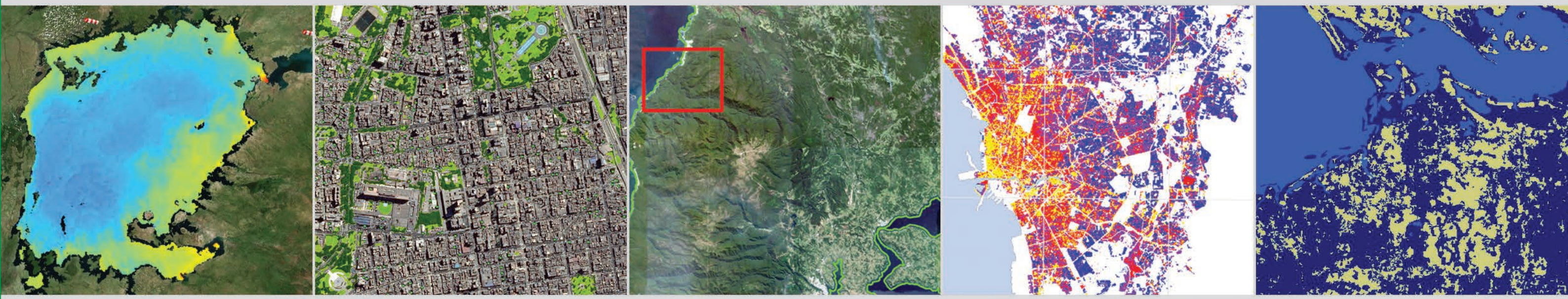
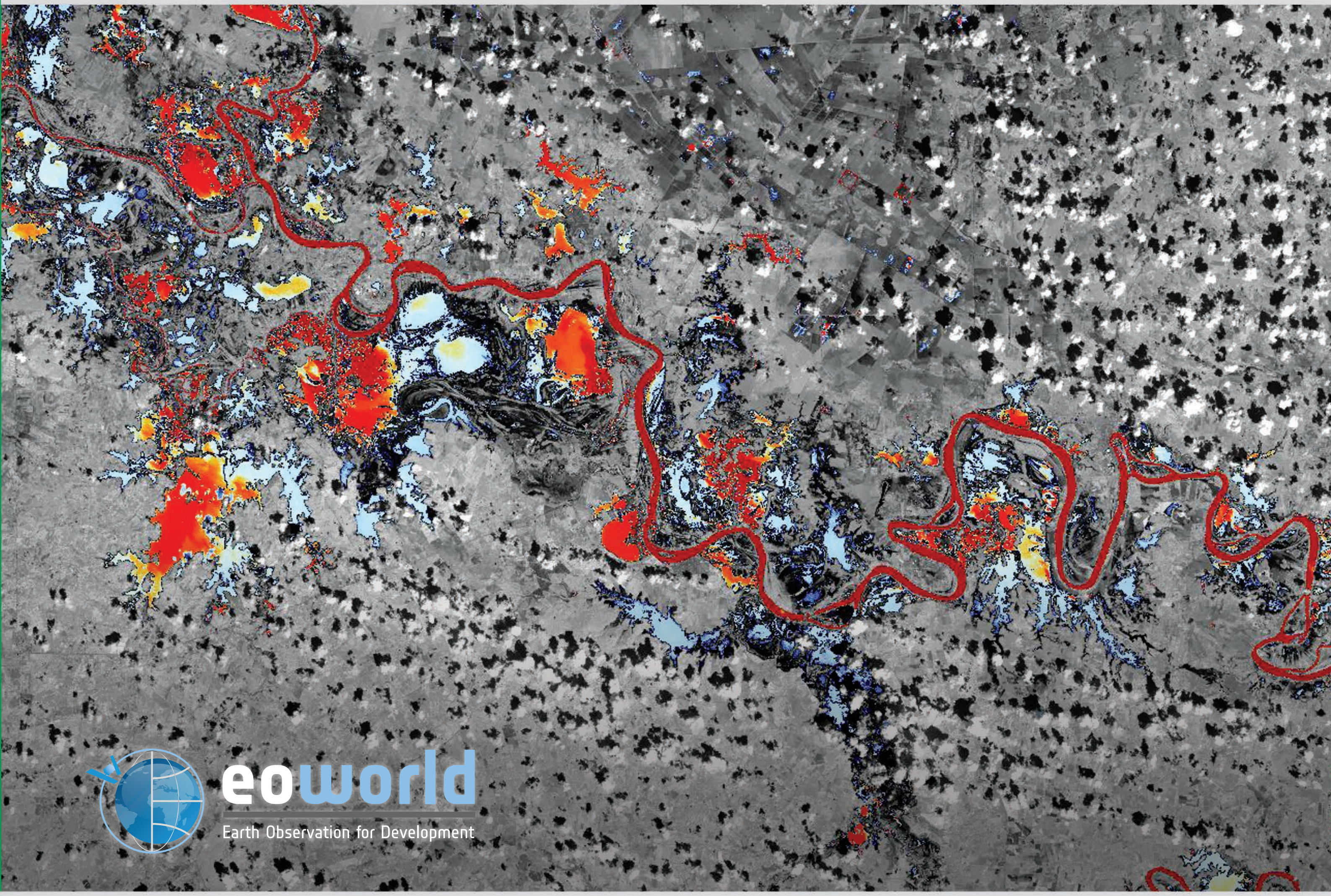
World Bank

European Space Agency

→ EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT

Partnership Report | September 2016





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Introduction

This report summarises the main results of a second batch of 18 contracts carried out in support of World Bank projects during the 18 months period of autumn 2014 until spring 2016.

All contracts were placed by ESA to specialist providers in the European EO services sector via an open procurement process that saw a large interest and highly competitive response from the industry.

This second batch of activities built on the success and awareness raised by the first batch of 15 EO demonstrations that took place in 2011-13. They were similar in purpose and scale, however, these additional contracts took more EO capabilities to a wider range of World Bank teams and Bank programs/initiatives, covered further geographic regions and organisations in client countries, and included the use of Sentinel data (i.e. Sentinel-1A launched in April 2014, and Sentinel-2A launched in July 2015) for the first time in the production of EO-based information in the context of bank activities.

This second batch of activities now concludes the initial phase of small-scale demonstrations of EO-based information. The results achieved have laid the foundations and prepared the path for a new phase of activity to begin.

ESA is now scaling-up with larger, regional demonstrations over the period 2016-19, and a more strategic approach focusing on 10 (high-priority) thematic domains of international development where EO can deliver key information which are: ***Agriculture and Rural Development, Water Resources Management, Urban Development, Marine Resources, Risk Management and Disaster Reduction, Energy & Extractives, Forest Management, Ecosystems services, Fragile & Conflict States, and Climate Resilience and Proofing***. First activities are starting in 2016 in the domains of Agriculture and Rural Development, Water Resources Management, Urban Development, and the remaining 7 thematic areas of above will be started in mid 2017.

A key aspect in this work will be the close collaboration and partnership with both the leading International Financing Institutions and their Client States in co-designing and implementing the activities together. This new phase represents an exciting development, and should represent a key milestone towards the main goal, which is to establish EO-based products and services used as ‘best-practice’ environmental information, and planned into the working processes and financing of international development.

Geographic location of projects

18+ demostration **PROJECTS**

Delivering high impact EO-based information solutions to support targeted international development programmes

WORLD BANK GROUP

Integrated Coastal Zone Management in India

Users:

- World Bank Global Practice on Environment and Natural Resources
- Ministry of Environment and Forests (MOEF), Government of India
- Society for Integrated Coastal Management (SICOM), MOEF, Government of India
- Government of the States of Gujarat, Odisha and West Bengal
- National Centre for Sustainable Coastal Management (NCSCM)

EO services provided

- Sediment Load Mapping
- Shallow-water bathymetry
- Benthic Habitat Mapping

Service Providers

- EOMAP (Germany)
- Brockmann Consult (Germany)

Background

Indian coastal areas are under significant threat from climate change driven phenomena such as rapid sea level rise and ocean warming and acidification. National and regional government organizations are working to counter increased coastal flood risk as well as the loss of key fish species and coastal habitat degradation. Several actions have been initiated since 2010, including enactment of new regulations for management and governance of coastal and marine areas and a national coastal zone management program. As part of the response to these threats, the World Bank is investing hundreds of millions of dollars into the Integrated Coastal Zone Management (ICZM) Project to assist Government of India to implement a comprehensive coastal management framework for the country. This is to build knowledge and institutional capacities for planning and managing coastal environment issues to ensure more effective and sustainable development of the coastal economies in the region.

Among the various issues being addressed by this investment program, there are three areas where the utility of satellite derived information is being assessed. These are:

- improving the understanding of sediment transport dynamics and the interaction with coastal infrastructure development,
- providing a cost effective baseline coastal bathymetric mapping capability,
- monitoring and assessing the status of key coastal habitats.

Sediment Transport Dynamics

In many parts of India, infrastructure developments (eg. ports, breakwaters and shore protection structures, dams on rivers and estuaries) have altered coastal hydrological processes which directly impact sediment availability and movement. This has resulted in significant changes to accretion and erosion of beaches, and curtailed the beach building and sand compensation processes. For coastline conservation, and more specifically to conserve the beaches, it is essential to understand the balance between sediment added to and removed from the coastal systems as well as the main transport dynamics. Determination of this sediment budget is essential to assess the impact of any coastal developmental and protection activity involving construction of breakwaters, jetties and groynes.

The key parameters to estimate are the sediment load from rivers, the movements of sediments around the coastal regions and the resulting distribution levels. Customised processing of satellite imagery can provide estimates of suspended sediment in water bodies such as coastal waters as well as the load from rivers as a result of the modulation of the water transparency by the presence of sediments in the water column. By compiling time series of satellite observations (eg. monthly mean sediment concentrations), the dynamics and evolution of sediment budgets and transportation can be determined over a wide area in a cost effective manner. This also enables better identification of "hot-spot" areas subject to high levels of loading. In addition, when combined with

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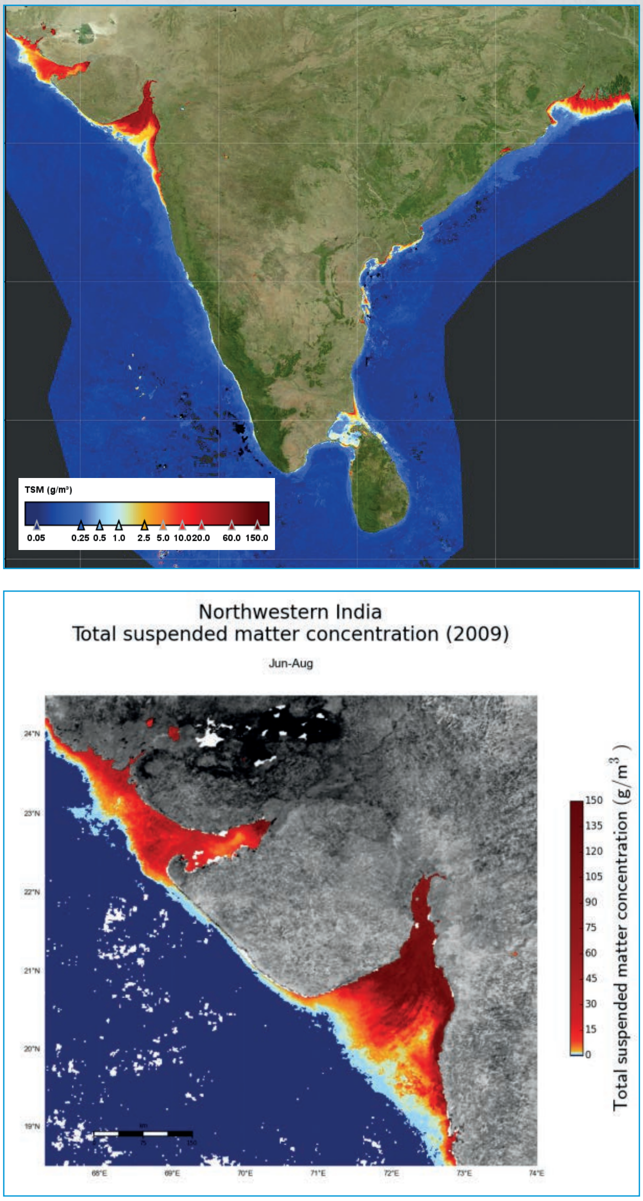

additional data such as current velocities, areas subject to rapid changes can be better delineated.

Shallow-water bathymetry

Reliable bathymetric maps are a prerequisite for coastal planning but are costly to produce using conventional techniques. Nautical charts are available for the entire coast of India but these provide minimum water depth for navigation purposes not actual depth contours at a particular point of the tidal cycle and are therefore of limited value for coastal management and engineering design. In some areas (eg. the immediate vicinity of ports), accurate bathymetry data are available but these cover only limited areas and may not be sufficiently up to date in areas of high sedimentation. Conventional acoustic techniques that are used for mapping bathymetry in deeper waters are more difficult and risky to use in shallow and near shore waters due to the nature of the equipment being deployed and the need to space survey lines more closely together in shallow waters due to the geometry of the measurement process. This leads to a higher unit cost for mapping shallow areas.

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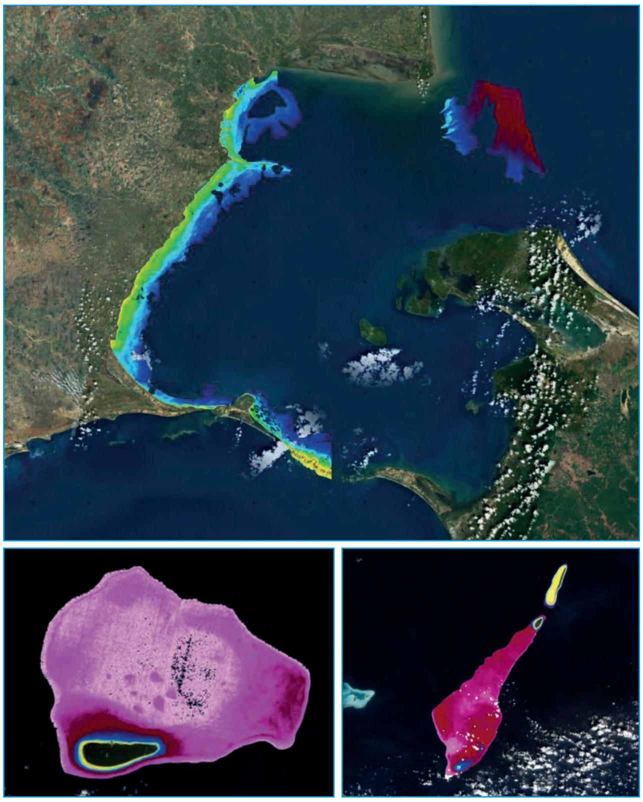

1. Total Suspended Matter distribution 2003-2012. Envisat MERIS data © ESA. Credits: EOMAP & Brockmann Consult for ESA/World Bank.
2. Satellite-derived bathymetry based on Landsat data. Palk Bay (left) and Androth (top) and Kadmat/Amini/Pitti, Lakshadweep Islands (bottom). Landsat data © USGS. Credits: EOMAP & Brockmann Consult for ESA/World Bank.

However, effective coastal mapping is not possible without reliable, up-to-date sea bed maps. Sea bed bathymetry directly impacts on coastal wave and current processes and influences the evolution and functioning of important habitats such as sea grass. Coastal infrastructure such as cables, pipelines, bridges etc. is also highly sensitive to sea bed structure and the design and operational safety of these assets requires accurate knowledge of the bathymetry and any changes. Given the scope for rapid changes to the sea bed in near coastal areas, the operational need is not only for baseline bathymetry but also for regular updates.

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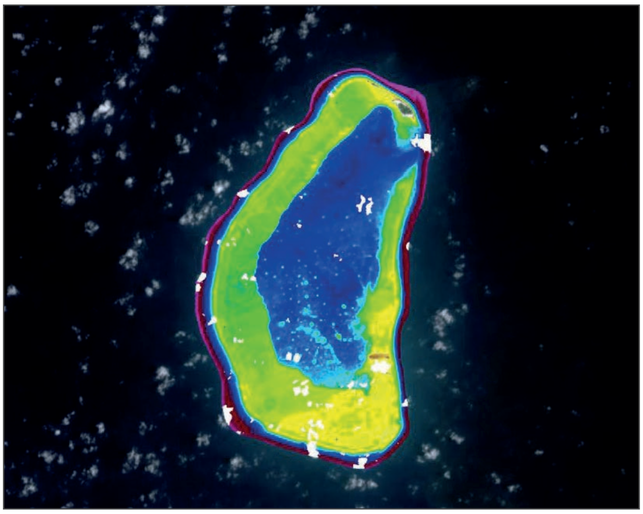

Satellite remote sensing can provide depth measurements in coastal areas up to depths of 30-40m at a much lower cost than conventional mapping techniques. This is based on measuring the modulation of sunlight reflected off the sea bottom by the water column. Map scales of between 1:5000 and 1:50000 can be generated, depending on the spatial resolution of the satellite. While depth accuracy is lower than the level obtained with dedicated ship based surveys, the costs and turn-around times of satellite based techniques are significantly reduced and the attainable accuracy is sufficient for many of the planning and monitoring applications requiring depth maps.

Benthic Habitat Mapping

Sea grass forms a dominant benthic cover in intra-tidal and mid-tidal zones of shallow water and sheltered locations such as the seas, gulfs, bays, backwaters and lagoons. Around the Indian coast, it occurs as extensive beds in many parts, especially in Gulf of Mannar, Palk Bay, Lakshadweep group of islands, and Andaman and Nicobar Islands. Seagrass meadows are highly productive, support high biodiversity and are considered as one of the most carbon-rich ecosystems. Unfortunately, seagrass meadows are declining at a rapid rate, with about 5% of seagrass meadows lost annually.

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Preserving and protecting these habitats requires extensive monitoring which is costly and time consuming. Conventional approaches rely on in-situ mapping and sampling which requires divers and is prone to inaccuracy

3. Satellite-derived bathymetry based on Landsat data. Bitra Par Lakshadweep, India. Landsat data © USGS. Credits: EOMAP & Brockmann Consult for ESA/World Bank.

