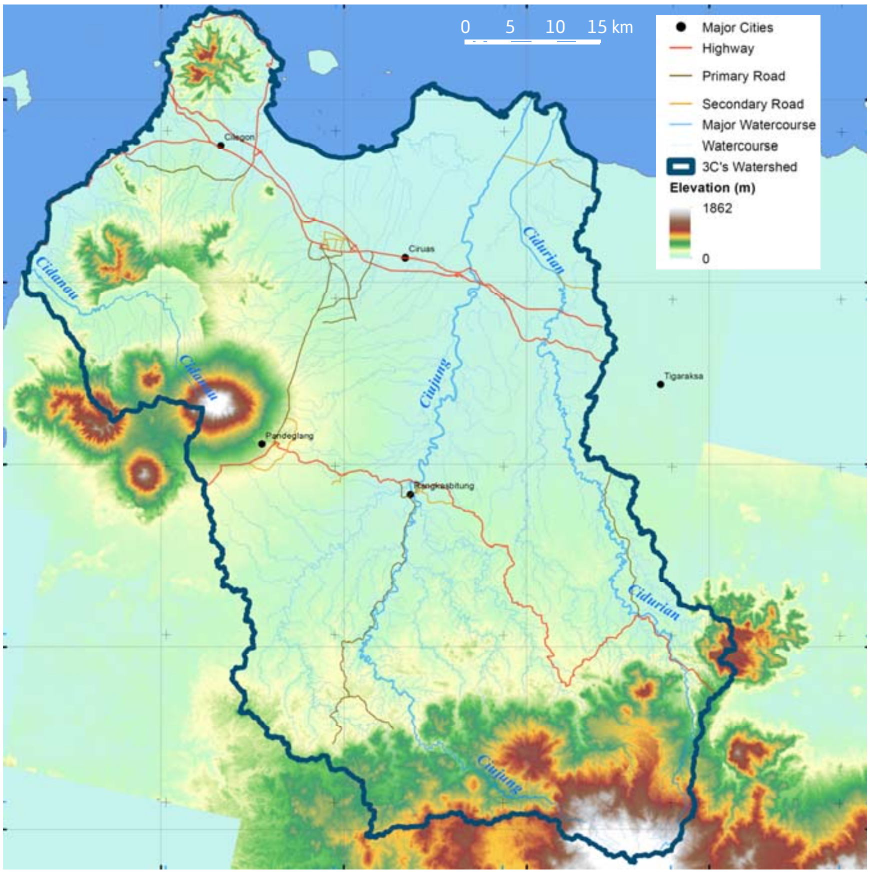
Regional and precision DEMs

High-resolution DEMs were produced for all three project areas using the PRISM sensor onboard the ALOS satellite, with a spatial resolution of 2.5 m. Elevation values were extracted using stereo pairs collected between 2008 and 2011 and the resulting DEM was resampled to 10 m. Elevation values were referenced to above mean sea level (AMSL) and advanced manual editing and filtering to remove artefacts related to the coastline and water surfaces was performed. For areas of dense cloud cover and haze, 30 m Shuttle Radar Topography Mission (SRTM) data was used to interpolate the voids. The production of the DEM required the use of 116 ground control points (GCP) with accurate horizontal and vertical positioning. The Badan Informasi Geospatial (BIG) geodetic control network data (Ina-CORS) was used as reference during the field survey. Forested and mountainous areas of central Seram were inaccessible and primary GCP points were not collected in these areas.

To improve the utility of the EO-based DEM products future enhancements were identified: 1) integrating existing river network data during the DEM creation process to ensure surface drainage flows match the observed river network; 2) producing more cross-sections along river networks to increase the confidence in the accuracy of the product (e.g., over 100 existing cross sections for multiple rivers in Banten Province), and 3) combining river net-

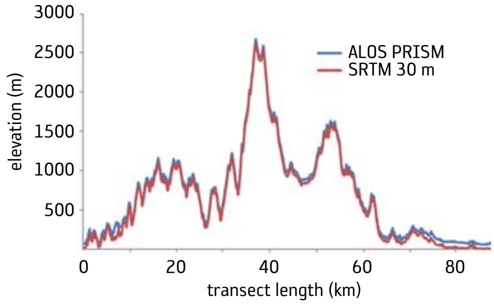


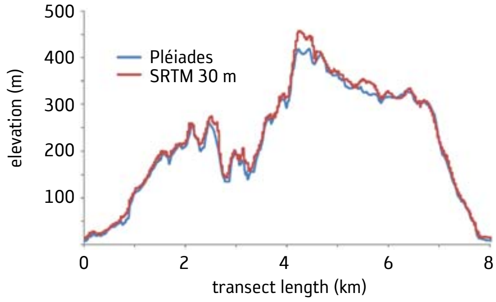
Comparison of the GoI 2013 land cover dataset *(left)*, the EOTAP LULC product (middle), and the RapidEye image *(right)* for the 3Cs RBT study area. RapidEye data © BlackBridge.



Regional DEM product derived from stereo ALOS PRISM data for the 3Cs RBT. ALOS data © JAXA.

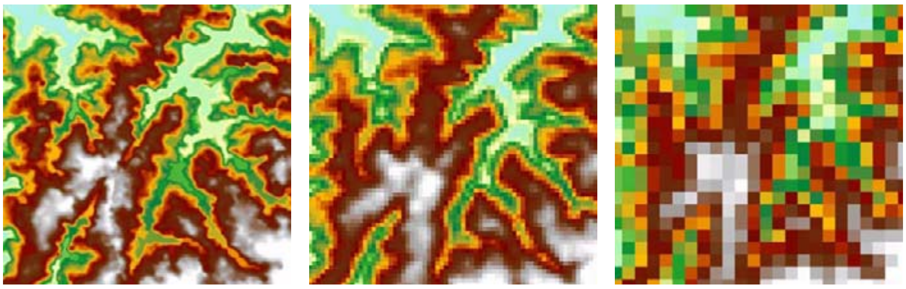
Examples ofcomparisons between extracted elevation profiles. *Top:* Ambon Island regional DEM. *Bottom:* Kota Ambon precision DEM.





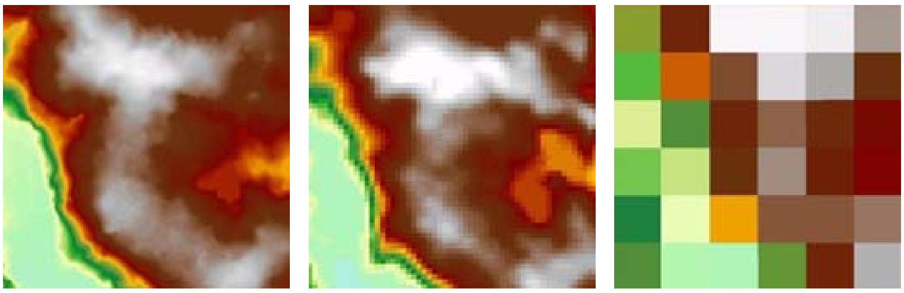
0 1 km

Comparison of the regional DEM product derived from ALOS PRISM at 10 m resolution *(left)* with the SRTM 1 arcsecond DEM (approx. 30 m, *middle*) and the SRTM 3 arcseconds DEM (approx. 90 m, *right*). ALOS data © JAXA. SRTM DEM © NASA/JPL.



0 500 m

Comparison of the precision DEM product derived from Pléiades at 1 m resolution *(left)* with the regional DEM product derived from ALOS PRISM at 10 m resolution *(middle)* and the SRTM 3 arcseconds DEM (approx. 90 m, *right*). Pléiades data © CNES, distribution Airbus DS. ALOS data © JAXA. SRTM DEM © NASA/JPL.



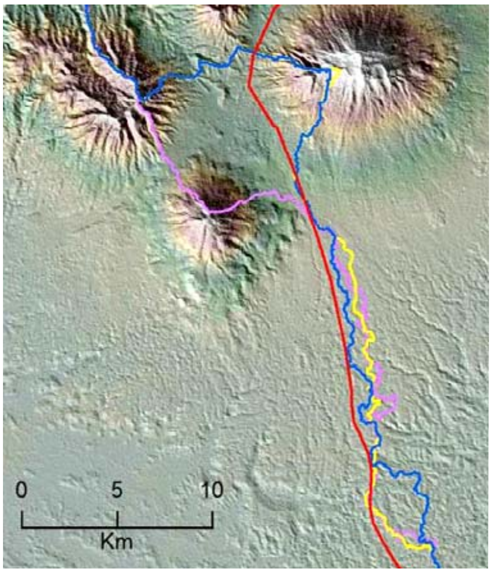
work cross section data with DEM values to estimate water flows. Furthermore, additional validation of the DEM products should be completed for flatter floodplain areas as well as mountainous areas, to quantitatively determine the bias and limitations of the DEM products.