4. Benthic Habitat maps in Palk Bay and benthic type map of Androth (unconsolidated sediment, submerged vegetation, coral reef, other). Landsat data © USGS. Credits: EOMAP & Brockmann Consult for ESA/World Bank.

(eg. due to the use of sketch maps by divers and problems in geolocation). As a result, many sea grass beds have not been mapped for 10 years or more. By using satellite imagery, the extent of sea grass beds can be delineated more efficiently and changes in coverage monitored. This approach still requires in-situ measurements to monitor the status of the sea grass (eg. using genetic data, chemical contamination etc) but the data collection efforts can be reduced and optimised to priority areas where important changes are occurring.

Over the last 10 years, sea grass maps have been compiled only for a few select locations over the Indian coastal zone. By using the current generation of high resolution multispectral satellite imagery (which ensure measurements in all relevant spectral bands), it was possible to provide maps of the extent of the different benthic habitats, primarily sea grass beds and coral reef ecosystems. This enables rapid and cost effective mapping not only of the current status of benthic habitats but also identification of trends using historic imagery.

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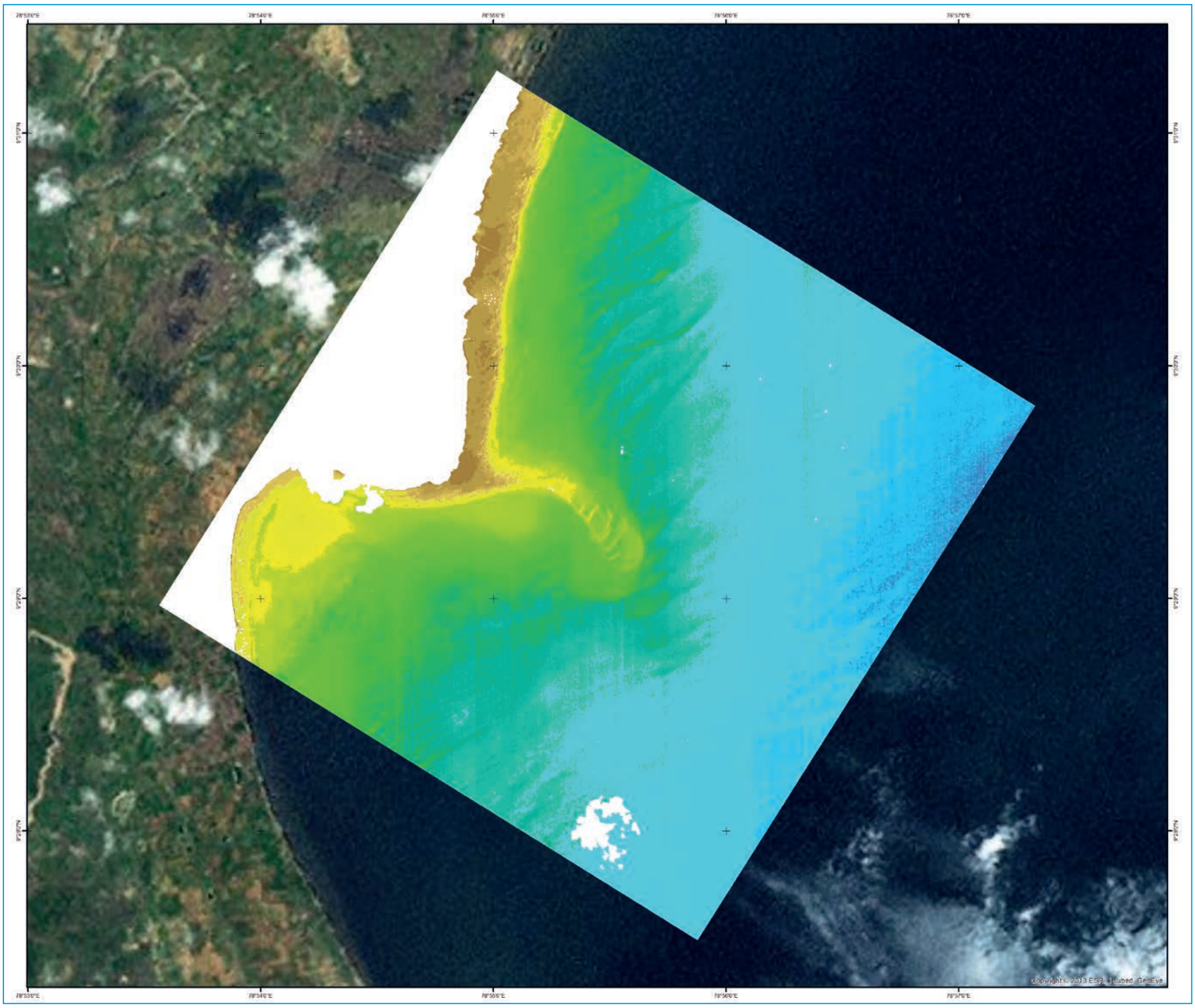

5. Satellite Derived Bathymetry. Palk Bay, India. World View data (c) World view. Credits: EOMAP & Brockmann Consult for ESA/World Bank

Conservation of Coastal Watersheds in Mexico

Users:

- World Bank Global Practice on Environment and Natural Resources
- National Commission for Protected Areas (Comisión Nacional de Áreas Naturales Protegidas, CONANP)
- National Forestry Commission (Comisión Nacional Forestal, CONAFOR)
- National Institute of Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático, INECC)
- Mexican Fund for the Conservation of Nature (Fondo Mexicano para la Conservación de la Naturaleza, FMCN)

EO services provided

- Water quality monitoring
- Land cover/use change maps
- Terrain maps

Service Providers

- Geoville (Austria)
- Brockmann Consult (Germany)

Background

Mexico ranks fourth among the world's 15 mega-biodiverse countries, representing 10–12% of global biodiversity. Mexico's biological wealth supports the health and livelihoods of 112 million people. But these ecosystem goods and services are at risk. Soil erosion affects almost half its territory and many of Mexico's rivers are considered to be highly polluted. In addition, Mexico will be disproportionately affected by climate change with coastal communities highly exposed to flooding and inland communities increasingly affected by drought and landslides. Effectively addressing these issues requires an integrated approach for managing land, water resources and development.

The World Bank is supporting the "Conservation of Coastal Watersheds in the Context of Climate Change" project to promote integrated environmental management to conserve biodiversity, contribute to climate change mitigation, and enhance sustainable land use. The project is a unique partnership of three federal agencies, one private fund in Mexico, and the World Bank. It concentrates on six watersheds along the Gulf of Mexico and ten watersheds along the Gulf of California. One key element is a monitoring activity to support development of Watershed Action Plans to define priority sites. This element is also intended to strengthen local capabilities to characterise changes in land use and associated ecosystem services. This will support sustainable land and water resources management to build resilience and better combat biodiversity loss and land degradation.

ESA project activities involved, among other things, establishing a baseline to further implement soil protection, improving agro-ecosystem practices and rehabilitation of riparian zones, estimating climate change tendencies with the change patterns in the land use, preventing watershed erosion, and modelling of the carbon cycle. Although partners had access to a range of in-situ data sets, these were not comprehensive in their coverage and their heterogeneity constrained the extent to which a fully integrated watershed level approach could be put in place. By using satellite information, it was intended to address these constraints and implement cost effective and consistent integrated monitoring. Two main information sets were considered – river and coastal water quality and land cover change.

Water quality monitoring

EO data were used for quantification of suspended sediment in rivers and water bodies in the costal watersheds as well as coastal areas. EO-based Water Quality assessment including monthly averaged products and maps of water constituents have been generated for the Gulf of Mexico coast and provided in 300m and 1200m resolution for the years 2002 – 2013 (Figure 1).

The data products include:

- chlorophyll concentration
- total suspended matter concentration
- visible depth
- dissolved organic matter absorption.

Coastal Zone Management

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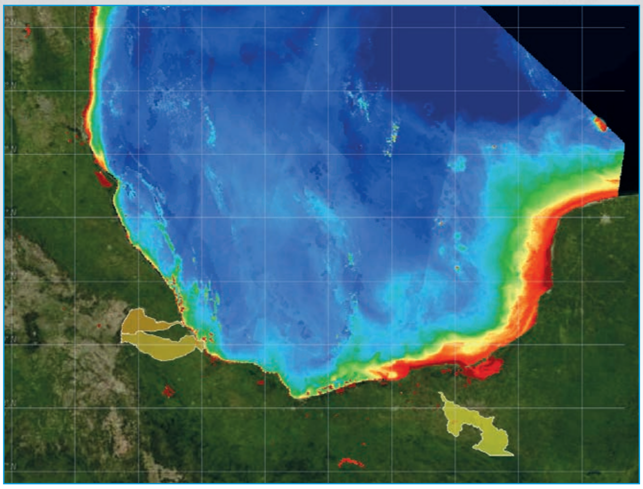

Historic EO-based water quality assessment services relied on data from the ESA MERIS instrument to generate a set of 300m resolution products up to 20 times per year. With the launch of ESA's Sentinel-3 mission in 2016, improvements to this type of measurement are ensured until beyond 2030. In particular, the OLCI Ocean Colour instrument provides measurements in more spectral bands (21 compared to 15 on MERIS) and with an improved update frequency enabling improved characterisation of the sediment flow in river networks and coastal zones.

By integrating data from the ESA Sentinel 2 satellite it was also possible to generate water quality information in estuarine areas with a better spatial resolution, enabling the characterisation of fine scale hydrological and coastal processes. This type of capability was demonstrated during the project using historic data from the RapidEye and Landsat satellites which enabled characterisation of suspended sediment levels with a spatial resolution of 5m but with less frequent updates (3-5 times per year). Figures 2 and 3 showcase turbidity products that were delivered for the Usumacinta watershed.

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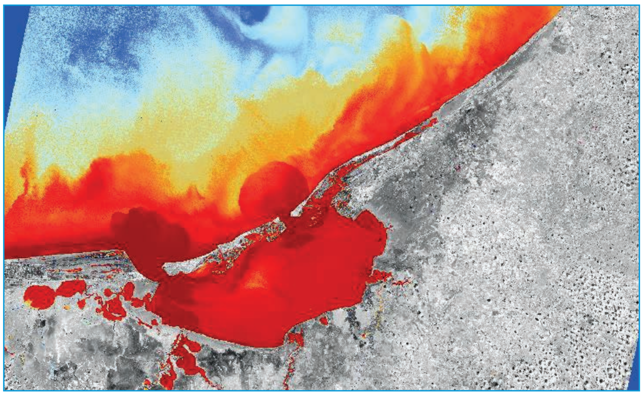

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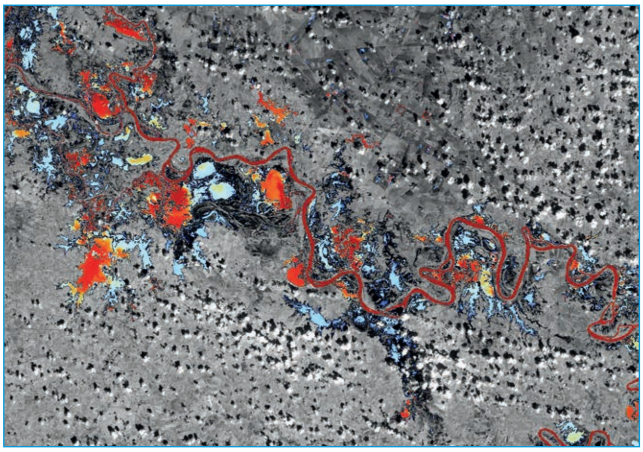

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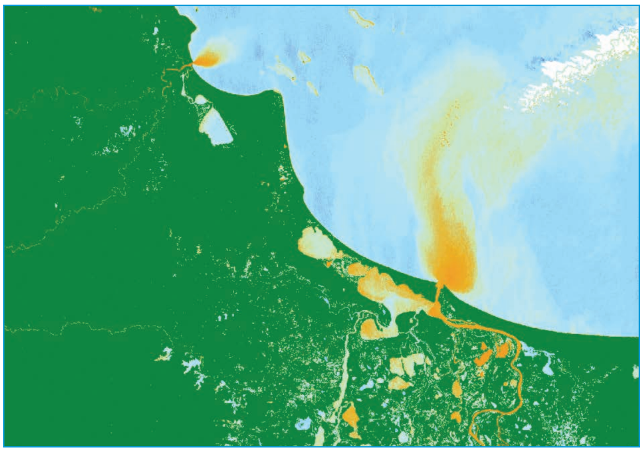

1. Chlorophyll concentration derived from MERIS FR with CoastColour processing for the Mexican Coast, overlaid by the three selected watersheds. Envisat MERIS data © ESA. Credits: Brockmann Consult & Geoville for ESA/World Bank.

2a. The Total Suspended Matter concentration derived Landsat image from 28.01.2014. Landsat data © USGS. Credits: Brockmann Consult & Geoville for ESA/World Bank.

2b. Total Suspended Matter derived from Landsat data, central parts of the Usumacinta Watershed. Landsat data © USGS, RapidEye data © Blackbridge. Credits: Brockmann Consult & Geoville for ESA/World Bank.

3. Brightness/Turbidity of the water showing clearly the river plume in the turbidity values. River plume monitoring can be an indicator for erosion and help design measures for erosion protection. Landsat data © USGS, RapidEye data © Blackbridge. Credits: Brockmann Consult & Geoville for ESA/World Bank.

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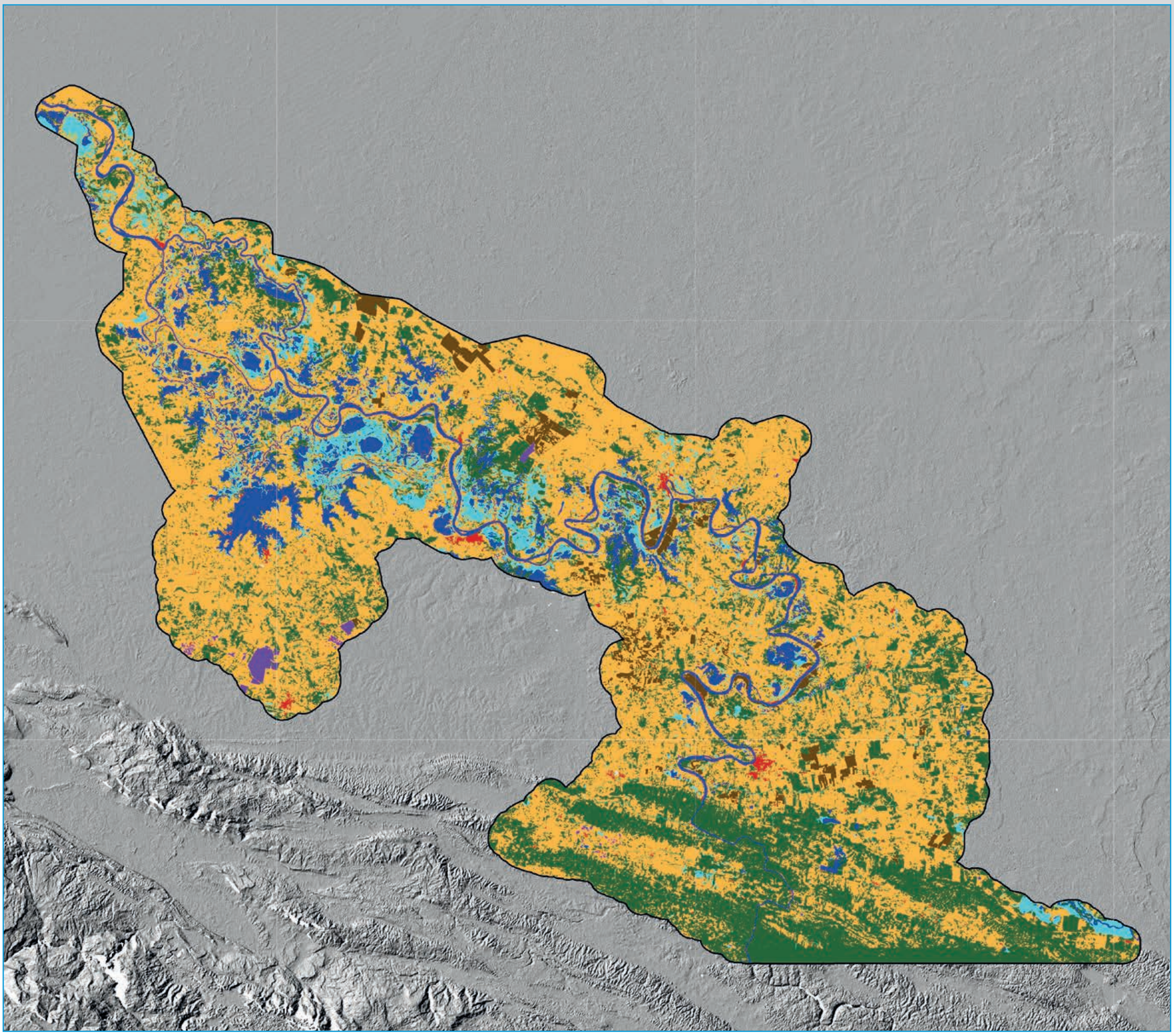

Land cover/use change maps

Land cover and land cover change maps have been provided for three river basins La Antigua, Jamapa, and Usumacinta. In addition, the product suite includes tree cover density and density change maps for all three sites. These products are based on RapidEye and Landsat data, and have been generated for two reference years: status product based on recent imagery from 2014 (and 2013), and historic maps for 2003 using Landsat data from 2003 (and 2002).

Results

The EO derived information products were considered major inputs into the relevant Integrated Water Action

4. Land use in the Usumascita watershed. Landsat data © USGS. Credits: Brockmann Consult & Geoville for ESA/World Bank.

Coastal Zone Management

Plans developed as part of the overall watershed management projects funded by World Bank and GEF. In particular, it enabled analysis of change at local scales within watersheds instead of previous national level approaches. In addition, the more rapid availability of EO derived information, as compared to conventional data collection approaches, enabled the analysis projects to be completed on shorter time scales and more cost effectively.

Looking forward, it is intended to use the information products generated as part of a baseline assessment to elaborate Payment for Ecosystem Services programmes.

In addition, there is a strong interest from the government agencies involved in the project to expand the use of EO derived information products to all watersheds in Mexico. The exact mechanisms are under discussion, in particular with respect to what activities are addressed within ESA follow-on activities and what are addressed by World Bank and GEF financing.

EO products	Applications
Land cover maps	• Baseline for land cover in the project areas of interest (AOI) • Input for carbon cycle models • Input for erosion modelling • Identification of priority sites for additional project activities
Land cover change maps	• Detection of land degradation, especially of the forested areas • Calculation of long term deforestation and land degradation rates the watersheds level
DEM	• Input for the erosion model
River sediment transport	• Indicator for erosion • Baseline data for investigation of the influence of measures concerning soil protection, improved agro-ecosystem practices and rehabilitation on riparian zones • Support to the management of marine natural protected areas
River Water Quality products	• Input for the construction of IWAPs
Coastal Water Quality products at river mouths	• River plume monitoring as indicator for erosion and influence of measures towards erosion protection • Support to the management of marine natural protected areas
Coastal Water Quality products (CHL) along the coast	• Input for the carbon cycle models • Support to the management of marine natural protected areas

Table 1. Overview of planned usage of the different EO products/information

Detection and Characterization of Illegal, Unlicensed and Unreported Fisheries Activities in West Africa

Users:

- World Bank Global Practice on Environment and Natural Resources
- Liberian Bureau of National Fisheries
- Liberia Fisheries Monitoring Center (FMC)
- Direction Protection et Surveillance des Pêches (DPSP) in Senegal
- CSRP / SRFC (Unité de Coordination des Opérations de Surveillance, UCOS), Senegal

EO services provided

"Near Real Time" Vessels Detection based on the SAR data

Service Providers

- KSAT (Norway)
- Fisheries Analytical Capacity Tank (FACT) (United Kingdom)
- ExactEarth (United Kingdom)

Background

Illegal, Unlicensed, Unreported (IUU) fisheries activity is estimated to represent between US$10 and 25 Billion per annum in lost revenue for coastal states, in particular, developing countries with an Exclusive Economic Zone (EEZ). In West Africa, it is estimated that IUU fisheries could account for up to 40% of the total fish catch. However, many countries within the West Africa Region lack the basic tools to control access to marine resources (for example registration of fishing vessels, transparency in the sale of fishing licenses, monitoring catch levels, etc). In particular, countries throughout the region are unable to systematically detect and track fishing vessels entering their EEZ, essentially rendering their marine resources to excessive exploitation. This lack of effective surveillance coupled with the growing global demand for fish as a source of protein to feed growing populations will continue to encourage international fleets to operate in West African waters.

The World Bank has set up the West Africa Regional Fisheries Program to strengthen the capacity of Cape Verde, Liberia, Senegal, and Sierra Leone to govern and manage their fisheries resources, reduce illegal fishing, and increase local value added to fish products. This has resulted in systematic registration of most of the artisanal fishing vessels in these countries as well as putting in place transponder based monitoring of foreign vessels with permits to fish in the waters of these countries.

However, IUU fishing continues and can be difficult to detect when this takes place outside the coverage of coastal surveillance stations. Practices such as at-sea transfer of catch also complicate the effective monitoring of fishing activities. Even vessels with transponders and permits that provide quotas for allowed catch volumes can spoof the transponders and engage in unlicensed activities.

By using satellite based radar imagery together with transponder data from fisheries management systems and the Automatic Identification System (AIS), it is possible to generate a more comprehensive description of vessel movements in the region. The satellite radar imagery can be rapidly processed and integrated with transponder data and license databases to identify vessels illegally operating in the region or to detect suspicious activity such as extended proximity of vessels at sea (usually indicative of an at-sea transfer).

"Near Real Time" Vessels Detection based on SAR

To integrate satellite imagery into fisheries management operations and IUU fisheries detection, it is essential to ensure that the required data fusion can be effectively implemented (which requires rapid access to a range of data sources and databases) and that the information is "actionable" – ie. that the relevant authorities can use the information to apprehend vessels engaged in IUU fishing activities. Furthermore, the system needs to be sufficiently flexible to cope with seasonal movement of fish species (and therefore IUU fishing activity).

A demonstration exercise was set up to cover the EEZs of Senegal and Liberia. Satellite radar imagery were analysed to detect all vessels in the area of interest. This provided an indication of vessel size, heading and location. This information was combined with information from the fisheries information transponders (called the Vessel Monitoring System or VMS) and the Automatic Identification System (AIS) transponders so that all vessels engaging in legal activities could be identified.

The monitoring was performed in two time periods. The first phase was in cooperation with the Liberian Bureau of National Fisheries MCS department, and particularly with the Fisheries Monitoring Center (FMC) and took place in the period from mid-June 2015 to mid-September. The second phase involved cooperation with the Direction Protection et Surveillance des Pêches (DPSP) in Senegal, and was performed in the period from start of September 2015 until the start of November 2015. The required information content included:

- Detection of large non-African fishing vessels
- Vessel tracking information correlation
- Classification and identification of potential IUU vessels
- Analysis confidence measure
- Anomalous behaviour detection
- Compilation of fishing activity statistics
- Identification of IUU hotspot areas
- Analysis of fishing activity levels and geographical distribution

The outputs were an integrated characterization of vessel locations, types and movements to provide indications of IUU fisheries activity. In addition, the imagery enabled the detection of illicit discharges by vessels into the marine environment. The surveillance was based on SAR imagery from Radarsat 2, TerraSAR-X, Cosmo Skymed and, once it became operational, Sentinel 1 (Table 1). The images were analysed by operators at the TEOS centre

Satellite	Senegal DPSP	Liberia FMC
RADARSAT-2	52	52
RISAT-1	43	56
TerraSAR-X	2	5
Sentinel-1	5	4
Total	102	117

in Tromsø within 30-60 minutes of the satellite passing over the area of interest. The output file containing details on detected vessels was then correlated with national VMS data from the countries National Fisheries Monitoring Centres and with AIS data from both conventional coastal AIS stations and also from satellites fitted with special antennae enabling them to detect the AIS transmissions from space. The latter enabled access to AIS data beyond the range of shore based AIS stations to ensure effective coverage of the entire EEZ of the participating countries. The resulting information was also correlated with fishing

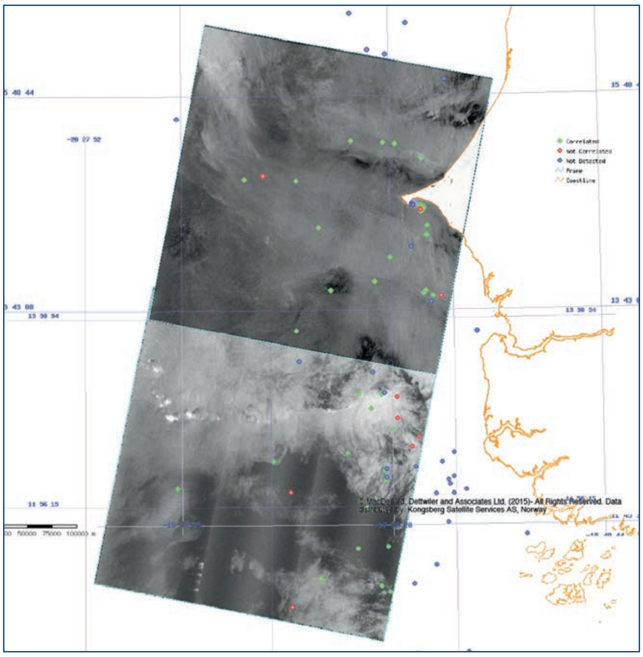

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Table 1. Acquired SAR scenes during the project.

1. Vessel detection based on a Sentinel-1A acquisition on 27 September 2015 at 19:17UTC outside Senegal. Green dots are vessels detected correlated with AIS, red dots are vessels detected not correlated with AIS, while blue dots are AIS where no vessels could be detected. Copernicus Sentinel data 2015. Credits: KSAT, ExactEarth & FACT for ESA/World Bank.Envisat MERIS data © ESA.

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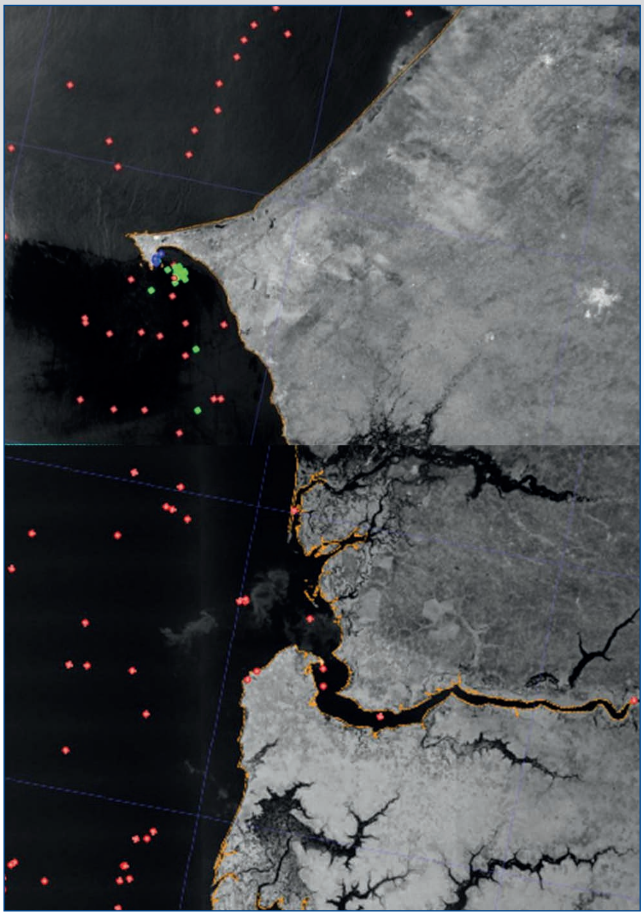

licence information in each national Monitoring Centre and suspicious vessels were identified.

A PDF vessel detection report was produced for each of the acquired SAR scenes. The details for vessels detected in the imagery, the AIS reporting vessels and the correlated vessels were given in the report (Figure 1). A weekly Intelligence Report (INTREP) was also produced by The Fisheries Analytical Capacity Tank (FACT) and provided to the relevant authorities, based on the vessel detections reports and any additionally available VMS or vessel information. In the INTREP an activity analysis for the given area was presented and recommendations for possible follow up were given. FACT was further in constant contact with authorities to provide further operational input and support as requested.

Results

The project represented a unique source of situational awareness information for each National Monitoring Centre. The centres were provided access to the vessel detection reports based on SAR imagery and containing the exact position, estimation of size, heading and speed of each detected vessel.

As a result of these trials a total 510 vessel targets were detected in the SAR images covering the Liberian EEZ: 221 of these could be correlated with a reported AIS track, while 289 could not be correlated to a reported AIS track (some of them indicating possible IUU activity).
In Senegal a total 1942 vessel targets were detected in the images covering the AOI for Senegal: 771 of these could be correlated with a reported AIS track, while 1171 could not be correlated. In addition, FACT aggregated the information with other available sources to generate IUU intelligence reports, providing information on IUU fishing hotspots and general statistics.

These results strengthened the capabilities of each country to conduct their law enforcement activities more effectively. The project demonstrated that the SAR-based vessel identification can significantly enhance the conventional monitoring systems and provide more transparent situation awareness to enable law enforcement activities. Moreover, in course of the project implementation, a number of workshops and meetings with the local stakeholders have been organized. In Senegal the National Fisheries Control and Protection agency (DPSP), the Maritime Security Agency (HASSMAR) and the Senegalese Navy have been trained on the system functions and use. The Senegalese authorities together with technical experts from the project analyzed SAR, AIS and VMS data against known fishing areas, in order to identify possible illegal fishing operators.

Marine Resources Management


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December 28, 2015

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Sachiko Kondo / World Bank

STORY HIGHLIGHTS

- *Liberia's Bureau of National Fisheries, with the help of The World Bank West Africa Regional Fisheries Program (WARFP), provided evidence of foreign vessels illegally fishing in West African waters in 2011 and 2012.*

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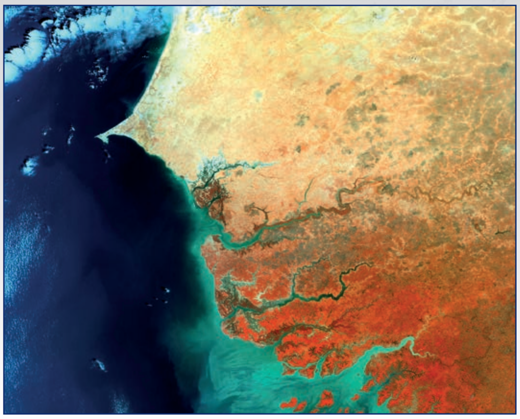

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2. The screenshot of the World bank Featured Story on combatting illegal and unreported fishing in West Africa and the progress of WARFP (West Africa Regional Fisheries Program) available at http://www.worldbank.org/en/news/feature/2015/12/28/european-commission-gets-tough-with-eu-flagged-trawlers-with-a-little-help-from-liberia
The images show fishing community at Liberia's Robertsport fish landing site being developed under the WARFP program.
Image © Anna Burzykowska/World Bank

Support to the Pacific Regional Oceanscape Investment Program

Users:

- World Bank Global Practice on Environment and Natural Resources
- Fisheries Department of the Tuvalu Ministry of Natural Resources
- Environment Department of the Ministry of Foreign Affairs, and the Funafuti Kaupule (Local Council)
- SOPAC Division of the Secretariat of the Pacific Community (SPC) in Suva, Fiji.

EO services provided

- Land cover change mapping
- Monitoring and mapping of the oceanographic conditions (water transparency, concentration of suspended materials, sea surface temperature wind and waves)
- Macro algae extent and coral status mapping

Service Providers

- CLS (France)
- IRD (France)

Background

Tuvalu is one of the four countries included in Phase 1 of the World Bank Pacific Regional Oceanscape Investment Program (PROP). Its aim is to improve the sustainable management and use of both oceanic and inshore fishery resources, and to support the conservation of coastal and oceanic waters. Despite its small size, the country is home to important marine ecosystems currently under pressure due to the growing population, leading to problems of waste disposal, coastal zone degradation, soil sealing and land degaradation, which are reducing the pollution attenuation capacity of the natural environment. In particular, outflows from the large number of domestic septic tanks (there is no centralized sewage system) have polluted the groundwater lens, rendering it unfit for domestic use. At the same time, the islands are exposed to climate change driven pressures such as rising sea levels and increased sea temperatures and acidity levels threatening sensitive marine ecosystems.

Over the last decade, the coral reefs in Tuvalu have been subject to increased levels of overgrowth by macroalgae. This impacts significantly on the coral ecosystems, in particular altering the trophic balance of the lagoon and coastal zone causing a prevalence of algae-eating fish over the preferred carnivorous fish and increasing the levels of toxins generated by microalgae within the food chain. The reduced level of fishing encourages increased levels of pig farming in the islands, generating higher volumes of waste.

To tackle the issue of macroalgae proliferation, it is essential to build a detailed understanding of the processes driving the algal growth. Two main drivers were identified – nutrients from groundwater leaching into the Funafuti lagoon and processes linked to sea temperature rise. However, the level of environmental monitoring, in particular access to historic measurements of marine conditions, are extremely limited. As a result, it was decided to test the utility of satellite derived information for understanding the dynamics of the habitat evolution. Two main classes of analysis were conducted:

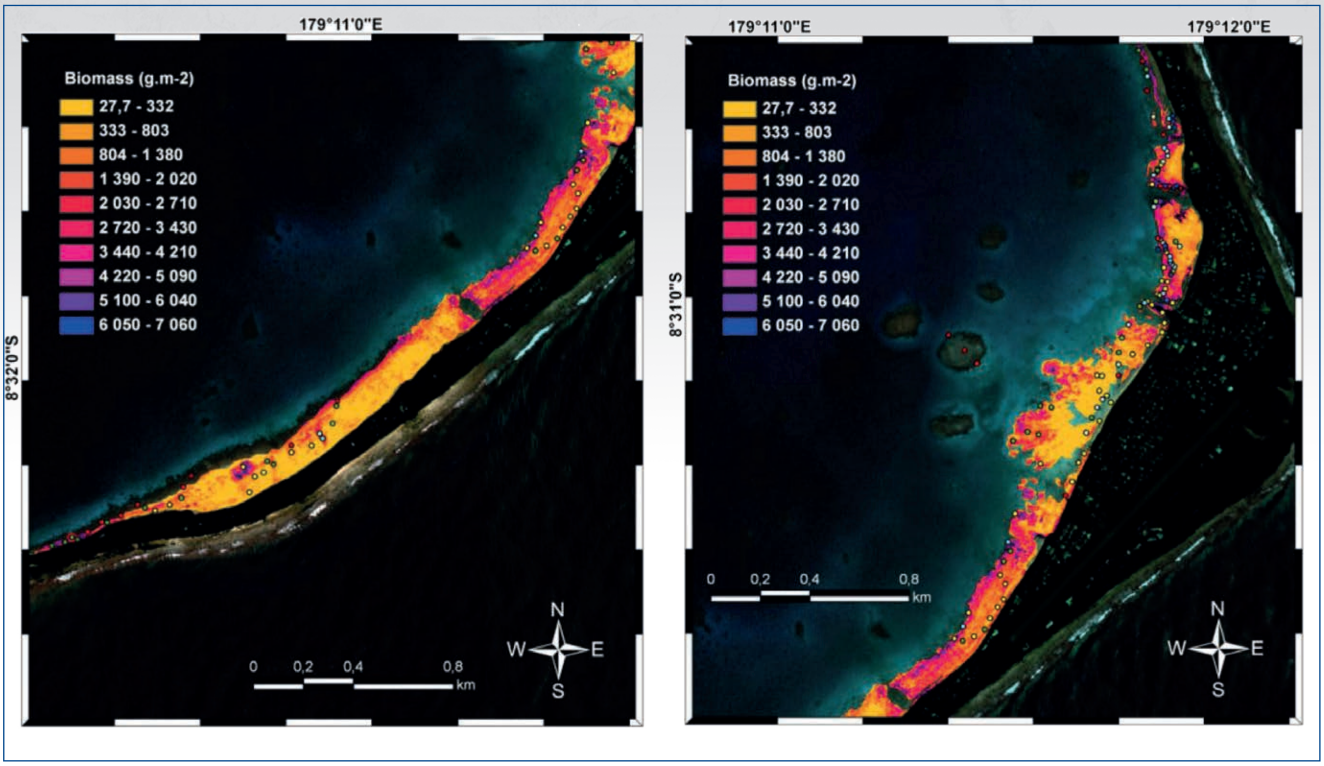
1) analysis of the changes on the island and lagoon, including the growth of macro-algae and the change in the status and health of the coral reefs
2) analysis of the changes in ocean conditions and their correlation with macro-algae growth.