Challenges and limitations

The main challenges in developing the EO-based products was the lack of ancillary data (e.g., road network and cadastral data), persistent cloud cover and presence of haze, and the lack of sufficient ground validation data. Limitations resulting from insufficient ground validation data could have been minimised with the use of alternative validation data sources (e.g. aerial photography captured by Unmanned Aerial Systems – UAS). Persistent cloud cover could have been overcome through a more comprehensive use of the image archives to select cloud-free scenes. Based on end-user feedback, the vintage of the satellite image would have little effect on the final DEM product. However, this would be more important for the creation of the LULC product. The availability of ancillary land use data would also have addressed information gaps where spectral information alone was not sufficient to extract the necessary LULC categories (e.g., industrial areas, primary and secondary forests, etc.).

As persistent cloud cover and limited access to remote areas are common challenges in Indonesia and other parts of the tropics, use of alternative technologies and data sources such as radar imagery which is less susceptible to

Watershed boundary
DGWR
PRISM
SRTM 30 m
ASTER GDEM



The impact of DEM choice on the delineation of watershed boundaries: ALOS PRISM-based, SRTM 30 m resolution, and ASTER GDEM, 30 m. The basin boundary as provided by DGWR is also displayed.

cloud cover is an attractive option. Radar technology can be a reliable source of remote sensing data that can support LULC mapping and monitoring. Freely available options such as Sentinel-1 could be used to determine baseline land cover categories such as forest and non-forest and flooded paddy fields that are able to assist in studying water run-off or erosion potentials across landscapes.

Impact and benefits

Incremental changes in land cover in the river basins across Indonesia have led to watershed degradation and impacts on valuable ecosystem services. Assessing the LULC and topography within watersheds can identify important areas for protection and restoration to reduce extreme runoff, soil loss, and sediment loads entering river systems. However, completeness and currency of LULC data varies greatly across Indonesia, and up-to-date land cover information is not-readily available for remote areas.

Overall, the products developed under the EO support project fulfilled the important information needs related to flood risk management planning and hydrological modelling at accuracies suited to the needs of the DGWR. The LULC product provided new and improved information. Previously, supplemental information, such as ground based surveys, of land use and land cover was required to help estimate flood impacts to the surrounding settlement areas. Increased detail provided by the urban LULC product for Kota Ambon will enable DGWR and ADB to conduct new tasks and analyses that previously were not possible, such as modelling flooding impact on residential areas. Furthermore, the information gained from higher resolution DEMs will help the DGWR and ADB reduce uncertainty and risks within flood modelling studies.

The LULC dataset derived from RapidEye provides an up-to-date baseline to support assessments of watershed condition that is more detailed compared to existing datasets. Comparing the LULC products against the 2013 national land cover data sets obtained from the Ministry of Environment and Forestry, the RapidEye LULC product derived in the EO support project is more detailed, especially in the delineation of urban settlements (see figures on p. 33).

Topographic data such as DEMs are fundamental sources of geospatial information required for hydrological analyses, such as hydrodynamic modelling and accurate catchment delineation. Topographic data also supports the study of erosion potential, defining low-lying areas, topographic depressions, and slope gradients. SRTM and ASTER GDEM provide a free source of topographic and elevation data. However, without further post-processing and editing, incorrect drainage information, watershed boundaries and gradient profiles are obtained. The horizontal and vertical accuracy of SRTM data is not suitable for floodplain analysis since drainage patterns and simulated flood extent cannot be captured with sufficient detail, especially in low-lying areas.

The ASTER GDEM dataset improves on SRTM accuracies. However, since the dataset is a DSM, accurate drainage and elevation profiles can only be extracted after extensive correction of elevation values to remove peaks and sinks associated to surface features.

The PRISM-derived DEM products fulfil an important information need by providing a much-improved and more detailed representation of topography allowing for more accurate catchment delineations, definition of drainage patterns, and calculation of upstream areas. The greater level of detail in surface topography obtained by the PRISM-based DEM products allows for more accurate watershed boundary delineation. For example, the figure on the left illustrates the boundaries for the 3Cs RBT study area derived from ALOS PRISM, SRTM 30 m, and ASTER GDEM. These boundaries are also compared to the basin boundary obtained from the GIS dataset supplied by DGWR. Generally both the PRISM-derived DEM and SRTM 30 m data set have similar boundaries while the ASTER GDEM and DGWR data set produce significantly different boundaries. Differences in upstream drainage can have significant impacts on estimated water flow and flood volume calculations given these important metrics are a function of drainage area, slope, soil sealing among other parameters.

Based on a review meeting with the ADB and DGWR, future EO-derived LULC products will support two-dimensional floodplain hydrodynamic modelling and assessment of flood hazard and risk while reducing uncertainty and project risk. Flood management activities will be enhanced and improved on through the use of the EO-based products. Specifically, the basin-wide LULC product for all three study areas extracted from high resolution satellite imagery will 1) provide a more detailed description of river features including river flooding zones, allowing for better prediction of flooding effects in critical areas; and 2) support levee monitoring and identification of critical levies within the basin.

"The product is helpful at the project management planning stage of the flood management activity, especially to get an overview of land use and land cover over the project area. [Topography] is quite useful to create some hydrological modelling."

Ir. Birendrajana,
Head of Technical Planning Subdirectorate (Rivers and Coastal),
Directorate General of Water Resources, Ministry of Public Works

Service sustainability

The LULC and DEM products in the present project are particularly relevant to disaster risk management, hazard monitoring, environmental assessment and monitoring, and route and facilities siting and planning. Their incorporation into ADB project workflows and activities would provide more confidence in subsequent analysis conducted by these projects and typically reduce costs compared to other methods of data collection.

The products can also be used to derive other geospatial information such as erosion potential and runoff potential. An approach to sustainability is to demonstrate their multiple uses and work with EO product suppliers to standardise products and services. Some EO services have been standardised, such as elevation products from some vendors. However, the standardisation in these cases tends to be targeted to the source image products from each vendor, and not necessarily to the specific needs of individual end users. ■

Utility Assessment Meeting with the DWGR at the Ministry of Public Works, Jakarta, 18 September 2015.

Project K

→ URBAN SERVICES IMPROVEMENT IN MANDALAY, MYANMAR

Users

ADB Southeast Asia Department, Urban Development and Water Division (SEUW)

Mandalay City Development Committee (MCDC)
Mandalay Technological University (MTU)
Department of Agricultural Land Management and Statistics (DALMS, formerly SLRD, Settlement and Land Records Department), Ministry of Agriculture and Irrigation
Department of Meteorology and Hydrology, Ministry of Transport

Provided EO Services

1. Urban land cover / land use classification and its changes over time
2. Flood risk assessment and Digital Elevation Model (DEM)
3. Regional land cover / land use classification and its changes over time
4. On-demand rapid flood mapping

EO Service Provider

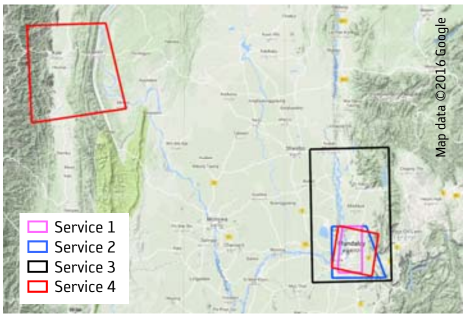
Gisat s.r.o. (Czech Republic)

Contacts

Eri Honda – Principal Urban Development Specialist, ADB SEUW

Philippe Bally – ESA, *Philippe.Bally@esa.int*

Tomas Soukup – Gisat s.r.o., *tomas.soukup@gisat.cz*



Location of the project areas.

Rapid development of cities does not always go hand to hand with development of public services and critical infrastructure. Sustainable economic growth shall be supported by poverty mitigation, improvements in the field of public health and protection and development of regional growth potential. As part of the Country Partnership Strategy with Myanmar, ADB is investing to improve critical infrastructure, coupled with affordable access in order to promote sustainable and inclusive economic growth. This strategy supports government objectives of poverty reduction and national reconciliation. ADB's *Mandalay Urban Services Improvement Project* (MUSIP) contributes to a better urban environment and public health in Mandalay city through improved access to sustainable urban services, including water supply system improvements, enhanced drainage and flood protection and improved wastewater management. The project is expected to help Mandalay increase its development potential as a regional economic growth centre.

The EO support project delivered information for the Mandalay area required to support the efficient planning and execution of the investment programme, in particular to ensure that climate resilience considerations can be effectively integrated into the proposed development. The delivered products include detailed urban and peri-urban land use and land cover mapping and changes at urban block level, a maximum water extent mask for the last decade as identified from satellite imagery, modelled water extents for predefined recurrent frequency intervals, flood occurrence probabilities, and regional land use / land cover changes in a wider area along the Irrawaddy River.