Very high resolution mapping of the Funafuti lagoon

Detailed analysis of the coastal area around Tuvalu, in particular the Funafuti lagoon was conducted to investigate the following issues:

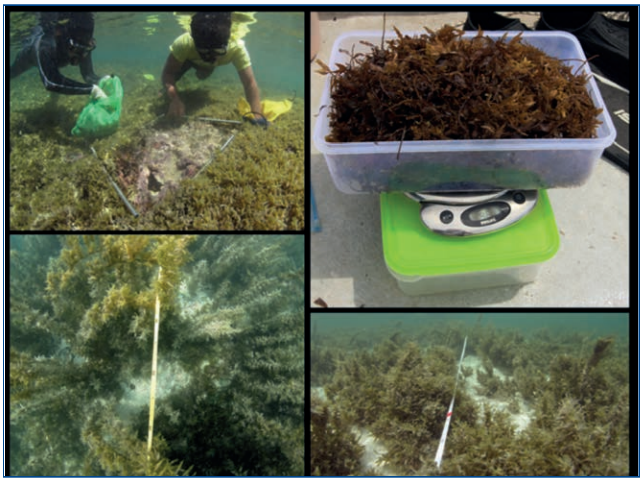
- the status of bloom of the Sargassum polycystum around Funafuti using a combined in situ and remote sensing approach
- the distribution and biomass variation of the macro-algae over 2014 and 2015
- the historic development of macro-algae growth in the past decade using a time-series of images
- seasonal variations in the macro-algae biomass (in order to correlate these with changing land use practices)
- variations in land occupation and land use on the islet of Fongafale

Marine Resources Management



1

Figure 1 shows the map of Sargassum biomass computed for the Fongafale area using a 2014 Pleiades image. The exact origin of the macroalgae remains to be investigated. One hypothesis is that specimen of Sargassum have been brought by ballast water from fishing or other vessels that stopped at Funafuti. The second hypothesis is that the algae was present in the atoll in remnant conditions, but recent environmental changes (nutrification, lack of competitors, etc.) have promoted the bloom. More in situ information had to be collected to analyse any eventual relationship between potential drivers (such as reported pig farms settlement) from 2010 and increasing nutrients discharge in the lagoon.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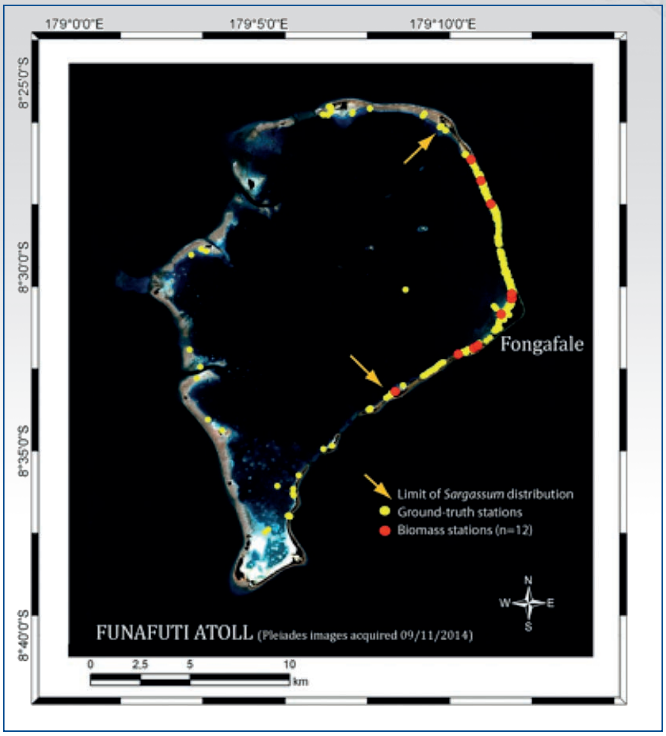
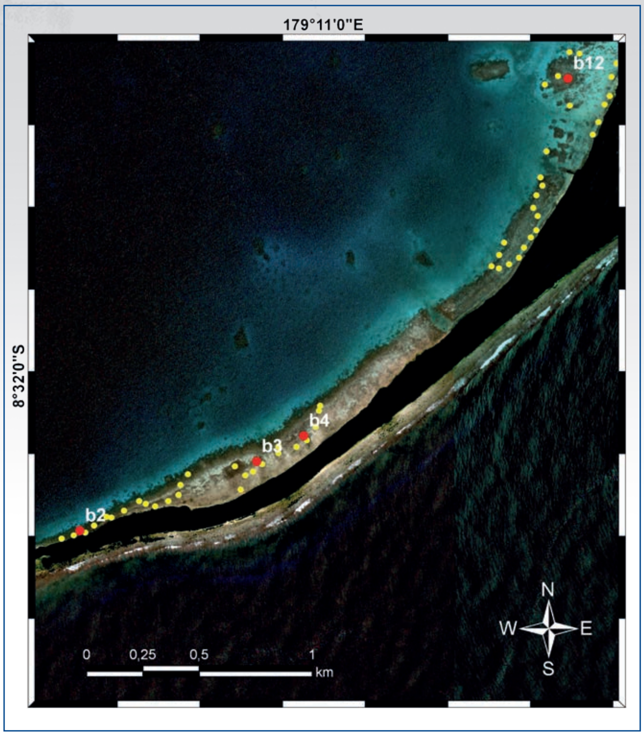
1. Map of Sargassum biomass computed for the Fongafale area using the 2014 Pleiades image. Map displaying the location of ground-truth data classified according to height, cover and presence/absence of Sargassum. Red dots indicate no Sargassum, cold color (blue-green) indicate high biomass (due to either high size or dense cover or both while warm colors (yellow, orange) indicate low biomass (due to either small size or low cover or both). Pleiades data © Airbus. Credits: CLS & IRD for ESA/World Bank.
2. Ground-truthing in Tuvalu, November 2014. Credits: IRD for ESA/World Bank.

3





Monitoring and mapping of the oceanographic conditions

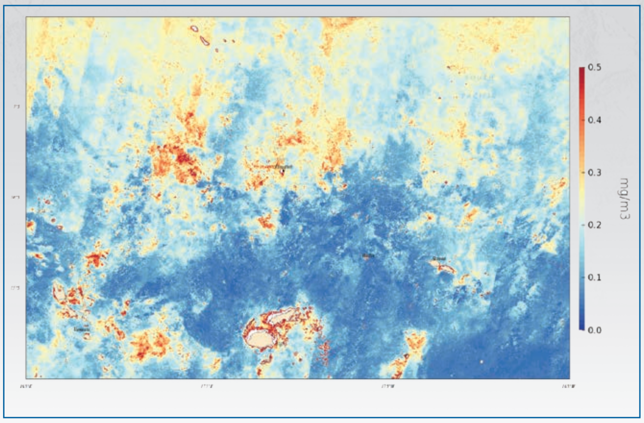
The second objective of the project was mapping and monitoring of the oceanographic conditions around the Funafuti lagoon as well as the lagoon conditions in order to investigate any potential link between deteriorating environmental conditions and climatic impacts. Satellite derived information provided a unique picture of Funafuti landscape at several thousand kilometres, in order to identify any possible influence of climatic conditions on local processes happening in the lagoon.

A range of oceanographic information products were generated including water transparency, chlorophyll-a concentration, CDOM (Coloured Dissolved Organic Matter), TSM (Total Suspended Matter) and sea surface temperature at spatial resolutions of 300m – 1000m. The information was generated as monthly and seasonal averages over period 2006 – 2011.

High concentrations of Chl-a (Chlorophyll-a), CDOM (Coloured Dissolved Organic Matter) and TSM (Total Suspended Matter) are mainly found near the coasts of the main islands (Fiji, Vanuatu, Samoa) including also atolls like Funafuti. Far from the coast they are varying seasonally and reach their lowest concentrations during dry season. The maps of Chlorophyll-a concentration in Figure 4 illustrate these trends. The map of TSM presents the same seasonal pattern with higher values far from the islands during wet seasons (Figure 5). It was also possible to detect yellow substance variations occurring in the areas surrounding the lagoon that could reflect nutriment increase from effluent discharge (Figure 5d).

3. Map showing the location of our presence/absence and semi-quantitative visual observations throughout the atoll. The orange arrow points to the last sightings of Sargassum when going north or south from the village. At both north and south limits, Sargassum were rare, and of the short morphotype. The observations on the east side seem almost continuous. Thus, a zoom is provided to show an example of actual density of observations, in the south of Fongafale (with 4 biomass stations). Pleiades data © Airbus. Credits: CLS & IRD for ESA/World Bank.

4a



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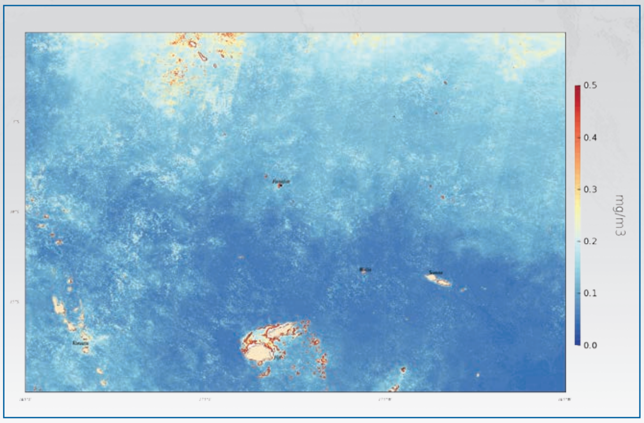

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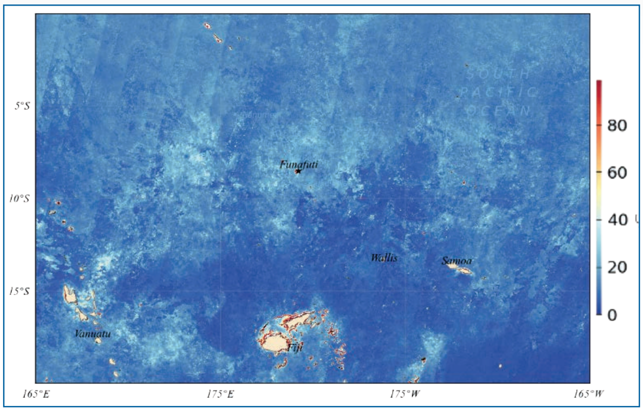

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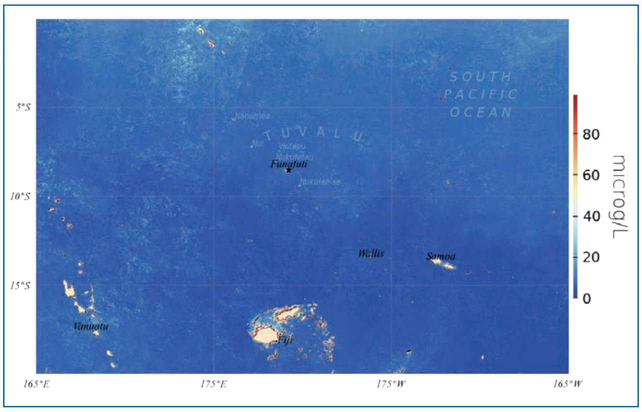

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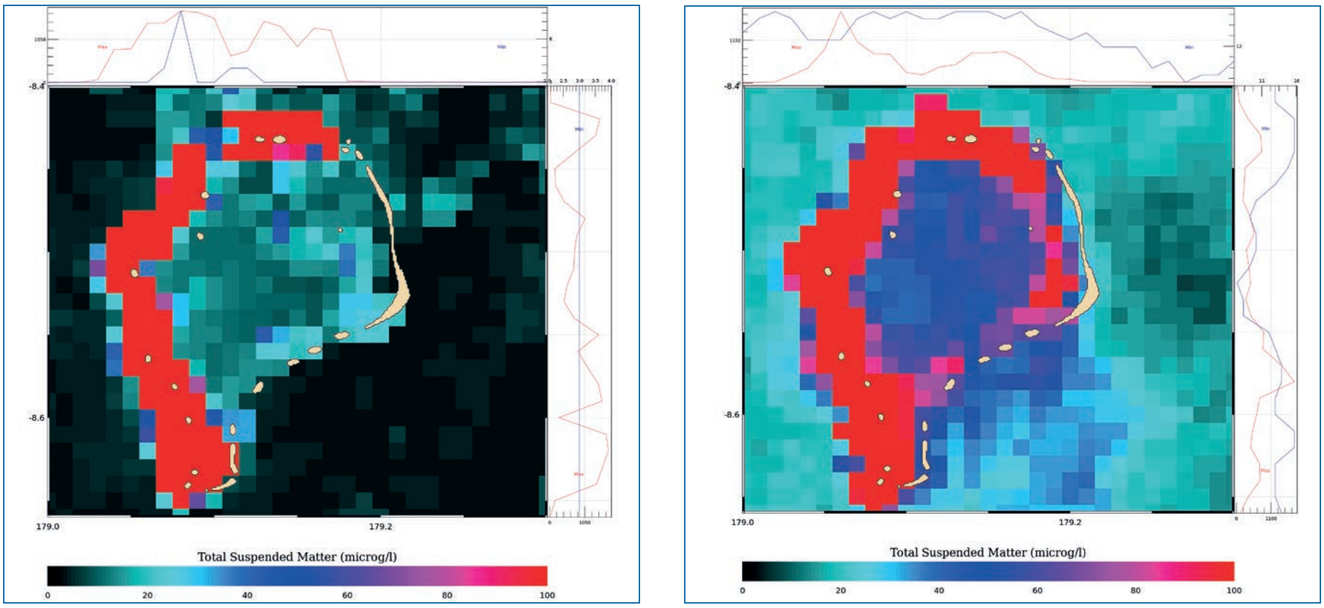
January 2007

January 2001



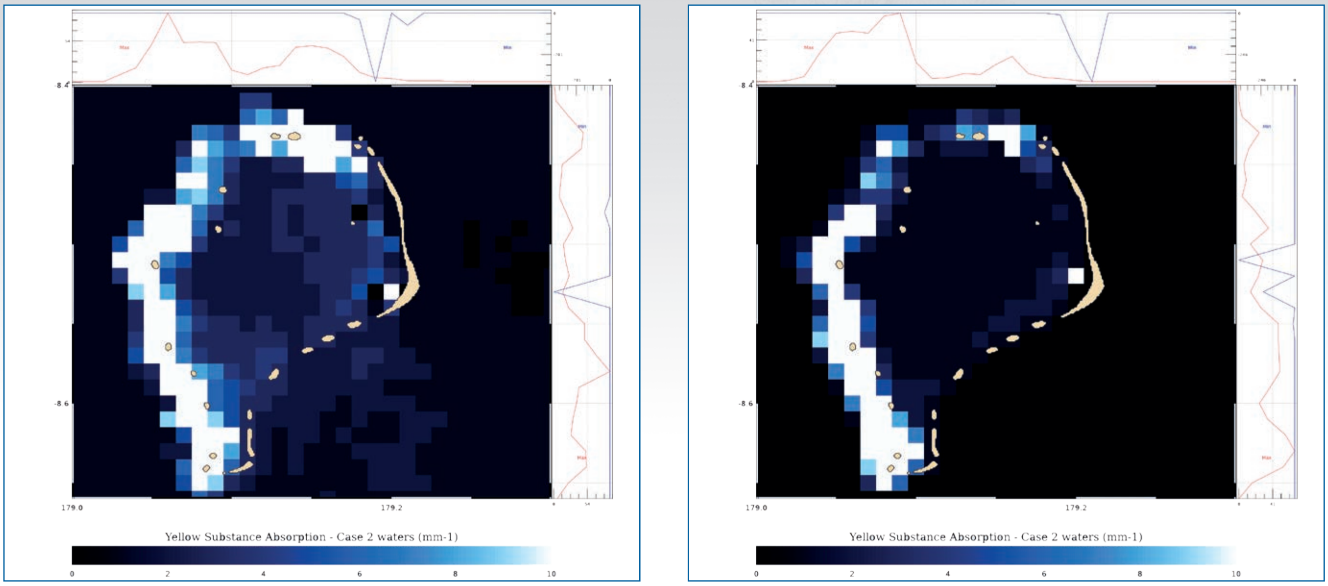
4ab. Maps of Chlorophyll-a concentration during January 2011 (a) and July 2011 (b). In January some isolated patches of Chlorophyll-a are visible far from the islands, in contrast with July. Envisat MERIS data © ESA. Credits: CLS for ESA/World Bank.

5ab. Maps of total suspended matter (TSM) during January 2011 (a) and July 2011 (b). Envisat MERIS data © ESA. Credits: CLS for ESA/World Bank.

5c. Example of TSM inter-annual variability within the Lagoon environment, in January 2007 (left) and in January 2011 (right). Envisat MERIS data © ESA, Terra MODIS data © NOAA. Credits: CLS for ESA/World Bank.

5d

January 2011 July 2011



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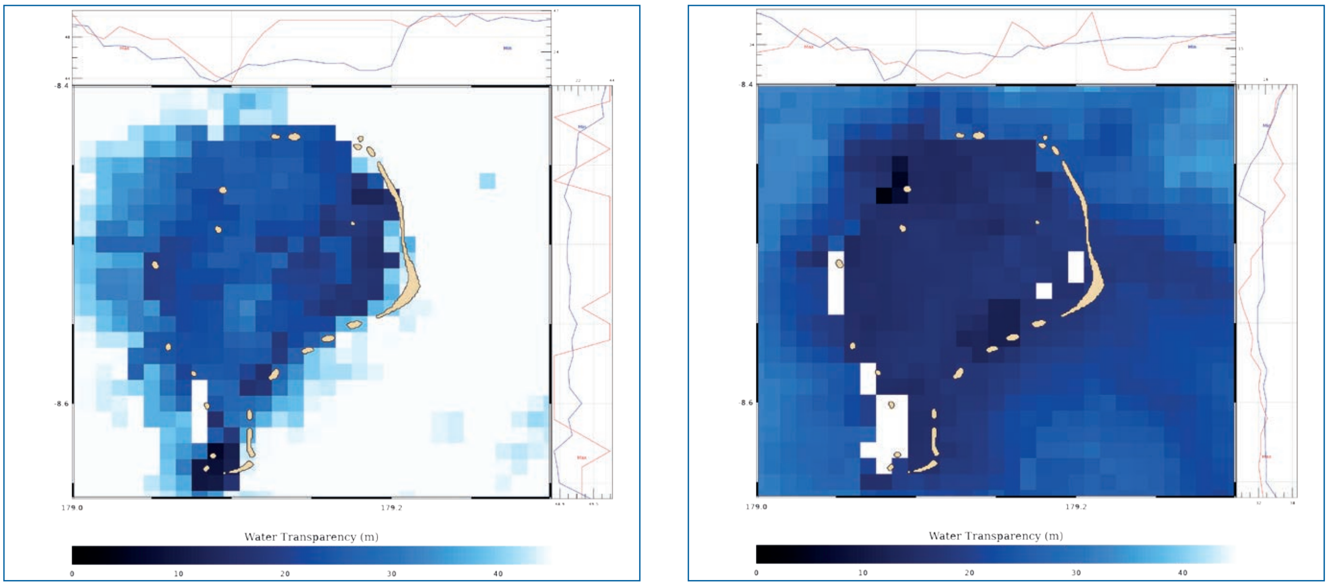
April 2008 September 2008

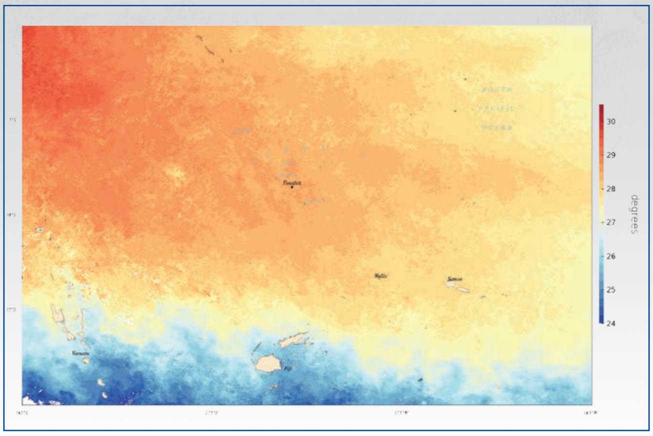


5d. Yellow substances in January 2011 (left) and July 2011 (right). Envisat MERIS data © ESA, Terra MODIS data © NOAA. Credits: CLS for ESA/World Bank.

6. Example of seasonal variability in water transparency outside the lagoon in April 2008 (left) and September 2008 (right). Envisat MERIS data © ESA, Terra MODIS data © NOAA. Credits: CLS for ESA/World Bank.

7. Sea surface temperature (seasonal average and maximum/minimum value) Resolution: 1 km, monthly and seasonal at the Funafuti Lagoon and surrounding coastal areas. Period: 2007-2012. Envisat MERIS data © ESA. Credits: CLS & IRD for ESA/World Bank.

7



Finally, water transparency also exhibits strong spatial patterns in relation to the presence of islands, large lagoons and seasons i.e. water is less transparent in the lagoon than outside the lagoon (Figure 6).

It was possible to conclude that the oceanographic conditions in Tuvalu are influenced by climate, in particular by the differences between the dry and wet season and drought episodes which occur primarily during La Niña years. However, the correlation between oceanographic conditions and macro-algae growth periods was not established.

Results

The satellite derived information provided a unique dataset to support the monitoring of particular phenomena occurring in the Tuvalu area and the surrounding oceanographic conditions. The availability of consistent time series of measurements enabled a characterization of the dynamics of macro-algae growth and an initial analysis of correlations between periods of rapid expansion and other changes in the region.

As a direct result of the satellite observations, it appears possible to conclude that climatic conditions are not linked to periods of increased macro-algae growth. This means that nutrient discharge is a more likely cause and this is taken into account in future investments in the region.

Moving forwards, additional support for improved environmental management of Funafuti lagoon is currently being sought from the Global Environment Facility, and will be channelled through the PROP. The EO information has provided essential information relevant to GEF-supported activities. The maps produced in the framework of this project can be now used to:

- select areas for future biomass monitoring across a range of algal density,
- visualize the spatial variation of algal biomass in 2014 and 2015, and compute biomass differences,
- compute biomass for selected areas, or compute evolution of biomass for selected areas,
- target areas for Sargassum harvesting in the highest biomass areas,
- prioritize areas for cleaning and removing human made substrate suitable for algae,
- select experimental sites (eg. for algae growth, reproduction, resistance to wave energy; removal and regrowth studies; caging studies for herbivory or competitor controls; sediment trapping; nursery effects; etc.),
- conduct spatial analysis related to topic relevant for the ecology of the coral reef in adjacent to the Fongalele village.

In addition, there is considerable interest in the increased use of satellite data, combined with the knowledge of oceanographic and meteorological conditions, to detect and forecast Sargassum invasion. A pilot monitoring system using the MCI (Maximum Chlorophyll Index, the equivalent of the vegetation index on land) started in mid-2014 in French Antilles, which suggests that there will be an increasing demand on satellite information dedicated to Sargassum observation. The availability of improved ocean colour sensors, such as Sentinel-3, capable of making observations in additional spectral bands could also enable detection of Sargassum drifting beds between the Fiji, Wallis, and Tuvalu areas.

Comprehensive Climate Risk Mitigation in Sri Lanka

Users:

- World Bank Global Practice on Social, Urban, Rural and Resilience
- Global Facility for Disaster Risk and Recovery (GFDRR)
- Ministry of Disaster Management (Disaster Management Centre of Sri Lanka)
- Ministry of Irrigation and Water Resources Management
- Survey Department of Sri Lanka

EO services provided

- Historical flood mapping
- Land use/land cover change
- Digital Elevation Model
- Customized software tools

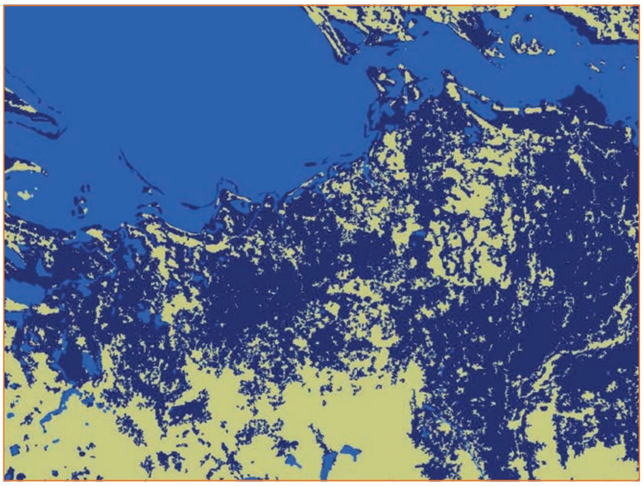
Service Providers

- Nazka mapps (Belgium)
- Remote Sensing Solutions (Germany)

Background

In response to the aftermath of the devastating 2004 Tsunami, the government of Sri Lanka has taken significant steps to strengthen the country's disaster risk management, to allow decision makers to make informed investments through technology solutions, and bring in necessary knowledge and expertise from different fields to develop comprehensive solutions to disaster risk management.

1



In 2014, the Sri Lankan Ministry of Disaster Management together with the World Bank launched a Comprehensive Climate Risk Mitigation program to strengthen the country's physical and fiscal resilience to hydro-meteorological disasters. As one of the first activities the Ministry of Irrigation and Water Resources Management (MI&WRM) carried out a comprehensive study in nine selected basins with an aim to conduct flood and drought hazard modelling, risk assessment and to plan for mitigation interventions, to develop capacity building and effective risk communication tools.

Historical flood mapping

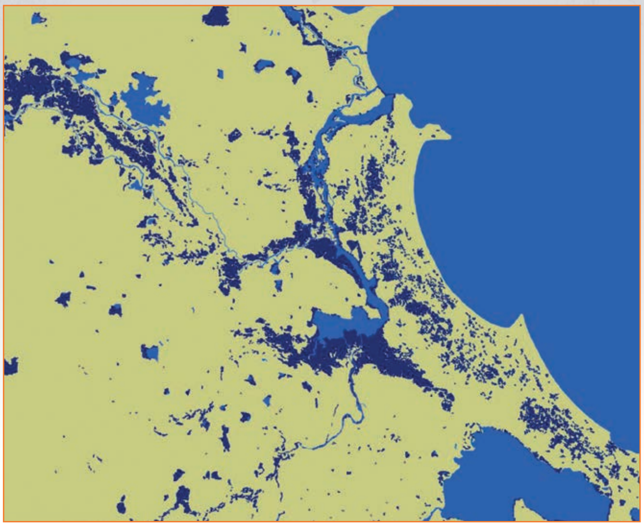
The calibration and validation of flood risk models requires information on past flood extents and such historical analysis contributes to hazard mapping. However the conventional means, which are typically used to record hydrological parameters of floods based on field surveys, often fail to record accurately their spatial extent over the entire basins. Using archive data from Earth Observation satellites allows to map the extent of past flood events and help provide a range of information services such as:

- flood inventory maps,
- flood duration per area,
- flood maximum extent,
- multiple flooding maps,
- maximum historical flood extent,
- flooding frequency per area,
- inundation depth,
- flood extent line,
- dike failure simulation,
- maps of estimates of return periods, and
- flood simulation products.

1. Example of the maximum flood extent map in Northern Sri Lanka in November/December 2008. Data source Envisat ASAR data © ESA, RADARSAT-2 data © CSA, SPOT 2 and SPOT 4 data © CNES, Distribution Astrium Services/ SPOT Image, Landsat data © USGS. Credits: nazka mapps & RSS for ESA/ World Bank.

Disaster Risk Management

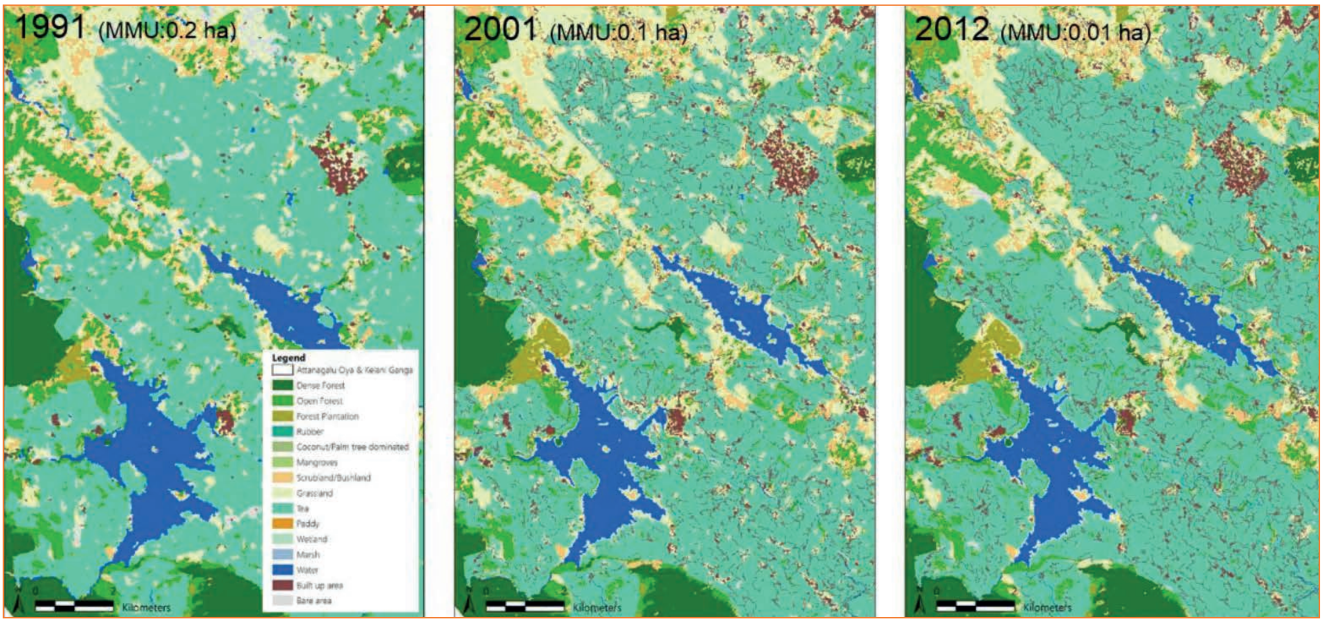
2



In the case of Sri Lanka the historical flood mapping was completed for four past flood events (May 2010, December 2007, November/December 2008 and May 2003) based on a time series of EO SAR data and optical data. Satellite based observations allowed to characterize the temporal signature of the flood events and to estimate their maximum extent; a total of 15 flood extent maps and 4 maximum flood maps were delivered (Figure 1).

In addition to mapping of historical flood extents, the project developed a demonstration of a rapid damage assessment service in response to the major flooding event caused by torrential rains in December 2014 affecting over a million people in the region. The International Charter Space and Major Disasters had been triggered by the United Nations on 29 December 2014 on behalf of the World Food Program. The Rapid Flood Mapping delivered under this project covered the Eastern districts of Ampara & Batticaloa as well as parts of Moneragala and Polonnaruwa. Two Sentinel 1 images were used to determine the flood extent on 24th of November & 18th of December 2014 while the emergency was developing and few days before the Charter was triggered. The demonstration was combined with products from the activation of the International Charter in order to provide a detailed geospatial analysis of the event (Figure 2).

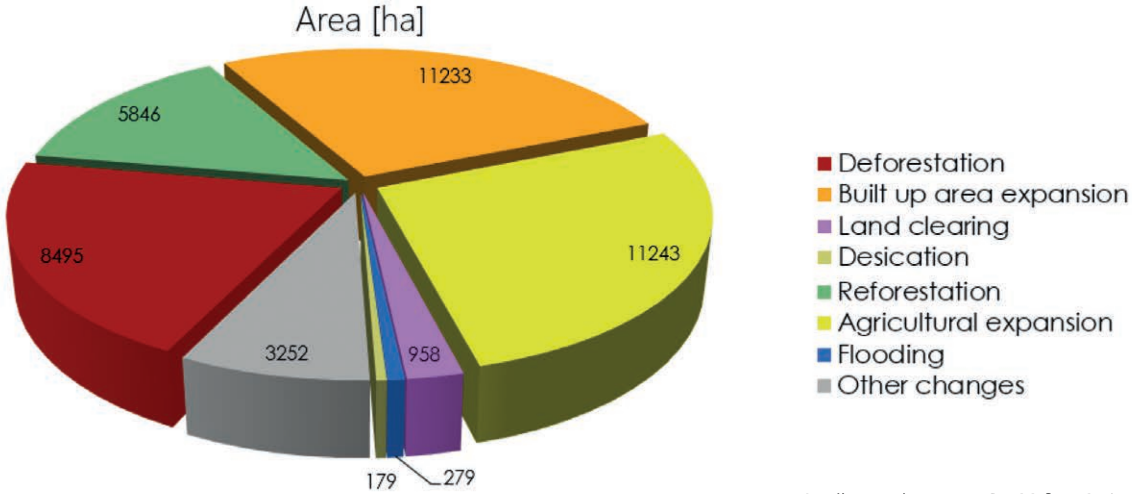
3



2. Maximum flood extent of the rapid flood map (December 2014). Sentinel-1 data © ESA, Landsat-7 data © NASA/USGS. Credits: UNITAR/UNOSAT, International Charter, enhanced by nazka mapps for ESA/World Bank.

3 . A subset example of the land cover/land use change maps for 1991, 2001 and 2012 for Kelani Ganga and Attanagalu Oya river catchments. SPOT data © CNES, Distribution Astrium Services/ SPOT Image, RapidEye data © BlackBridge. Credits: nazka mapps & RSS for ESA/World Bank.

LULC Change Statistics 1991-2012



Credits: nazka mapps & RSS for ESA/World Bank.

Land use/land cover change

What underpins many of the mapping services provided in disaster management and humanitarian aid projects is basic land use mapping. Data from satellite EO provide standardized geographical reference dataset that can be applied for flood risk mitigation, including identification of land use pressures that lead to increased risk associated to flood hazard or high-value areas (agriculture, infrastructure) that require priority mitigation/recovery measures.

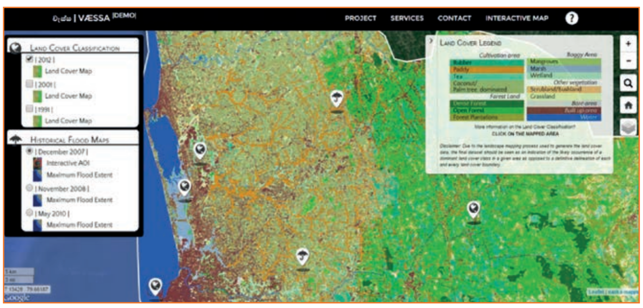
In this project three full-coverage land cover / land use maps were provided for the catchments of Kelani Ganga and Attanagalu Oya for 1991, 2001 and 2012 (Figure 3). Change analysis was correlated with historical flood information and provided information on risk drivers (i.e. unregulated urban sprawl or deforestation can cause frequent occurrence of floods). The study found, for example, 788 hectares of newly developed build-up areas were flooded in 2010 however the biggest land cover type affected was agriculture (64%).

Digital Elevation Model

The precise (Very High Resolution) Digital Elevation Model based on a photogrammetric processing chain of Remote Sensing Solutions GmbH using Pleiades imagery additionally provided height information as an input for flood modelling, quantifying water depths and estimating flood risk. The DEM was validated by the use of 160 survey points provided by the Sri Lankan Survey Department (Figure 4).