Products were derived by analysis of multi-resolution optical and radar satellite data, depending on required scale and information content. Geometric and thematic accuracy was assessed in an initial validation by using ancillary data obtained from the users or by pseudo-ground truth visual interpretation in additional very high-resolution satellite imagery. Service outputs were provided both as GIS-ready geospatial layers and in form of print-ready high-resolution maps. An analytical web-based data exploration tool was made available during the capacity building workshop (offline version) and online: http://project.gisat.cz/eotapk.

Current practices

In ADB there is a heritage of using spatial data to understand urban growth in the region, raise awareness within the respective cities and prepare for ADB future involvements. Nevertheless, current practices are based mostly on local mapping and in-field investigation. In particular for Mandalay city, SAFEGE (France) was engaged by ADB to conduct the MUSIP feasibility study or PPTA (Project Preparatory Technical Assistance). This contributed by a large number of geospatial layers, such as an urban basemap, information on hydrography, transportation, topography, floods. These are summarised in the so-called *ADB Map Atlas*. The data sources are inhomogeneous: field surveys, manual digitisation of satellite data (Google Earth), local topographic maps etc. Often they lack topologic consistency in terms of vector features connectivity and spatial relationships, as well as thematic and temporal consistency. Additionally, the data does not always cover the wider Mandalay area, including proposed city development zones (e.g. Amarapura and Patheingy). The EO support project aimed also at filling these gaps by delivering standard, harmonised information, retrospectively and up-to-date.

Urban land cover / land use

The service provided up-to-date (2014–2015, based on Pléiades 0.5 m resolution imagery) and historical (2002, QuickBird, 1.5 m resolution) urban land use information and its change, in Mandalay city. Also included were the identification/delineation of road networks, points of interest, agricultural plots and urban structural statistics including average building heights and disaggregated population at building block level. For the land use products, a thematic accuracy of at least 85% was attained.

Flood risk assessment

In this service mapping products were extracted from a combination of mostly radar data (ALOS PALSAR) and optical imagery (SPOT 4/5) at 10–20 m resolution, capturing the situation during the peak monsoon flood inundation periods for the years 2003 and 2006–2010.

Flood frequency (10/50/100-year) was analysed using the resulting flood inundation classification. Similarly, flood inundation extent and depth were extracted using flood-discharge modelling in the US Army Corps of Engineers' HEC-RAS software package. Based on previous outputs, flood risk for potentially affected built-up areas was assessed. A detailed digital terrain model based on tri-stereo processing of SPOT 7 imagery served as input to the modelling.

Thematic accuracy of flood inundation delineation was evaluated for dates with reference satellite data available. In all cases the accuracy was at least 85%.

Regional land cover / land use

This service saw the delivery of maps of land cover / land use and its changes for 2002–2014. The maps are based on medium-resolution imagery (in the order of 30 m) but have wider coverage and demonstrate the monitoring

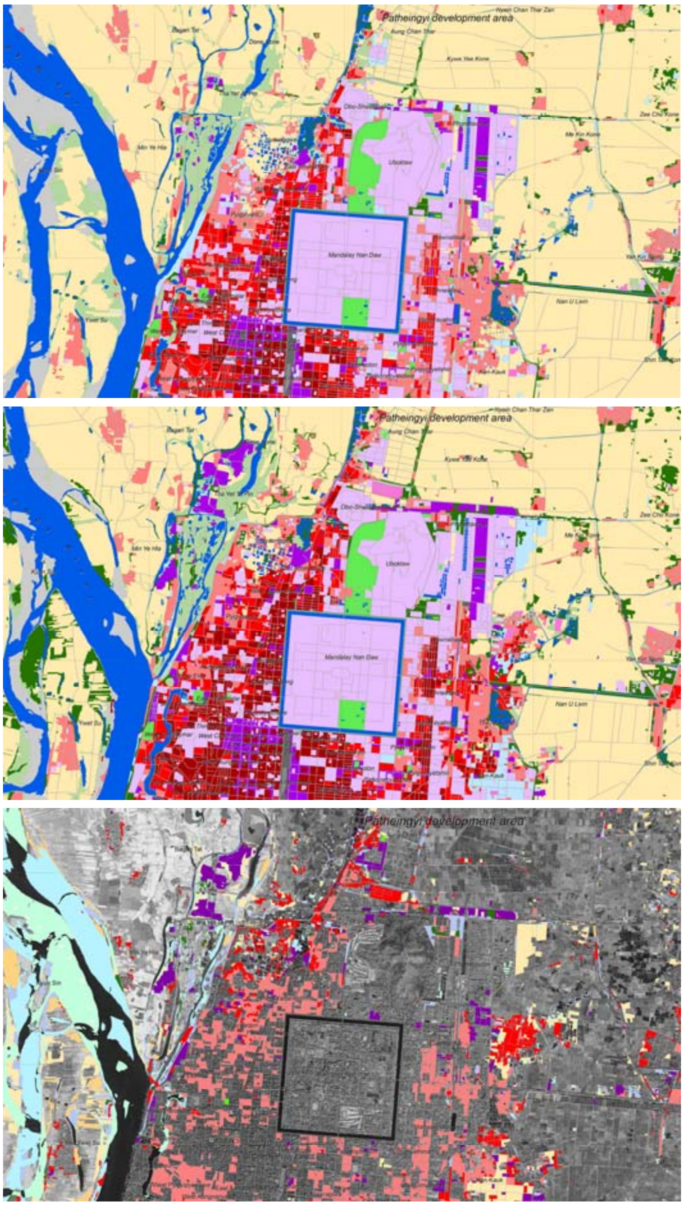
Example of a Service 1 product: detailed land use status classified and extracted at urban building block level for 2002 (*top*, based on QuickBird) and 2014–2015 (*middle*, based on Pléiades 1 and SPOT 7). The *bottom* image shows the identified changes (land use class transitions) overlaid on the Pléiades imagery. QuickBird data © DigitalGlobe. Pléiades and SPOT data © CNES, distribution Airbus DS. Ancillary information and toponyms provided by OpenStreetMap and ADB.

Haymarzala: Ward name Roads

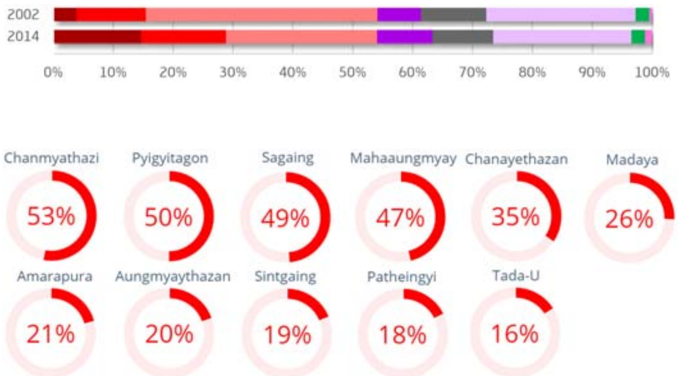
0 1 2 3 4 km

Land use
- Formal very high-density residential (sealing level >80%)
- Formal high-denisty residential (sealing level 50–80%)
- Formal low-density residential (sealing level 10–50%)
- Commerical and industrial
- Non-residential urban fabric
- Roads, transportation and associated areas
- Urban greenery
- Construction sites
- Agriculture
- Trees
- Other natural and semi-natural, incl. wetlands
- Vacant land not obviously being prepared for construction
- Bare land
- Water

Land use change
- Urban extension: extension of residential urban fabric
- Urban extension: extension of non-residential urban fabric
- Urban extension: extension of urban greenery
- Internal urban development
- Agriculture extension
- Agriculture withdrawal
- Natural and semi-natural areas internal changes
- Water bodies extension
- Water bodies withdrawal
- Natural and semi-natural development



Examples of statistics derived using the data exploration tool: the structure of urban land use classes in years 2002 and 2014 *(top)* and the share of changed area in each ward *(bottom)*.



capacity for support of environmental changes and impact assessment using at regional level in the Irrawaddy Valley near Mandalay. Overall thematic accuracy of at least 85% was achieved. Mapping was performed for December 2013 (Landsat-8) and November 2000 (Landsat-7), including mapping of the temporal changes.