Customized software tools

The developed 3D software tool (https://vimeo.com/129772512) contains all geo-information available in order to better visualize flood model results and the areas under high risk of flooding during various flood scenarios, giving decision makers the possibility not only to experience products in 3D, but also to better use results for improved risk management. Moreover, an interactive map (http://www.vaessa.nazka.be/vaessamap.html) allowed to visualise and study the project results via a open web-GIS interface. A story map (http://bit.ly/1BtGY5H) is also available to disseminate the results.



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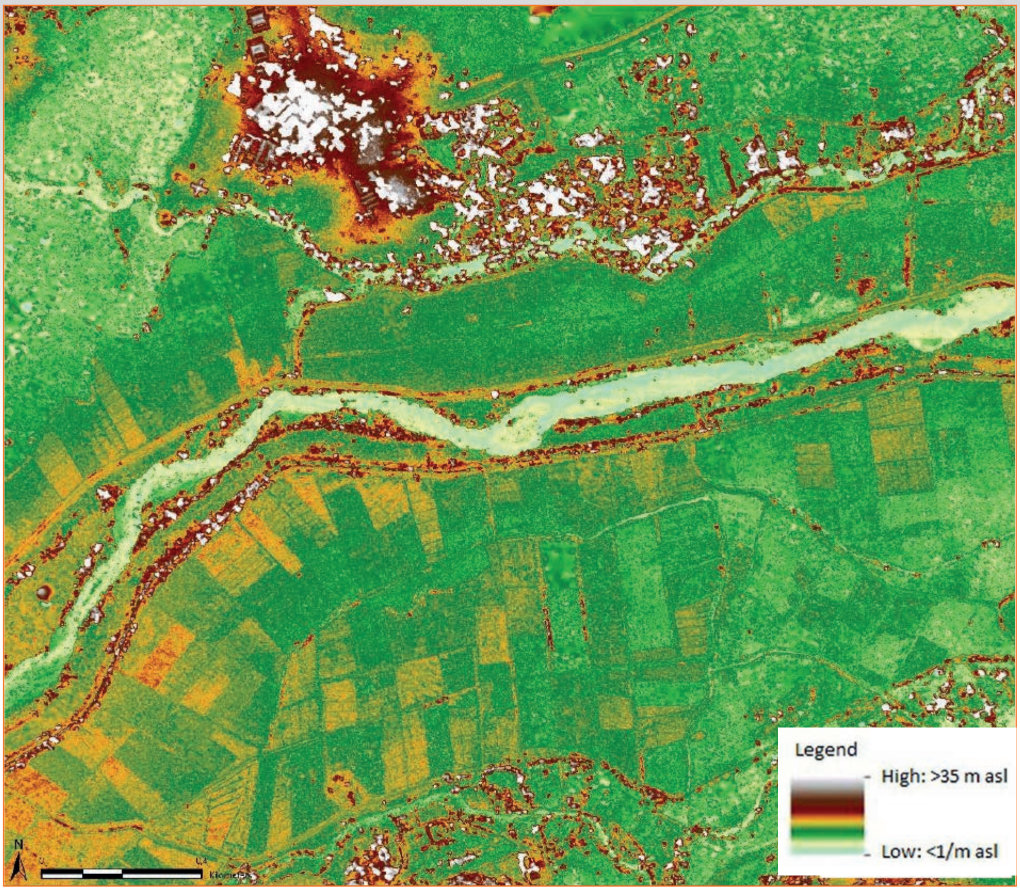

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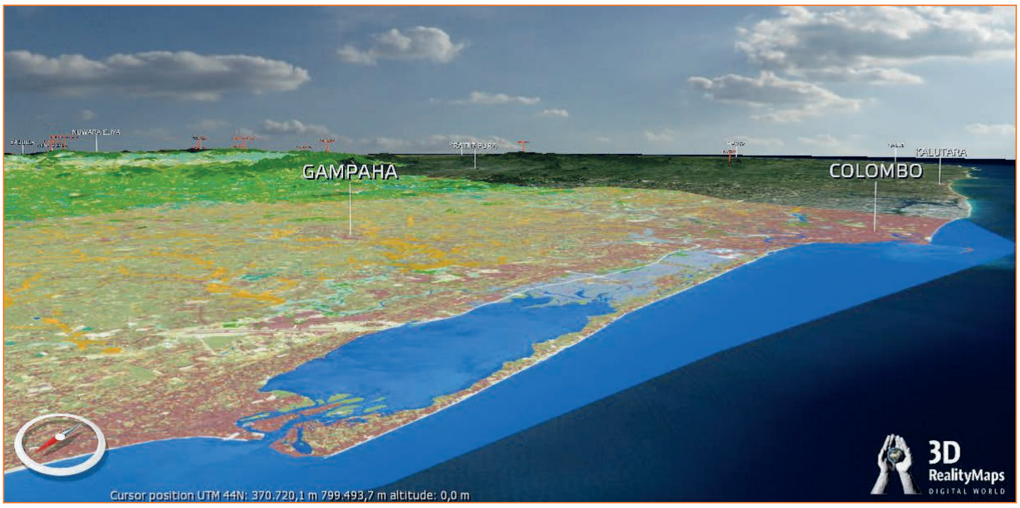


4. Precise DEM based on multitemporal tri-stereo Pleiades acquisition of VHR imagery for a selected area in Eastern Sri Lanka. The use of VHR data (50 cm) allows to distinguish landscape features with great details (riverbed, fields, infrastructure) as an input to flood models. Pleiades data © Astrium Services. Credits: RSS for ESA/World Bank.

5. A screenshot of the interactive map and the 3D tool, both supporting the analysis of land use and past flood maps (2D and 3D). Credits: nazka mapps & RSS for ESA/World Bank.

Risk Information Services for Disaster Risk Management in the Caribbean

Users:

- World Bank Global Practice on Social, Urban, Rural and Resilience
- Ministries of Works and Physical Planning, Physical Development, Public Utilities, ICT and Community Development Natural Resources and Agriculture in Belize, Dominica, Saint Lucia, St Vincent & the Grenadines and Grenada

EO services provided

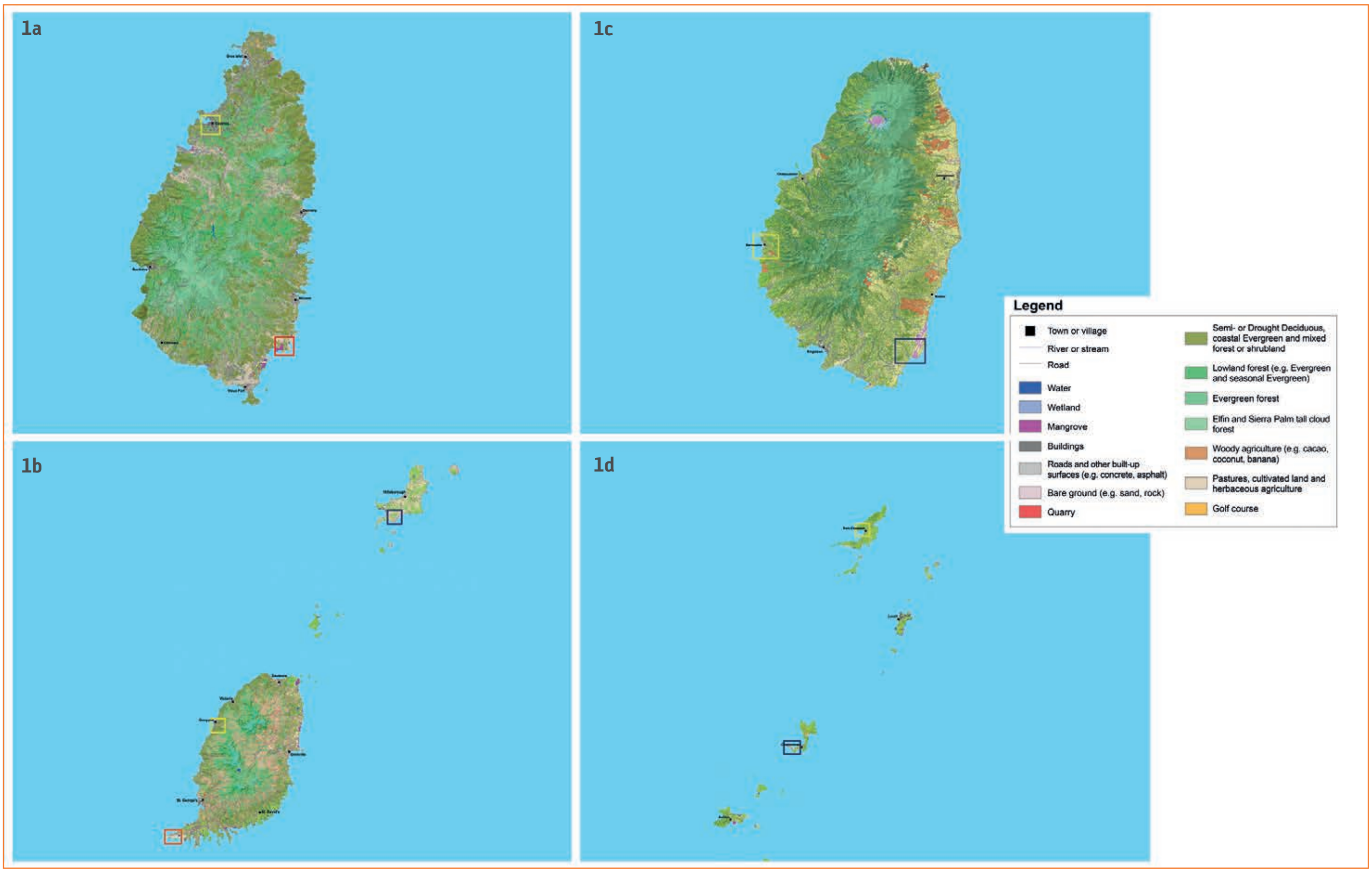
- Land use/land cover mapping
- Landslide inventory mapping
- Digital Elevation Model

Service Providers

- British Geological Survey (BGS)

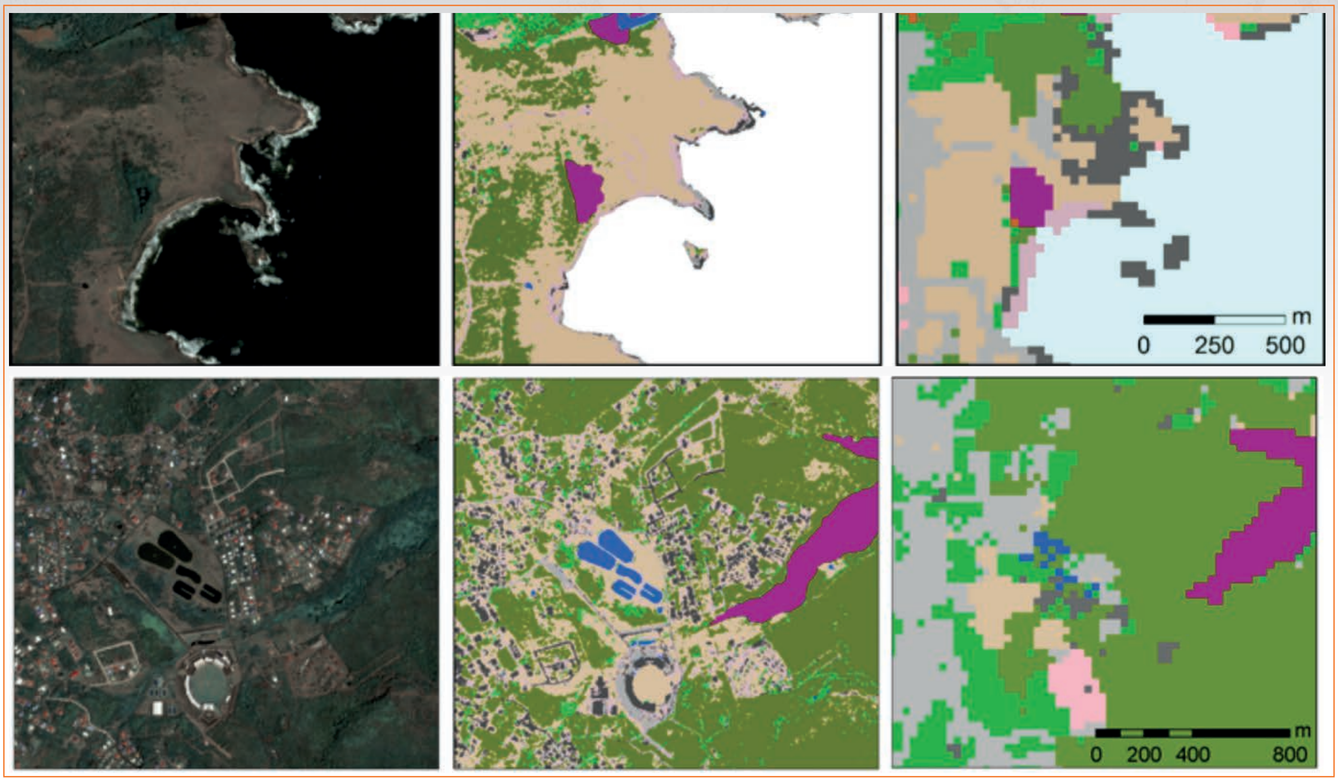
Background

The small Caribbean island nations – especially those of volcanic origin – are currently challenged to update their country development plans to mitigate the exposure of population and assets to existing and new risks. Due to their location in the Atlantic hurricane belt, the islands are prone to disasters: their steep terrain, together with heavy rainfalls, often leads to floods and landslides. They also face the threat of earthquakes and tsunamis due to the tectonic plate movements. Finally, sea level rise is affecting their coastlines putting people and assets at risk of climate change impacts.



1. High resolution land use maps of St. Lucia (a), Granada (b), St. Vincent (c) and Grenadines (d). Pleiades data © CNES, Distribution Airbus DS / Spot Image). RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

2



The World Bank is currently supporting the Caribbean region to create and use risk information for planning and development strategies in critical sectors. The activity forms part of the Probabilistic Risk Assessment (CAPRA) Program, which objective is to enhance the capacity of targeted sectors in South America to develop and mainstream disaster risk information into their development programs and policies. The delivery of knowledge products and services is managed by the Global Facility for Disaster Reduction and Recovery and financed by the ACP-EU Natural Disaster Risk Reduction Program and includes the creation of a geospatial information bases, spatial data infrastructures, development of a methodological framework for the development of hazard and risk information, and implementation of five national pilot hazard studies, among others.

Currently the Caribbean Risk Information Program project is focusing on Belize, Dominica, St. Lucia, St. Vincent and the Grenadines and Grenada. The ESA technical assistance led by the British Geological Survey provided a demonstration of the contribution of Earth Observation data and services to support landslide hazard assessment.

Land use/land cover mapping

Land use / land cover maps were developed for St. Lucia, Grenada, and St. Vincent & the Grenadines using high resolution or very high resolution optical satellite imagery: Pleiades imagery (acquired between 2013-2014) and RapidEye imagery (acquired 2010-2014) (Figure 1). These sensors have a spatial resolution (pixel size) of 2m and 5m, respectively, for the multispectral images. Additionally, the Pleiades dataset includes a 0.5m

2. Comparison of the level of detail provided in the 2014 2m land use/land cover maps (middle) and the 2001 30m maps (right). The land cover/land use products build upon the 2001 land cover maps developed by the Nature Conservancy's Mesoamerica and Caribbean Project. Pleiades data © CNES, distribution Airbus DS / Spot Image) Credits: British Geological Survey for ESA/World Bank.

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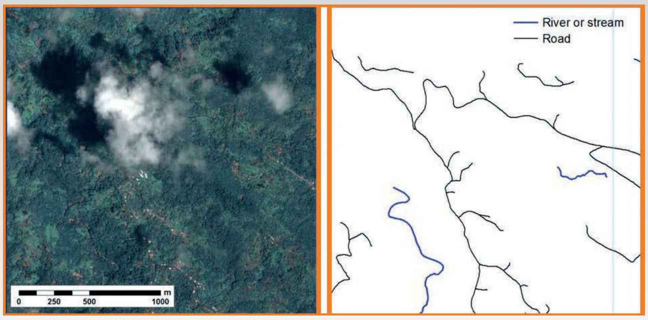
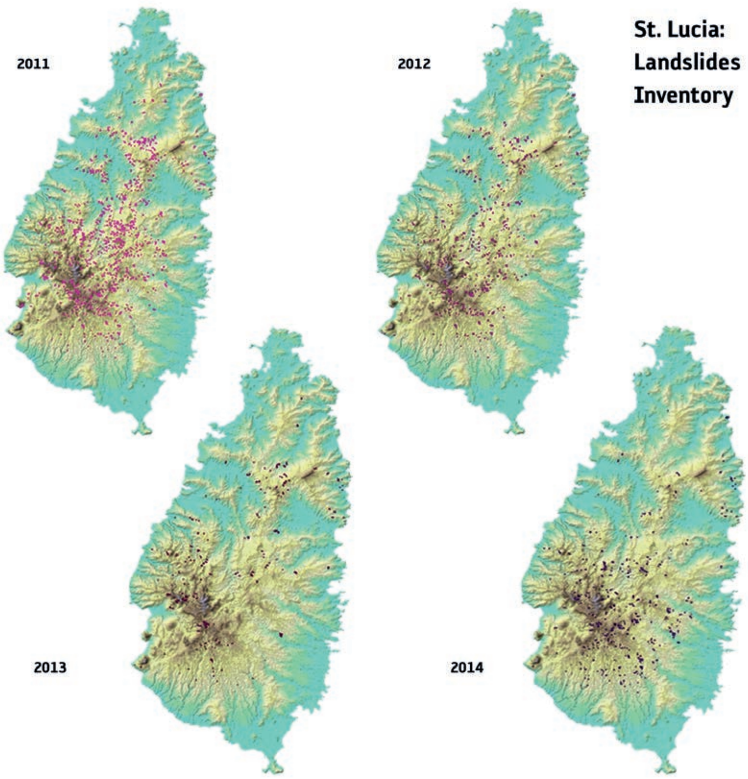


panchromatic imaging capability. Compared to the maps available to the authorities before, these land use/land cover maps represented substantial increase in terms of their scale of observations (Figure 2). As a result, the new maps provided much more detailed information about the distribution of different land use/land cover classes. Moreover, the water features and the basic road networks were manually digitised at 1:10,000-scale from Pleiades imagery (Figure 3).

Landslide inventory mapping

In Saint Lucia the landslides inventories are typically produced using conventional field surveys. However, if landslides are taking place in remote areas, inventories often cannot provide a reliable reflection of the spatial distribution of event occurrences. As a result, relatively few of them are being recorded and monitored over time.

4a

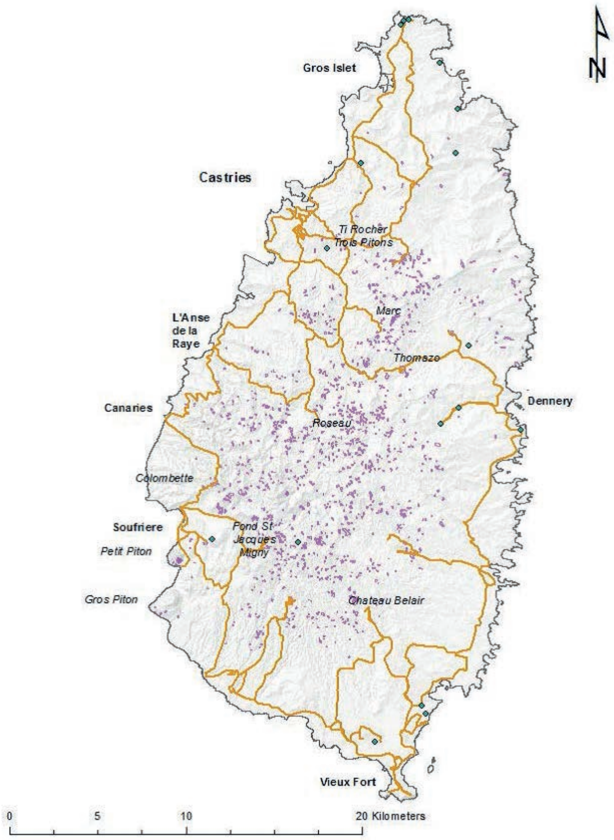


3. Delineation of rivers, streams and roads from pan-sharpened Pleiades imagery. Pleiades data © CNES, Distribution Airbus DS / Spot Image. Credits: British Geological Survey for ESA/World Bank.

4a. The number and distribution of landslides in St Lucia based on RapidEye (2011-2014) and Pleiades (2014) imagery. Minimum landslide dimensions in the database are approximately 200 m2. Credits: British Geological Survey for ESA/World Bank.

EO-based multi-temporal landslides inventory created for this project covered the island of Saint Lucia for the years of 2010-2014 (Figure 4a & 4b). As a result, 1233 landslide polygons have been classified as (i) active, (ii) with fresh signs of sliding land, or (iii) inactive as illustrated in Figures 5 and 6. The generated time series captured two major trigger events: the 2010 Hurricane Tomas and the 2013 Christmas Trough. The study has found that many of the smaller rural roads in the interior were dramatically affected by both events. Moreover, landslides triggered by Hurricane Tomas were rapidly covered by vegetation indicating a quick rate of recovery of the landscape, although, many events were re-activated during the Christmas Trough indicating an increased sensitivity of the landscape to disturbance, and thus higher disaster risk.

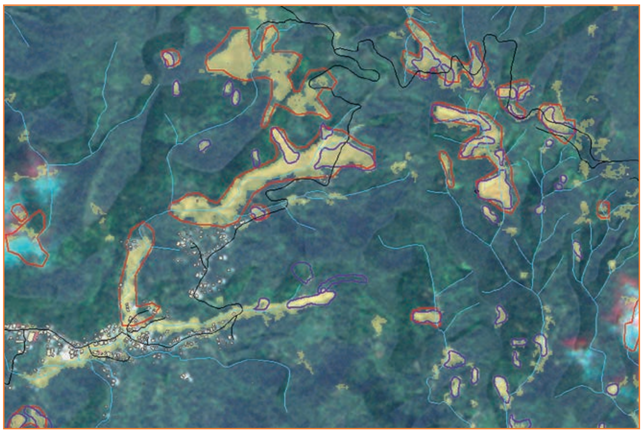
4b



Results

The main satellite data sources used in this trial were RapidEye images as well as Pleiades images. Manual interpretation required the detection of disturbance of vegetative cover and exposure of soils at the surface which was combined with other information such as position of the landscape features, and slope morphology.

Extending the multi-temporal record with new acquisitions allows to create further insights into landscape response to the triggers and this will be vital in establishing relevant hazard and risk assessments. However, this service has to be always customized to local conditions. For example, the landslides inventories in Granada were much more difficult to establish due to widespread cultivation practices that are resembling landslide signatures. Field verification remains an essential tool to ascertain the validity of image interpretations.



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4b. Map of St Lucia with landslide events in purple outline, identified from RapidEye and Pleiades satellite imagery 2011-2014. Field checking routes taken are shown in brown. Green dots represent land-use classification field check spots. Pleiades data © CNES, distribution Airbus DS / Spot Image). RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

5. The Fond St Jacques/Migny area on the 2011 RapidEye image. The light coloured pixels indicate the result of a 'bare earth' classification (areas larger than 300 m2). The red polygons represent the 2010 landslide inventory and the purple polygons the multi-temporal inventory where bare earth signatures in valleys and fields have not been included. The two landslide polygons in the center were generated in 2014. RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

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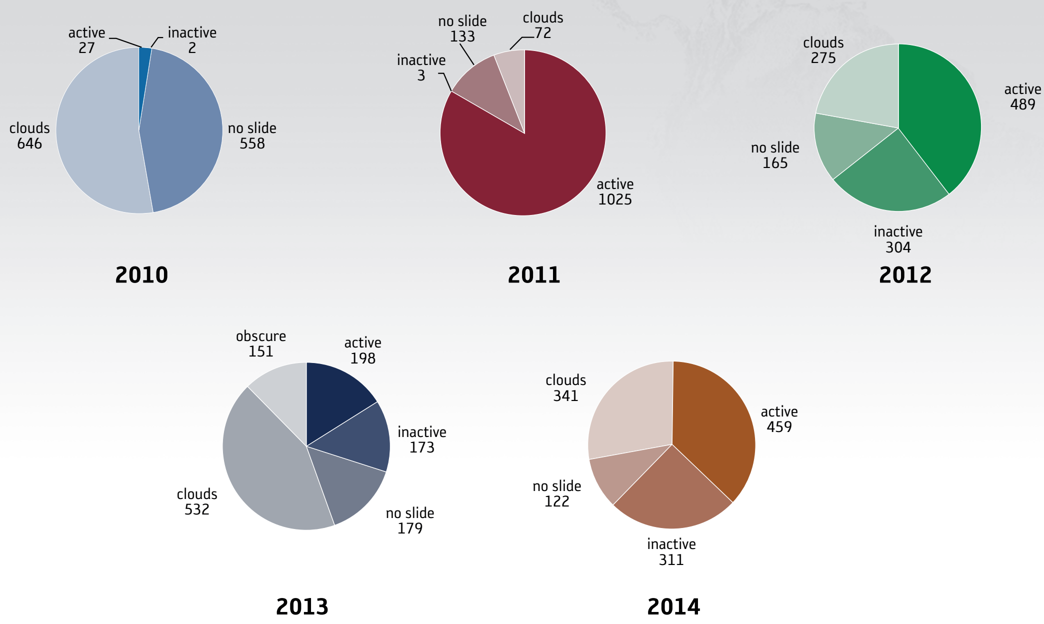

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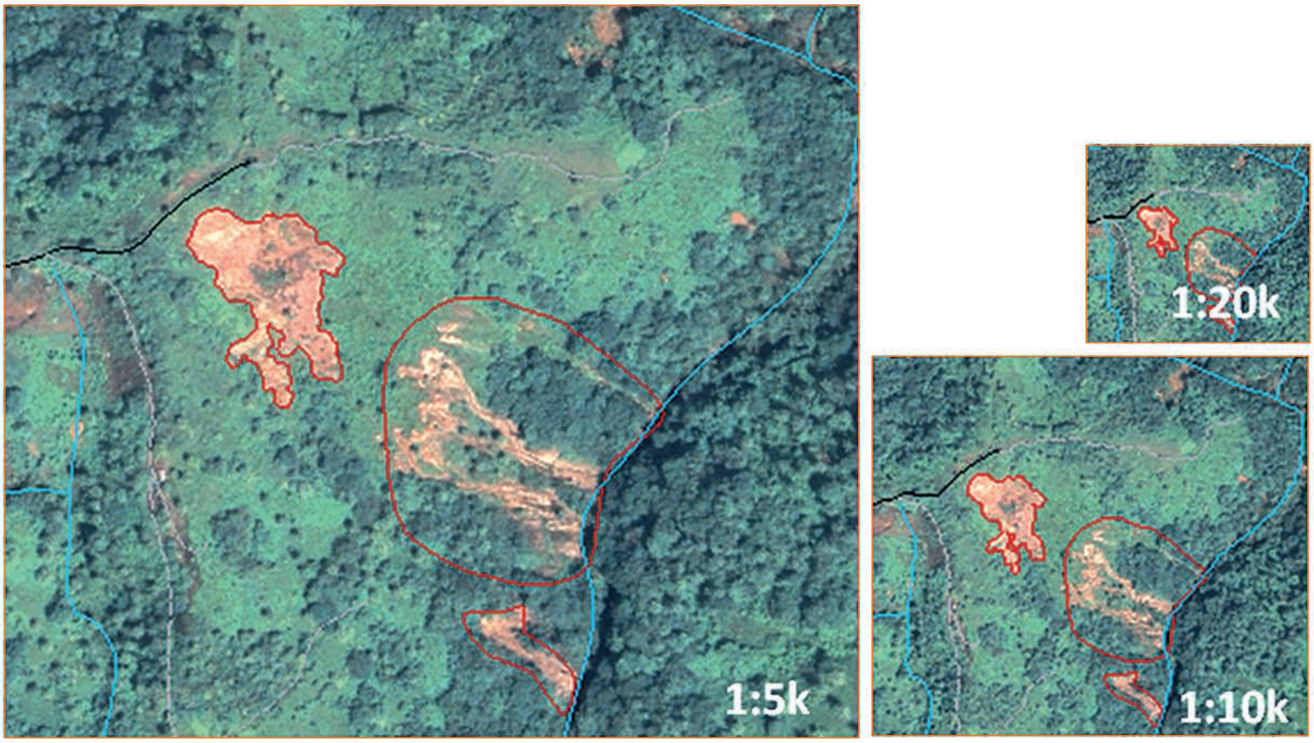

6. Summary of landslides identified for each year of the multi-temporal image stack from 2010-2014 in St Lucia. Pie diagrams indicate of the number of polygons classified as active, inactive, not a landslide and those where identification was not possible due to cloud cover or, in 2013, due to poor image quality in the SE section of island. Credits: British Geological Survey for ESA/World Bank.

7. An example of mapping at different scales at Chateau Belair using the 2014 Pleiades satellite image. The very high resolution satellite imagery allows interpretation at 1:5,000 scale making it possible to create a detailed outline of freshly exposed soils of a landslide (A), at 1:10k it is possible to roughly outline a small event (C) while at 1:20,000 scale a small cluster of linked events is grouped together (B). Pleiades data © CNES, distribution AirbusDS /Spot Image). RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

The project supported capacity development within government departments, among land owners and the general public. Several workshops were organized and included a range of stakeholders from World Bank to international development agencies, including the training workshop in the Netherlands on the use of geo-data for landslide and flood hazard and risk assessment with the users from the four Caribbean countries to identify new application areas.

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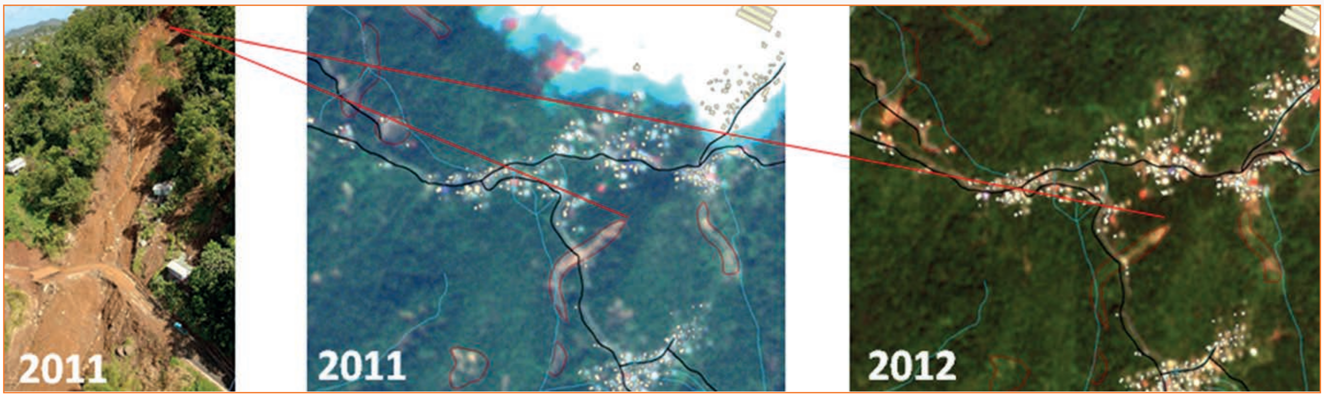

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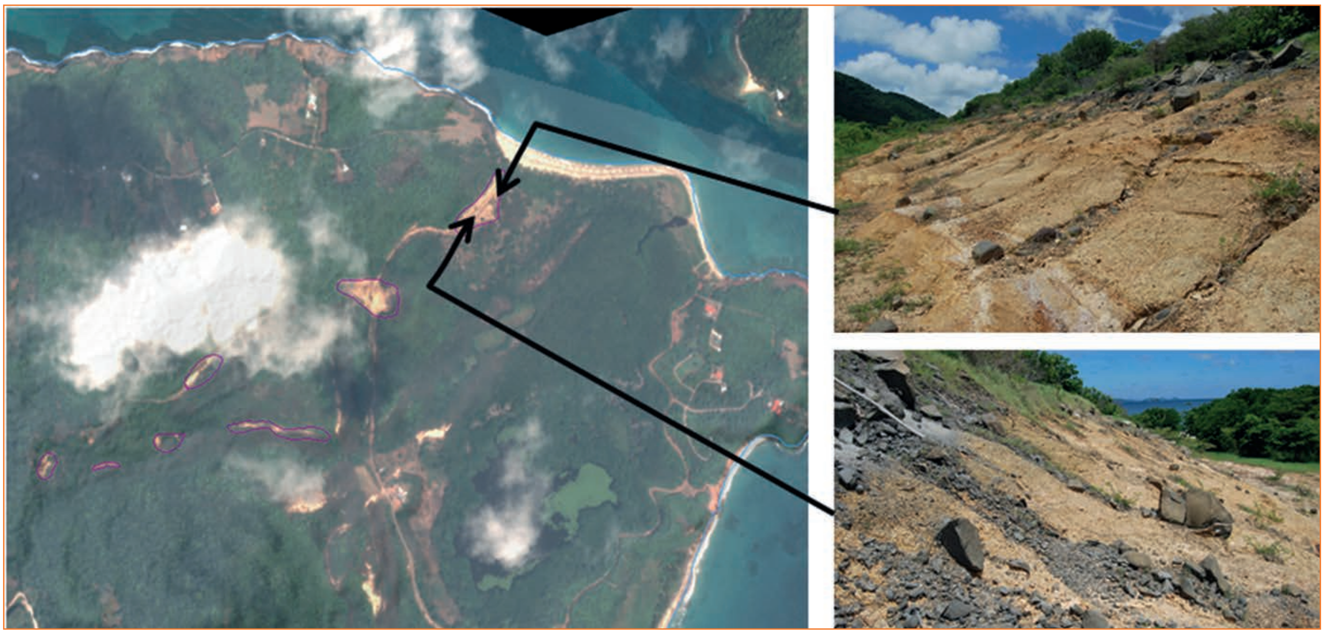

8. The landslide/debris flow event of Ti Rocher. To the left an oblique of the event is shown (source Economic Commission for Latin America and the Caribbean, ECLAC 2011). The event is clearly visible on the 2011 RapidEye image, while only a year later all landslide deposits below the road are covered by vegetation. Pleiades data © CNES, distribution Airbus DS / Spot Image). RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

9. Levera Point. Initially mapped as landslides, ground truthing indicated that these are predominantly surface erosion features. Pleiades data © CNES 2014, distribution Airbus DS /Spot Image). RapidEye data © BlackBridge. Credits: British Geological Survey for ESA/World Bank.

Sustainable Development of Mountain Regions in the Himalayas

Users:

- World Bank Global Practice on Social, Urban, Rural and Resilience, Disaster Risk Management and Climate Change Unit
- World Bank Country Offices in Bhutan and Nepal
- Hydromet Department and Department of Disaster Management of the Government of Bhutan

EO services provided

- Land use mapping
- Flood hazard assessment
- Landslide hazard assessment
- Glacial Lake Outburst Flood (GLOF) hazard assessment
- Digital Elevation Model

Service Providers

- MFB-GeoConsulting GmbH (Switzerland)
- Gamma Remote Sensing AG (Switzerland)
- SUPSI-IST Earth Science Institute (Switzerland)

Background

The Himalayan Mountains are spanning across eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. The region is home to more than 40% of the world's poor people and faces extreme vulnerability and risks due to climate change. It also includes four global biodiversity hotspots, including 488 protected areas, 330 important bird areas and 60 global eco-regions.