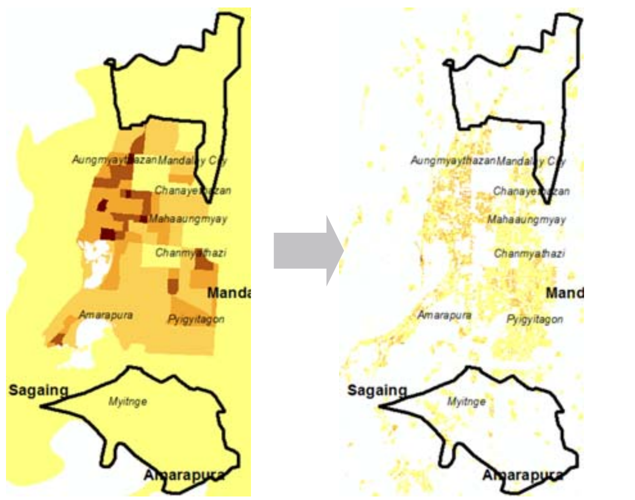
On-demand rapid flood mapping

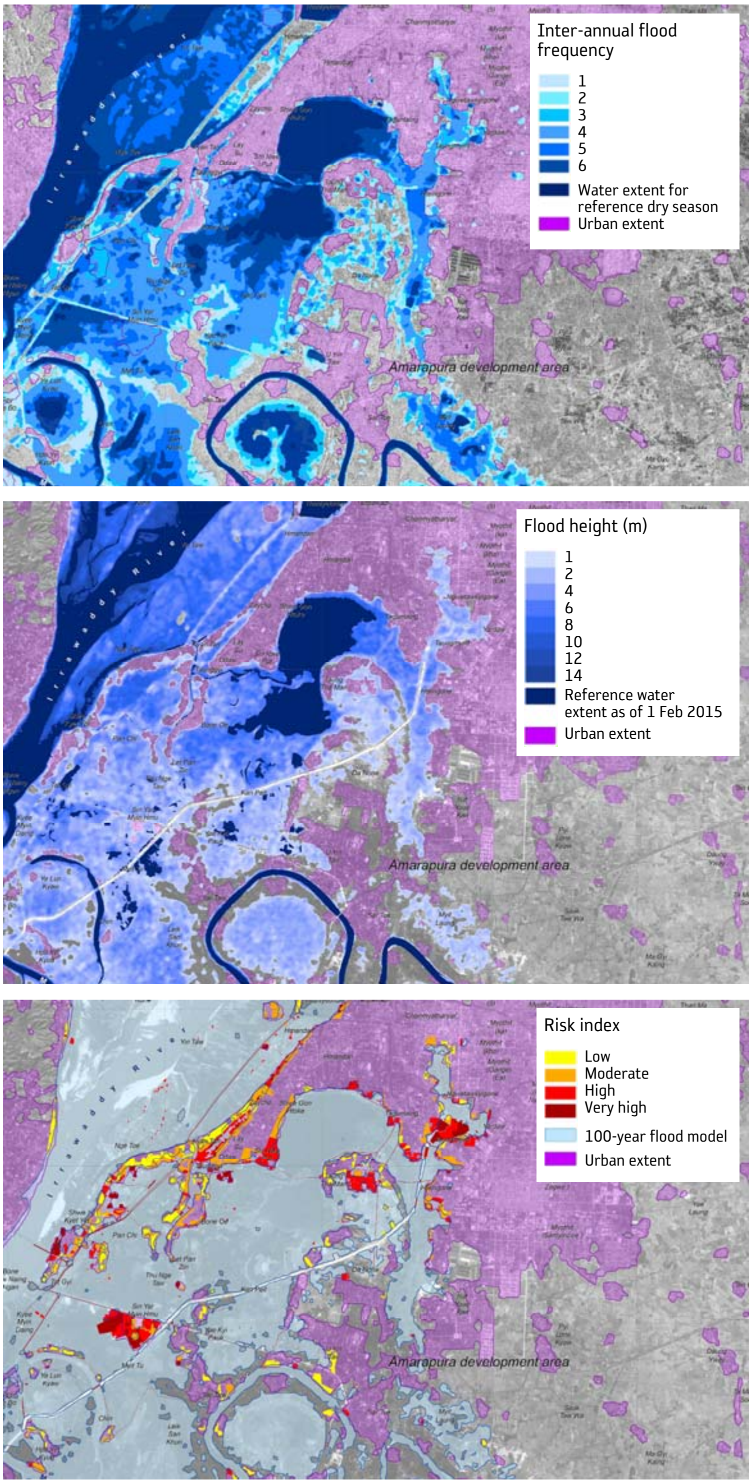
A demonstration of the operational rapid flood mapping capacity of the Sentinel-1 radar sensor at approx. 20 m resolution was demonstrated by analysis of time series from July-September 2015, when Myanmar was subject of severe floods which for some areas of the country were the worst in the last decade. Demonstration flood products (flood inundation extent and evolution) were delivered for Mandalay city surroundings and for Kalay city in the western part of Sagaing Region (the latter is not part of MUSIP).

Capacity building

During 2015 September 24–25 a very successful capacity building event was conducted at the MTU Department of Remote Sensing. The workshop aimed at supporting local stakeholders in understanding and utilising the products delivered by the project. Several thematic sessions were centred on the applicability and utility of the delivered products in an urban management context. More technical sessions aimed at capacity building in EO data analy-

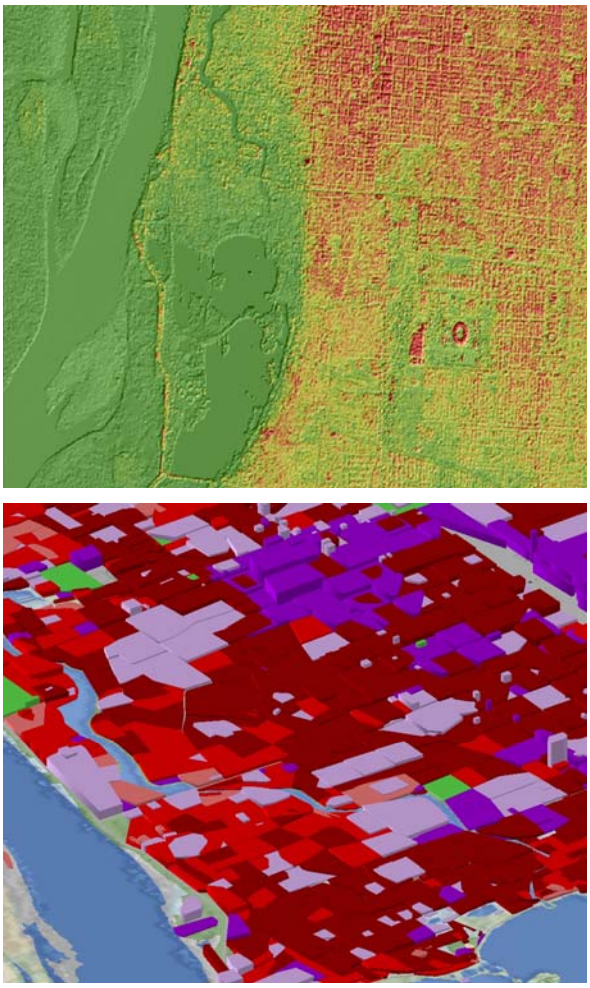
Example of disaggregating population density from census data available at administrative/ward level *(left)* to building block level *(right)*, by using satellite-derived information on land use (built-up density and building block typology) and building block average height (from the DEM). While this is still an approximation of the real situation, it yields a good insight into population distribution patterns. The black contours indicate the Patheingyi and Amarapura development areas.





Examples of flood risk assessment products.
Top: Flood frequency based on observations from the years 2003 and 2006–2010.
Middle: Modelled 100-year flood inundation and depth based on Digital Terrain Mode.
Bottom: Urban block-level flood risk index.
Image background: Pléiades © CNES, distribution Airbus DS.

Combining the land cover information from Service 1 with the Digital Surface Model from Service 2 *(top)* to obtain a 3-dimensional city model at building block level *(bottom)*. Elevation data based on SPOT 7 © Airbus DS.



sis techniques. Many of the considered topics were described by the participants as relevant but almost completely new to them. Workshop participants included the MCDC Department of Roads and Bridges, the MCDC Department of Buildings and Stores, the regional DALMS survey office, the DMS regional office as well as several MTU departments. Following the recommendation of the ADB partners, the latter will act as a focal point for distribution of delivered data to local users and assess needs arising from the follow-up implementation phase of the bank projects.

Impact and benefits

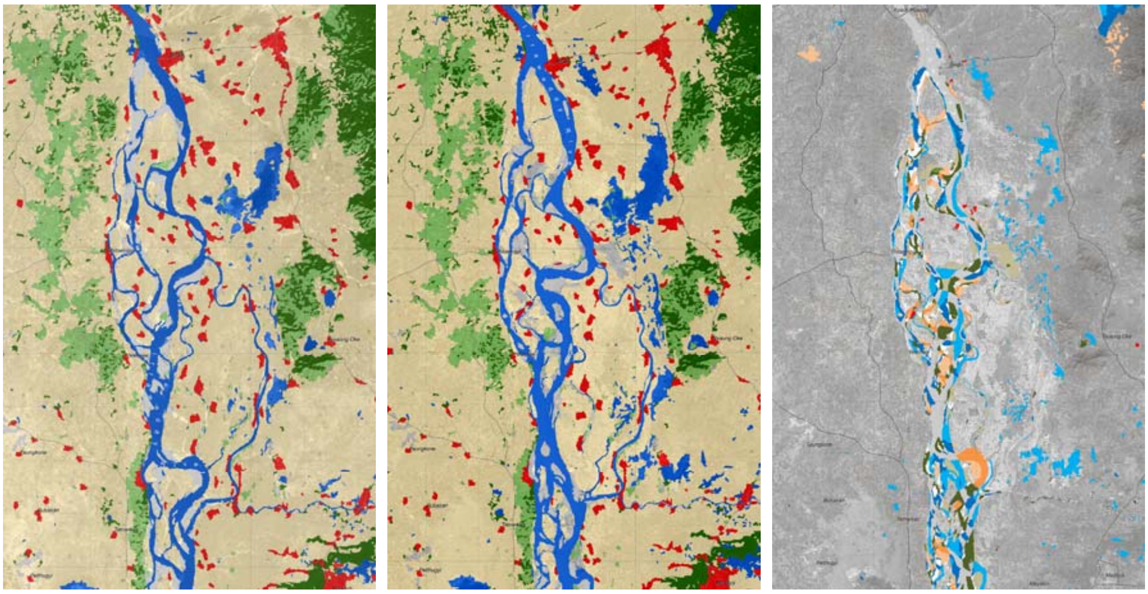
EO-based information products and services provide a structured information base to better understand and utilise even the data that ADB and the stakeholders in Myanmar already had.

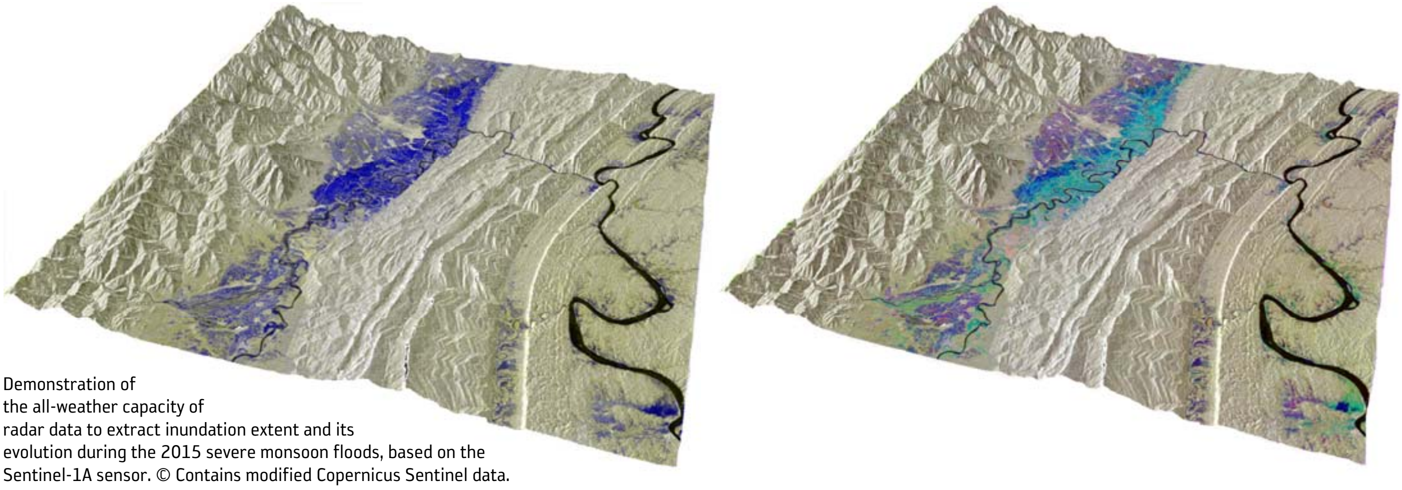
Although the project impact is not always easily measurable, it can be seen as twofold: 1) in the short-term, the improved geospatial information base should benefit MUSIP implementation and improve the analytical capacity of the principal local contractor; 2) in the long-term, the delivered capacity building should raise awareness among local stakeholders, specifically with MCDC. This will also support and facilitate future activities of ADB.

The project introduced some new analytical scope (land use accounting), standards (topology, attribution) and monitoring capacity (retrospective by archived data and up-to-date, especially in light of the newly launched Sentinel satellite missions). These techniques were generally not known to local stakeholders.

One of the caveats for future uptake and operations is the poor internet connection and GIS infrastructure in Myanmar. Support is also needed to im-

Detail of the regional-level mapping products along the Irrawaddy north of Mandalay: land cover for 2002 *(left)* and 2014 *(centre)* and the observed changes over time *(right)*.





Demonstration of the all-weather capacity of radar data to extract inundation extent and its evolution during the 2015 severe monsoon floods, based on the Sentinel-1A sensor. © Contains modified Copernicus Sentinel data.

prove access to EO data and the technical infrastructure capacity of key local stakeholders. Such support is already provided partly from the Chinese Center for Resources Satellite Data and Applications (CRESDA) by supporting the *Myanmar-China* Remote Sensing Satellite Data Sharing and Service Platform* created at the Remote Sensing Department of MTU in 2013.

"I found it relevant to involve [ESA and GISAT] in the Mandalay project as not only the products, but also the capacity development training were very useful. The project teamed up with Mandalay Technological University and they really appreciated the training delivered by GISAT. I am interested in continuing the work to integrate this technology into urban planning activities together with the recently-estabilished department for urban and land management at the Mandalay City Development Committee."

Eri Honda
ADB Principal Urban Development Specialist

* ADB recognizes "China" as the People's Republic of China.

Capacity building workshop at the Mandalay Technological University, 2015 September 24–25.

Project L

→ URBAN ENVIRONMENT AND CLIMATE CHANGE ADAPTATION IN VIET NAM

Users

ADB Southeast Asia Department, Urban Development and Water Division (SEUW)

Provided EO Services

1. Urban baseline assessment and change mapping
2. Coastal bathymetry mapping
3. Coastal habitat change mapping

EO Service Providers

GeoVille GmbH (Austria)
DHI GRAS A/S (Denmark)

Contacts

Eri Honda – Principal Portfolio Management Specialist, ADB SEUW

Gordon Campbell – ESA, *Gordon.Campbell@esa.int*

Leonhard Suchenwirth – GeoVille Information Systems GmbH, *suchenwirth@geoville.com*

Viet Nam is one of the most seriously affected countries worldwide by climate change processes such as sea level rise. It has progressed well towards reducing poverty, with poverty incidence declining from 58% in 1993 to 11% in 2010. However, the poverty incidence varies significantly across regions. The poor are vulnerable to environmental degradation and climate change effects. Industrialization, urbanization, and agricultural intensification have had harmful effects on land and water. Continued discharges of untreated waste to water and soil threaten water safety and thereby food security and reliable energy supplies.

The Viet Nam Socio-Economic Development Plan (SEDP) for 2011–2015 aimed to create a foundation for the country to be an industrialized country by 2020. Furthermore, ADB's Viet Nam Country Partnership Strategy (CPS) has elaborated three priority support areas for the urban development sector. One of these is the development of secondary cities as regional economic hubs to foster balanced regional development and strengthen rural-urban linkage.

The EO support project provided support to the ADB *Urban Environment and Climate Change Adaptation* project, whose main focus is to upgrade facilities to improve urban environmental conditions in two coastal secondary cities (Dong Hoi and Hoi An), to keep up with urban development and to reduce the impacts of natural disasters and climate change. Improved urban infrastructure and services will also increase economic opportunities for people living in the project areas, leading to poverty reduction. High priority is accorded to the construction of urban infrastructure, taking into account environmental protection and climate resilience. This includes the special importance of water supply systems, wastewater management, flood management and coastal protection, and basic infrastructure for new residential areas. Impacts of climate change are further exacerbated by increased rainfall and sea level rise, and poor management in solid waste. Flooding contaminated by wastewater can cause serious health risks. Careful assessments are needed on the extent of the potential impacts, on the bases of which appropriate response mechanisms need to be developed.

For the EO support project, the main requirements were related to land use and spatial planning for future city expansion as well as climate change resilient urban infrastructure design. Hence, elements from all the above mentioned service components were covered, with a focus on urban extent and development (urban physiognomy) as well as urban land cover (urban structure and function) and various sector-specific products in relation to the exposure of these coastal cities to flooding, sea level rise, erosion and saline intrusion.

Location of the project areas: Service 1 *(red)*, Service 2 *(blue)*, and Service 3 *(green)*.

Urban baseline assessment and change mapping

This service provided very high-resolution baseline urban information, including the delineation of different urban areas, housing types and urban land cover. This is required to support assessment of the distribution of different demand areas for access to water, waste water treatment and solid waste management as well as to estimate risk levels linked to climate change-related coastal flooding.

An important component of the service was the urban change mapping, which supports analysis of current trends in the development of the identified secondary cities in order to analyse intensification of agriculture, expansion of industrial areas and informal settlement areas as well as assessment of contamination in surrounding estuary regions.

For each of Dong Hoi and Hoi An, the product suite in this service included:

- Urban land cover / land use for 2014, based on Pléiades imagery,
- Soil cover for 2014,
- Coastal risk assessment: inland flooding potential, sea level rise (SLR), coastal erosion potential,
- Risk of saline intrusion to groundwater, and
- Urban land cover change for the years 2002–2006–2014.

Statistical analysis of the derived data underpins the slight continuous urbanisation between 2002 to 2014 in both Dong Hoi and Hoi An. A total of 182 ha and 246 ha were newly developed with urban land use in the two cities, respectively. In both cities, depending on the hazard under evaluation, significant parts of the urban environment are exposed.

Especially the very high-resolution land cover and change mapping would benefit from in-situ data to additionally improve the differentiation of urban land use classes . For the modelling of the risk of saline intrusion to groundwater local measurements of salinity and water levels were used, since it is not possible to directly map groundwater salinity from satellite data.

Coastal bathymetry mapping

Changes in bathymetry will impact the dynamics of coastal current systems and the propagation of ocean swell into shallow waters which in turn will impact on the risk of coastal flooding. By combining recent satellite-derived shallow water bathymetry with previously acquired conventional bathymetric information, changes in bathymetry can be analysed and areas of highest risk identified for remediation work.

The service provided information on water depth for shallow water areas, derived from WorldView-2 imagery. Depending on conditions, high-resolution maps can be derived with water depths down to approximately 10 m for coastal areas in Viet Nam. High resolution bathymetry could not be produced at any of the two study areas due to a combination of high sediment concentrations and sun glints. To exemplify the method and resulting data, a similar area south at Dung Quat harbour was considered instead. In addition and where applicable, benthic habitat maps were also provided.

The product suite included:

- Benthic habitat maps for 1998–2006–2013,
- Shallow area maps for 1998–2006–2013,

- Bare soil
- Grassland
- Residential
- Trees/shrubs
- Open sea
- Industrial
- Informal
- Other buildings
- Lake/river
- Aquaculture
- Mangrove
- Agriculture
- Streets
- Sealed (e.g. roads, parkings)

Service 1 – *left* and *middle:* urban land cover map, Dong Hoi, 2014 February 2. *Right:* the original Pléiades satellite image. Pléiades data © CNES, distribution Airbus DS.

Service 1 – Dong Hoi (2014). *Left:* imperviousness map. *Right:* soil cover map. Background map: Pléiades © CNES, distribution Airbus DS.

Degree of imperviousness (%)

- >80
- 30–50
- 50–80
- 10–30
- <10

- Agriculture

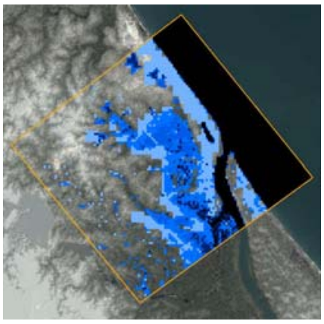
Soil cover

- low density of vivid vegetation
- high density of vivid vegetation

Service 1 – Coastal flood risk assessment for Dong Hoi. *Left:* Inland flood risk. *Right:* Coastal inundation / sea level rise. Background elevation map: SRTM DEM © NASA/JPL.

Relative inland flooding hazard potential

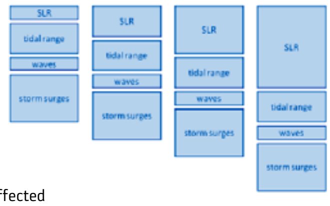
- no potential
- low potential
- moderate potential
- high potential
- very high potential
- water bodies

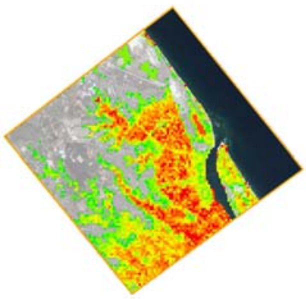


Relative coastal inundation potential (se level rise)

SLR Scenarios

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- not affected



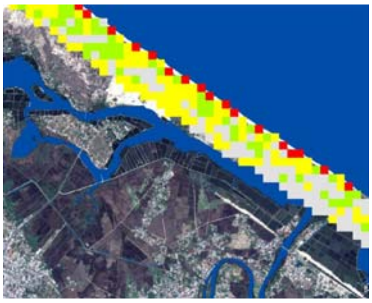


Service 1 – Examples of coastal erosion *(left)* and saline intrusion potential *(right)* mapping for Hoi An. Background map: SPOT 5 and Pléiades © CNES, distribution Airbus DS.

Coastal erosion hazard potential

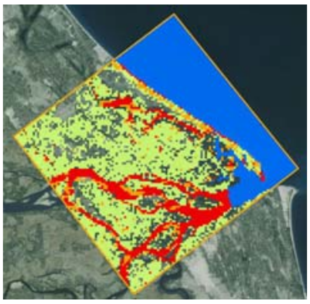
- water

- no potential
- low potential
- moderate potential
- high potential



Saline intrusion potential

- no risk
- low to moderate risk
- high risk
- very high risk
- open sea



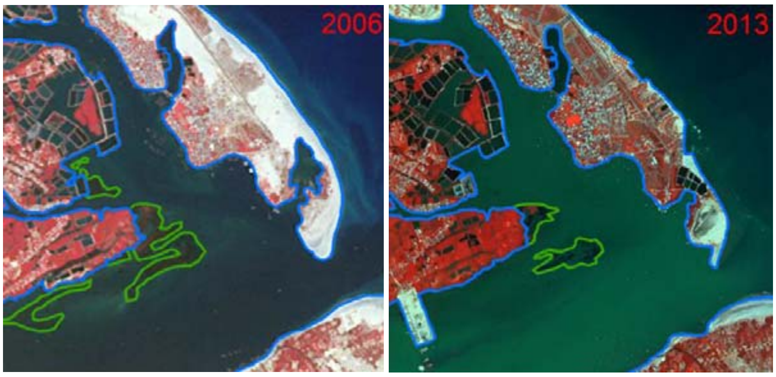
Service 1 – Example of urban change mapping for a part of Hoi An. SPOT 5 and Pléiades data © CNES, distribution Airbus DS.

Situation in 2006, as seen in SPOT 5 imagery.

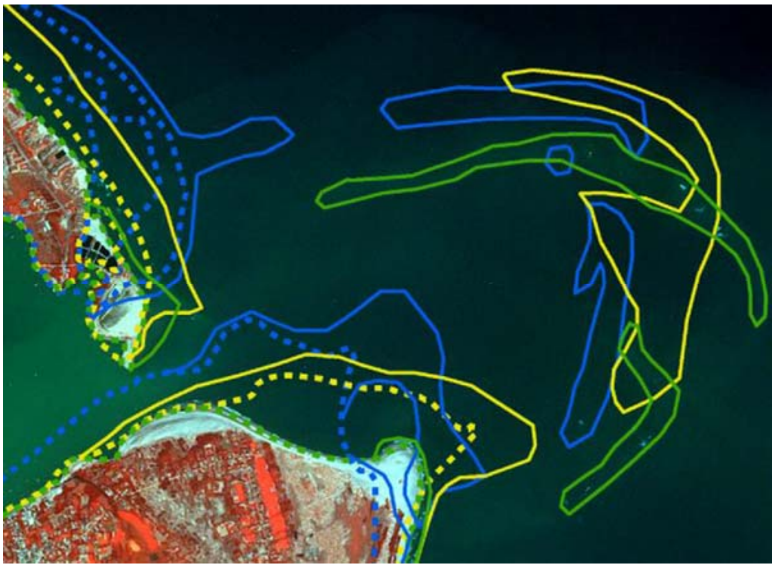
Situation in 2014, as seen in Pléiades imagery.

Urban change 2006–2014

- to bare soil (1)
- to grassland (2)
- to residential (3)
- to trees/shrubs (4)
- to open sea (5)
- to industrial (6)
- to informal (7)
- to other land cover (8)
- to lake/river (9)
- to aquaculture (10)
- to mangroves (11)
- to agriculture (12)
- to streets/roads (13)
- to sealed (14)



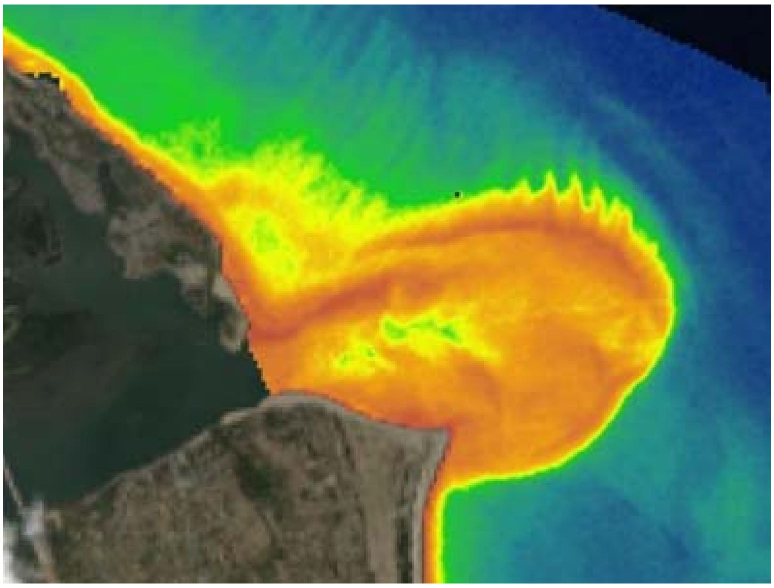
Service 2: Mapping of benthic habitats in near-shore shallow-water areas in Hoi An. Only areas of significant size have been delineated and no attempt has been made as to identify individual types of habitat due to the quality of the imagery data.
Input imagery: SPOT 2 and SPOT 5 © CNES, distribution Airbus DS.
SPOT 6 data © Airbus DS.



Service 2: Mapping of shallow areas in Hoi An. The map presents the dynamics of sediment transport and which areas are active. This is important for assessment of coastline changes and as support to navigation in the area.
Input imagery: SPOT 2 and SPOT 5 © CNES, distribution Airbus DS.
SPOT 6 data © Airbus DS.

Shallow areas

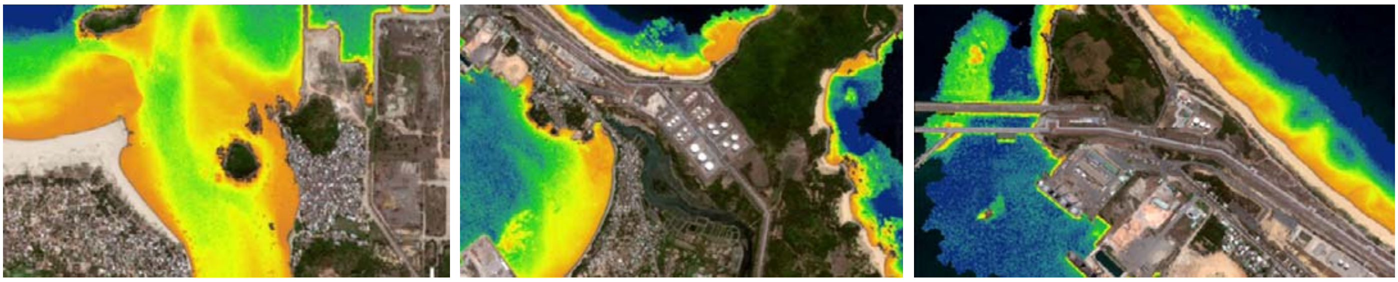
- 2013 shallow
- 2006 shallow
- 1998 shallow
- 2013 coastline
- 2006 coastline
- 1998 coastline



Service 2: Coastal (shallow-water) bathymetry mapping.
Left: Bathymetry based on medium-resolution data (Landsat-8, 30 m resolution) for river outlet near Hoi An in 2013.
Bottom three images: bathymetry based on high-resolution data (WorldView-2, 2 m resolution) along the coast east of Chu Lai Airport and around Dung Quat Port.
Landsat-8 data © USGS. WorldView-2 data © DigitalGlobe.

Bathymetry (m)
(left image)
0
–5
–10
–15

Bathymetry (m)
(bottom images)
0
–7



- Medium-resolution coastal bathymetry map, and
- High-resolution coastal bathymetry map.

The differentiation of the defined habitat classes is in general difficult due to their spectral characteristics. For example, mangrove classification is based also on the knowledge of the most likely occurrence.

Coastal habitat change mapping

This service collected change information on coastal habitats such as mangroves, which are often a more effective protection for surrounding coastline areas than artificial barriers and man-made dykes.

For the years 1998–2006–2013, the service included the following product suite for the extended areas of Dong Hoi and Hoi An:

- Coastal habitat change maps (coastal habitat conversion to agriculture or urban land use, as well as expansion of coastal habitats)
- Loss in vegetation cover,
- Changes in river boundaries, and
- Coastal erosion/deposition mapping.

The products are based on SPOT 2/5/6 imagery. The use of more homogenous input data (e.g. the recent Sentinel satellite series) with a better quality and consistency over time opens the possibility of constant and sustained habitat monitoring.

The major period of change was after 2006 in both cities, leading to a significant loss of marshes, coastal vegetation and sand dunes. Around Dong Hoi, 198 ha of coastal habitats were converted to agriculture or urban land between 1998 and 2013. In Hoi An, the equivalent area is 789 ha. Inversely, a total of approximately 800 ha of gains in (semi-)natural coastal habitats was observed, including in the detriment of water-covered areas (coastal aggradation).

Impact and benefits

In general, EO products are a key tool and a unique information source to support urban environment climate change activities. Land cover and land use information (including detailed urban classes, coastal bathymetry and habitats) derived from satellite data provide a standardised, reliable and cost-efficient view on the current situation and the changes that occur over time. This information is useful for the planning, monitoring and evaluation of urban and rural development activities as well as for disaster risk modelling.

The delivered maps allow for a remote assessment of e.g. urban growth, areas affected by high potential of natural risks. They can be used by local staff in the field to locate and examine hotspots of change or risk. Controlling and verification are supported by providing an independent source of information. Such a repeatable, scalable and expandable EO-based product portfolio is therefore suited to support ADB projects at different scales and stages.

Service 3 – Coastal habitat conversion to agriculture or urban land use, expansion of coastal habitats. Example for Hoi An.
SPOT 5 data © CNES, distribution Airbus DS.
SPOT 6 data © Airbus DS.

Situation in 2006 as seen in SPOT 5 imagery.

Situation in 2013 as seen in SPOT 6 imagery.

Coastal habitat change 2006–2013
change to agricultural or urban use
expansion of coastal habitat

Service 3 – Growth and loss of vegetation cover near Hoi An.
Left: true color imagery.
Right: growth and loss areas overlaid.
Input imagery: SPOT 2 and SPOT 5 © CNES, distribution Airbus DS. SPOT 6 data © Airbus DS.

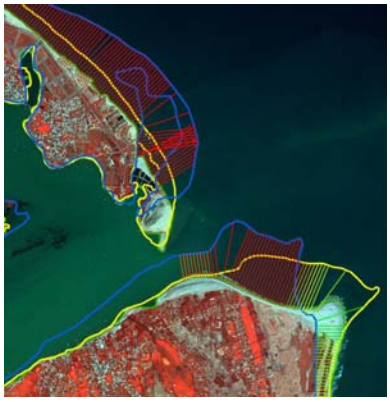
growth
loss

Service 3 – Changes in river boundaries.
Left: River boundaries and coastlines near Hoi An at three different points in time.
Right: Coastlines at three different points in time near Hoi An, showing transects coloured according to end-point rate. Background imagery for both images acquired 2013 April 5. Input imagery: SPOT 2 and SPOT 5 © CNES, distribution Airbus DS.
SPOT 6 data © Airbus DS.

Coastlines and rivers
1998
2006
2013

Coastlines EPR (m/year)
-34.7 – -12.5
-12.4 – -7.5
-7.4 – -5.0
-4.9 – -2.5
-2.4 – 2.5
2.6 – 5.0
5.1 – 7.5
7.6 – 12.5
12.6 – 15.0

1998
2006
2013



→ SERVICE PROVIDERS

	ACRI-ST	260 Route du Pin Montard, BP 234 06904 Sophia-Antipolis France	http://www.acri-st.fr	Project D, p. 14
	DEIMOS Engenharia SA	Av. D. João II, Nº 41 - 10º Edifício Torre Zen 1998-023 Lisboa Portugal	http://www.deimos.pt	Project C, p. 12
	DHI GRAS A/S	Agern Allé 5 2970 Hørsholm Denmark	http://www.dhi-gras.com	Project E, p. 16 Project L, p. 44
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	GeoVille GmbH	Sparkassenplatz 2, 3rd floor 6020 Innsbruck Austria	http://www.geoville.com	Project L, p. 44
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	Hatfield Consultants	#200 – 850 Harbourside Drive North Vancouver, BC Canada V7P 0A3	http://www.hatfieldgroup.com	Project J, p. 36
	Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente	PO Box 217 7500 AE Enschede The Netherlands	http://www.itc.nl	Project D, p. 14
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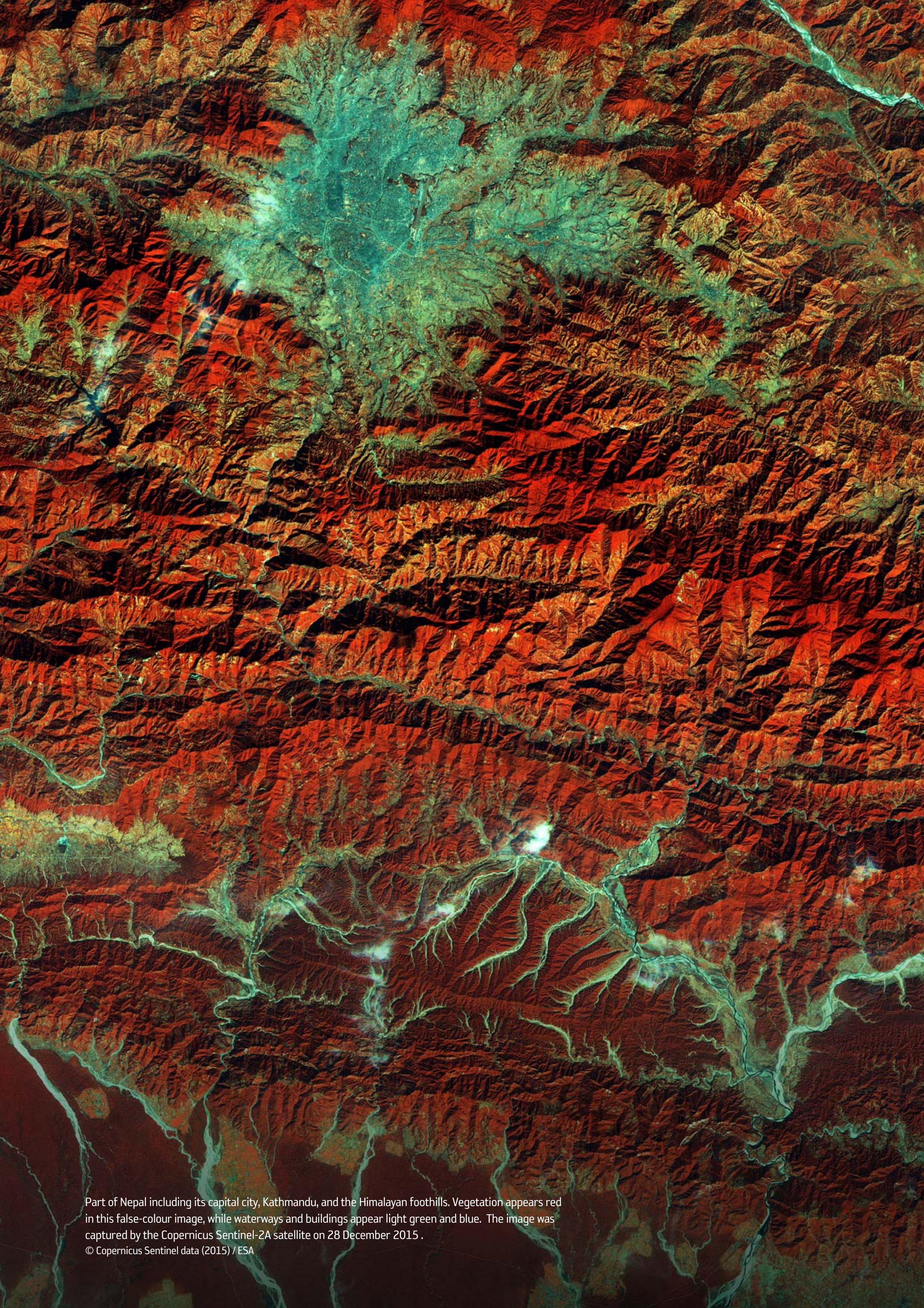
	SarVision	Agro Business Park 10 6708 PW Wageningen The Netherlands	http://sarvision.nl	Project H, p. 28
	SkyGeo Netherlands B.V.	Oude Delft 175 2611 HB Delft The Netherlands	http://skygeo.com	Project I, p. 32
	Starlab Ltd.	Building R103 – Room 1-11, Harwell Oxford Didcot OX11 0QX United Kingdom	http://www.starlab.es	Project B, p. 8
	TRE ALTAMIRA s.r.l.	Ripa di Porta Ticinese, 79 20143 Milano Italy	http://tre-altamira.com	Project B, p. 8



Part of Nepal including its capital city, Kathmandu, and the Himalayan foothills. Vegetation appears red in this false-colour image, while waterways and buildings appear light green and blue. The image was captured by the Copernicus Sentinel-2A satellite on 28 December 2015 .

→ THE EUROPEAN SPACE AGENCY – FURTHER READING

All About ESA – Space for Europe

From the beginnings of the 'space age', Europe has been actively involved in spaceflight. Today it launches satellites for Earth observation, navigation, telecommunications and astronomy, sends probes to the far reaches of the Solar System, and cooperates in the human exploration of space.
http://esamultimedia.esa.int/multimedia/publications/AAE-EN-2015/

Earth Observation for Sustainable Development – ESA-World Bank Partnership Report September 2016

Report describing ESA's newest batch of EO support projects in partnership with the World Bank 2013–2015.
http://esamultimedia.esa.int/multimedia/publications/ESA_WB_Partnership_Report_2016/

Earth Observation for Green Growth – An Overview of European and Canadian Industrial Capability

A showcase of the most operationally mature Earth Observation capabilities, especially for international development. The publication was prepared in a World Bank context.
http://esamultimedia.esa.int/multimedia/publications/EO_for_green_growth_complete/

Sentinels – Space for Copernicus

The Sentinels are a new fleet of satellites that form the heart of Europe's ambitious environmental monitoring Copernicus programme. Each of the six missions carries state-of-the-art technology to deliver a stream of complementary imagery and data for numerous services that will make a step change in the way we manage our environment, understand and tackle the effects of climate change, and safeguard everyday lives.
http://esamultimedia.esa.int/multimedia/publications/BR-319/

Sentinel-1 – Radar Vision for Copernicus

Sentinel-1 is the first in the family of Copernicus satellites.This new satellite carries an advanced radar instrument to image Earth's surface through cloud and rain and regardless of whether it is day or night. Delivering timely information for numerous operational services, from monitoring ice in the polar oceans to tracking land subsidence, Sentinel-1 is playing a vital role n the largest civil Earth observation programme ever conceived.
http://esamultimedia.esa.int/multimedia/publications/sentinel-1/

Sentinel-2 – Colour Vision for Copernicus

Offering 'colour vision' for the Copernicus programme, Sentinel-2 combines high-resolution and multispectral capabilities with frequent revisits to deliver view of Earth's changing lands in unprecedented detail. The mission will provide timely information for numerous practical applications, from monitoring the health of the world's vegetation and changes in the way land is used, to mapping regions struck by natural disaster.
http://esamultimedia.esa.int/multimedia/publications/sentinel-2/

Sentinel-3 – A Bigger Picture for Copernicus

Sentinel-3 is arguably the most comprehensive of all the Sentinel missions, which are dedicated to Europe's environmental monitoring Copernicus programme. The mission provides systematic measurements of Earth's oceans, land, ice and atmosphere to monitor and understand large-scale global dynamics and to provide critical information for ocean and weather forecasting – essentially offering a 'bigger picture' for Copernicus.
http://esamultimedia.esa.int/multimedia/publications/sentinel-3/

Earth Explorers – New Views of Dynamic Earth

Delivering a wealth of new information about our planet and forging state-of-the-art technologies, ESA's first three Earth Explorers – GOCE, SMOS and CryoSat – have been hailed as remarkable successes. These versatile satellite missions have surpassed expectations with a range of interesting and complementary results beyond their original goals.
http://esamultimedia.esa.int/multimedia/publications/BR-314/

ESA ESRIN – ESA's Eye on Earth

Dedicated to ESA's Earth-observing activities, ESRIN, in Frascati, Italy, is the European centre of excellence for exploitation of Earth observation missions.
http://esamultimedia.esa.int/multimedia/publications/BR-291/

The eastern edge of the Sundarbans in Bangladesh. The region of the Sundarbans appears in dark shades of green in this image, while the adjacent areas in brighter colours are densely populated and dominated by agriculture.
The image was captured by Sentinel-2 on 18 March 2016.