The World Bank is actively involved in projects related to hydropower and infrastructure planning (roads, dams, agriculture) in Nepal and Bhutan. In support of its investment projects it makes use of existing national data provided by the relevant national agencies from both

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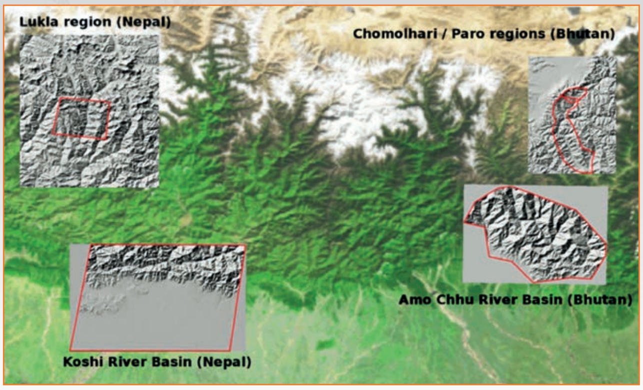

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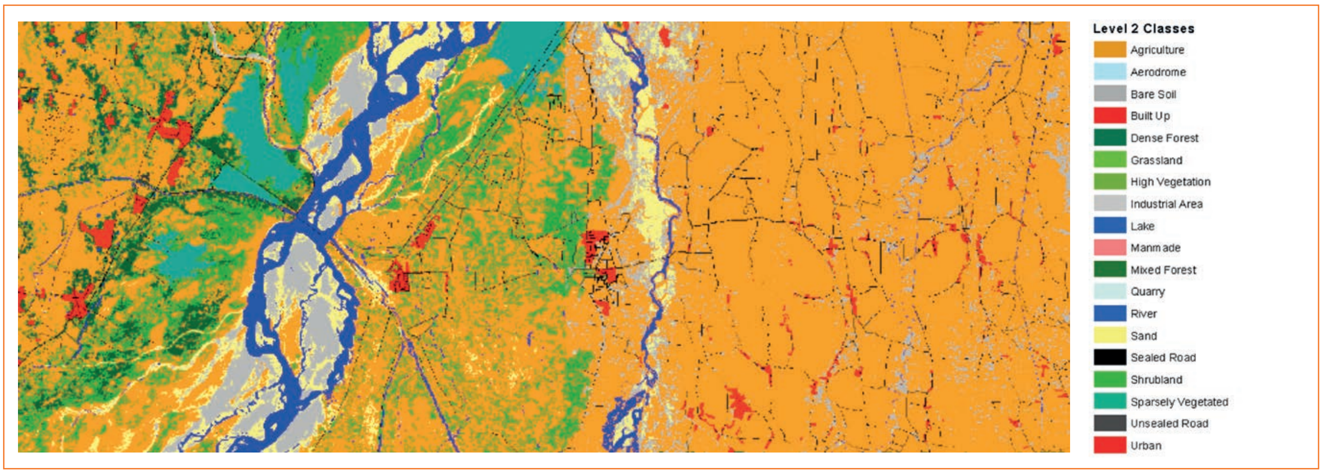

1. Location of the areas of interest in Nepal and Bhutan. The project used very-high resolution DEMs as support for landslide hazard mapping with 10m resolution derived from TanDEM-X as well as high resolution DEMs as support for land use mapping and flood hazard mapping with 30 m resolution from ASTER GDEM and SRTM. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.

1b. Land Use Classification over Koshi basin over Birpur area generated using Very High Resolution Optical data from KOMPSAT-2 and RapidEye satellites. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.

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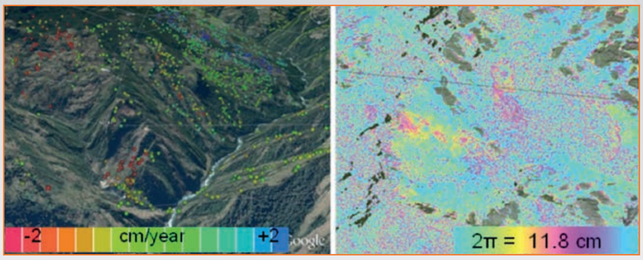

countries. However the available information, eg. land use maps and DEM, often have a low spatial resolution. In addition, the hazard information, such as landslide hazard maps and glacial lake outburst flood (GLOF) maps, sometimes do not cover the project areas or are outdated. In order to address these challenges ESA initiated a pilot demonstration of landslide and flood hazard mapping services for the Lukla region and Koshi river basin in Nepal and the Chomolhari Paro region and Amo Chhu river basin in Bhutan where investments are planned (Figure 1).

Land use maps

For all four selected areas of interest detailed land use maps have been generated based on Kompsat-2 and RapidEye imagery for the time period 2013/14 with a much higher degree of detail (spatial resolution of 2 m) than the mapping data that was available to the national users before. In particular, for remote and mountainous terrain, land use has been evaluated for the first time providing new information on land use types and distribution.

Landslide hazard mapping

The Lukla region in Nepal and the Chomolhari Paro region in Bhutan are prone to significant landslides

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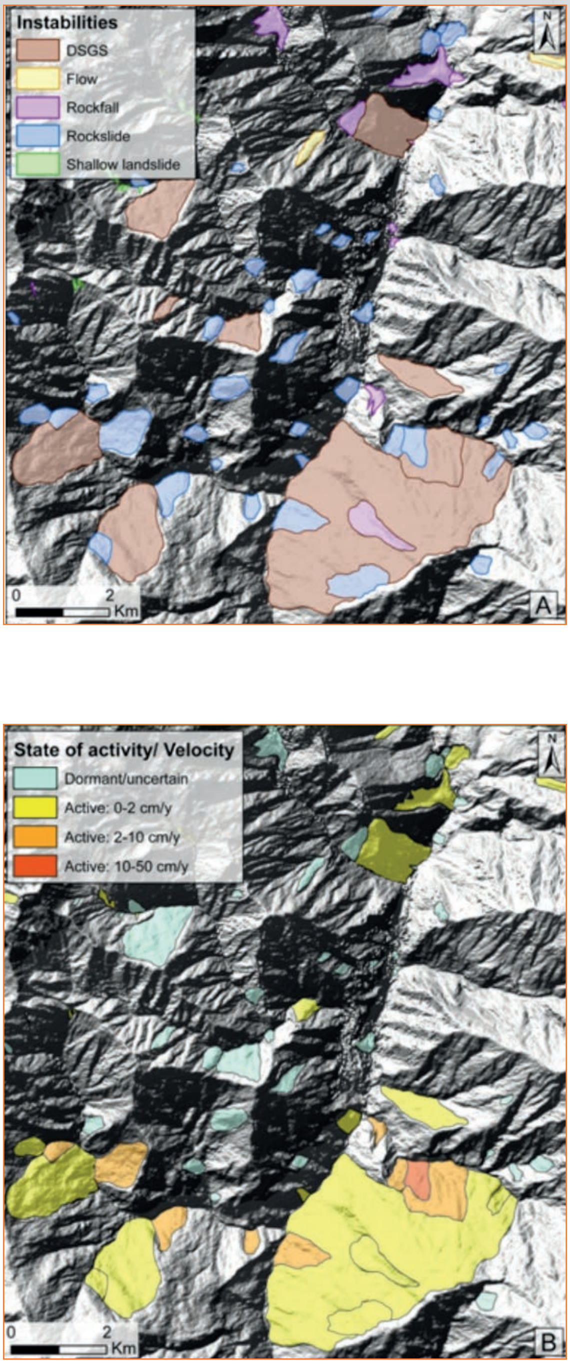

2. Example of intermediary product providing terrain motion measurements with centimetric precision: satellite SAR interferometry in Lukla region (Nepal) overlaid on a Google Earth image. Left: ALOS PALSAR based PSI product using data from 11.02.2007 to 19.02.2010; Right: conventional InSAR map using JAXA's ALOS data data from 30.12.2007 to 19.02.2010 © JAXA, Google earth image © Google earth. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.
3. The Lukla area landslide mapping. The compilation of landslide inventory maps (A) was based on the interpretation of satellite optical and stereo images (VHRO KOMPSAT-2, and HRO RapidEye and, Google Earth images) and the TanDEM-X 10 resolution DEM. The state of activity (B) was based on precise terrain motion measurements derived from SAR interferometry as illustrated in Figure 2. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.

because of the high relief and of intense rainfall during the monsoon season. In addition, these regions are tectonically active and slope instabilities may also be triggered by earthquakes.

EO-based landslide hazard assessment was prepared using photo-interpretation and a quantitative approach involving interferometric analysis of terrain motion. Surface displacement was derived from satellite SAR interferometry: Persistent Scattered Interferometry (PSI) and differential interferograms (DinSAR). DinSAR has been applied to stacks of ERS-1/2 SAR, ENVISAT ASAR, ALOS PALSAR, TerraSAR-X and Radarsat-2 images acquired between 1992 and 2014 from ascending and descending orbits for a better spatial coverage. Displacement was assessed based on the interpretation of the phase difference of the signals acquired by two satellite SAR acquisitions, after compensation of the topographic effects with use of the TanDEM-X DEM.

PSI was applied to stacks of ENVISAT ASAR and ALOS PALSAR images. The advantage of observing a wide portion of territory with satellite images is in consistent mapping of large areas and identification of landslides that are hardly recognizable through site surveys.

The state of activity of mapped landslides was summarized in three main classes: active, inactive/dormant and relict. The landslide hazard, was determined according to the guidelines developed for the mountainous regions in Switzerland: low intensity was assigned to landslides characterized by mean velocities below 2 cm per year, moderate intensity to velocities ranging between 2 cm-10 cm per year, and high intensity to velocity higher than 10 cm/a (Figure 3).

In total, 210 landslides were mapped, distinguished in 20 Deep Seated Gravitational Slope Deformations (DSGSDs, in yellow color in Figure 3a), 117 rockslides, 30 rockfalls,

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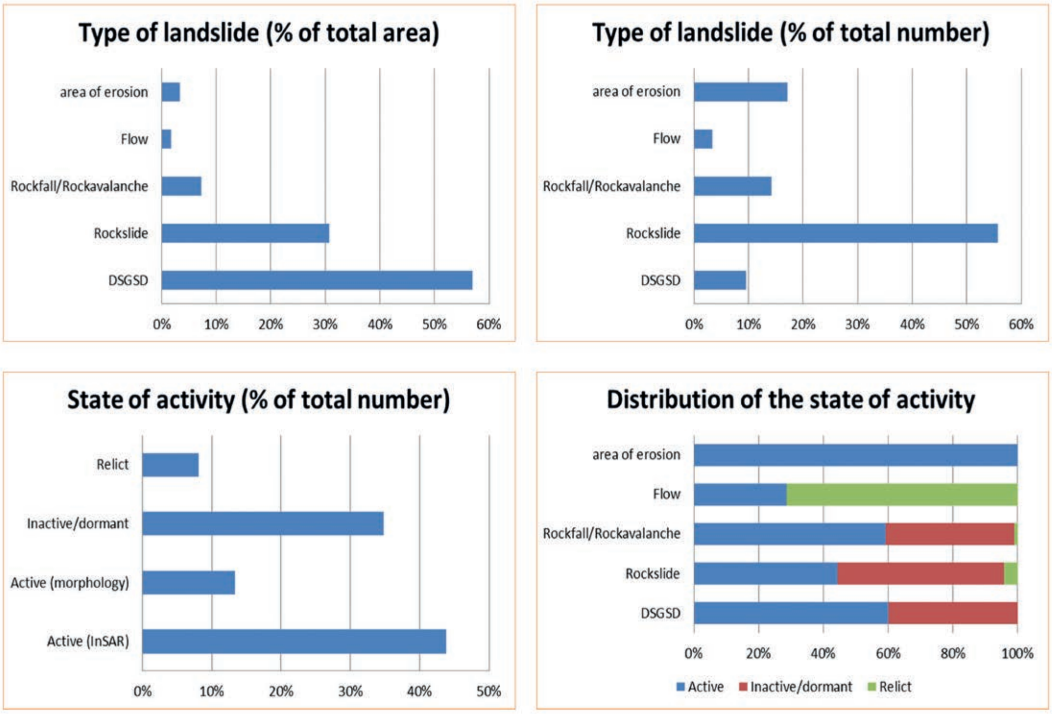

4. The Lukla area landslide hazard statistical analysis. Credits MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.

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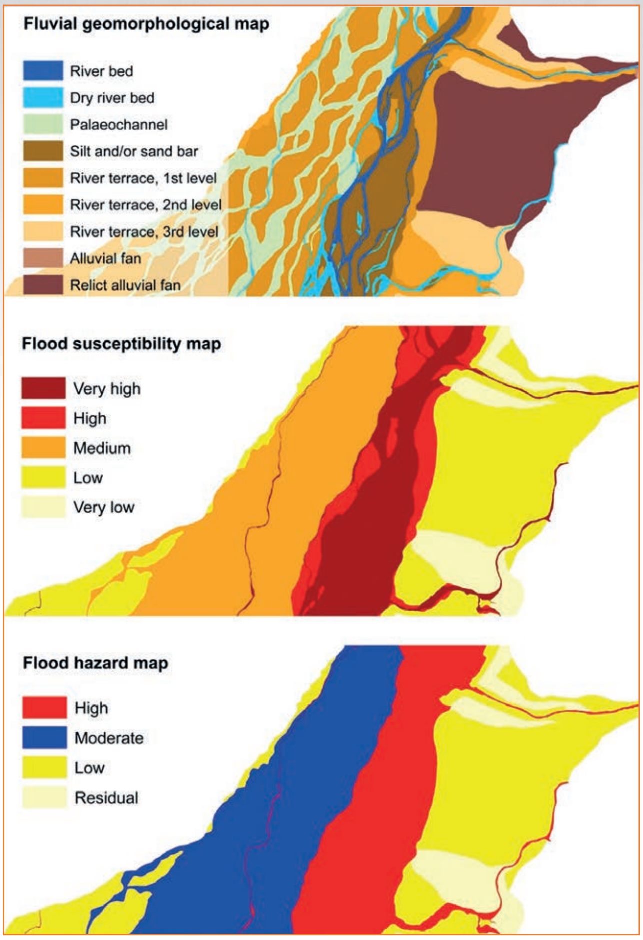

7 flows and 36 surficial slides (active erosion zones). The project found that 7.5% of the Lukla area extending over 725 km2 is affected by landslides. Considering the type of landslide, the major number is represented by slides (56%) but in terms of percentage on total landslide area, deep seated gravitational slope deformations cover the major surface (57% of total landslide area). Flows (eg. material that deform permanently under the influence of a constant mechanical stress) represent only the 3% of the total number of mapped landslides. Regarding the state of activity, most of mapped landslides were classified as active (44% of the total number). Such a classification of the landslides into seven categories helped in determining the priority sites for future intervention including preparation of risk maps on the local level (Figure 4).

Flood hazard mapping

Koshi (Nepal) and Amo Chhu (Bhutan) rivers are both foothill braided rivers. They are affected by channel mobility related to fluvial morphological changes, sediment fluxes and (especially for Koshi river) channel avulsion or abandonment. This determines a large unpredictability in the river behaviour, and has to be taken into account when creating detailed flood susceptibility and hazard maps.

Generated flood hazard map was based on a combination of a fluvial geomorphological map, flood susceptibility map and flood hazard map. The project delivered a detailed map of the floodplain, detailed map of flood susceptibility (very high, high, medium, low, very low) and detailed map of flood hazard (high, moderate, low, residual) for every geomorphological unit/subunit (Figure 5).

Glacial Lake Outburst Flood (GLOF) hazard assessment

The project also provided a Glacial Lake Outburst Flood (GLOF) hazard assessment for the supraglacial lake Wa-007 on the Thangothang Chhu glacier in the Chomolhari area in Bhutan. Earth Observation data was combined with in-situ information and flow modelling for a GLOF first-order hazard assessment based on a checklist using the “Slope Stability and Glacial Lake Monitoring” methodology, carried out between 2014 and 2016 by Gamma Remote Sensing, the Department of Geography of the University of Zürich, the Department of Geosciences of the University of Oslo and Asiaq (Greenland). The project team concluded that for Wa-007 the hazard for an outburst flood under the current morpho-climactical conditions is very low.

5. Example of the three maps produced in the context of flood hazard mapping for the Amo Chhu river in Bhutan. Geomorphological mapping was based on the interpretation of satellite optical and stereo images (VHRO KOMPSAT-2, HRO RapidEye and Google Earth images) and the ASTGTM2 30 m resolution DEM. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank

Results

Products and services were delivered to the World Bank and national users. The classification of the landslides into seven categories was considered very useful in determining the priority sites for intervention and landslide hotspots. Moreover ESA developed further discussions with the Buthan's College of Natural Resources concerning the use of satellite technologies for risk management in the country.

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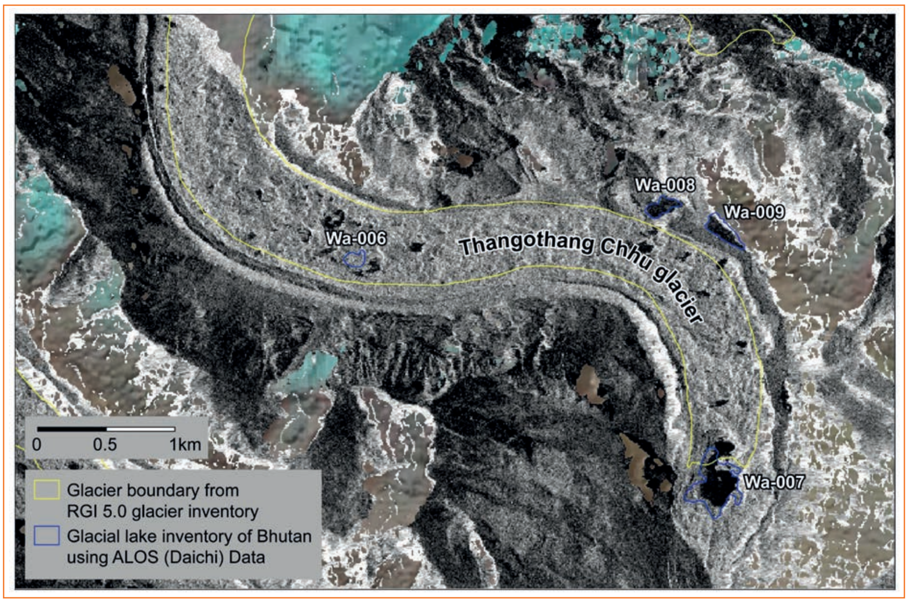
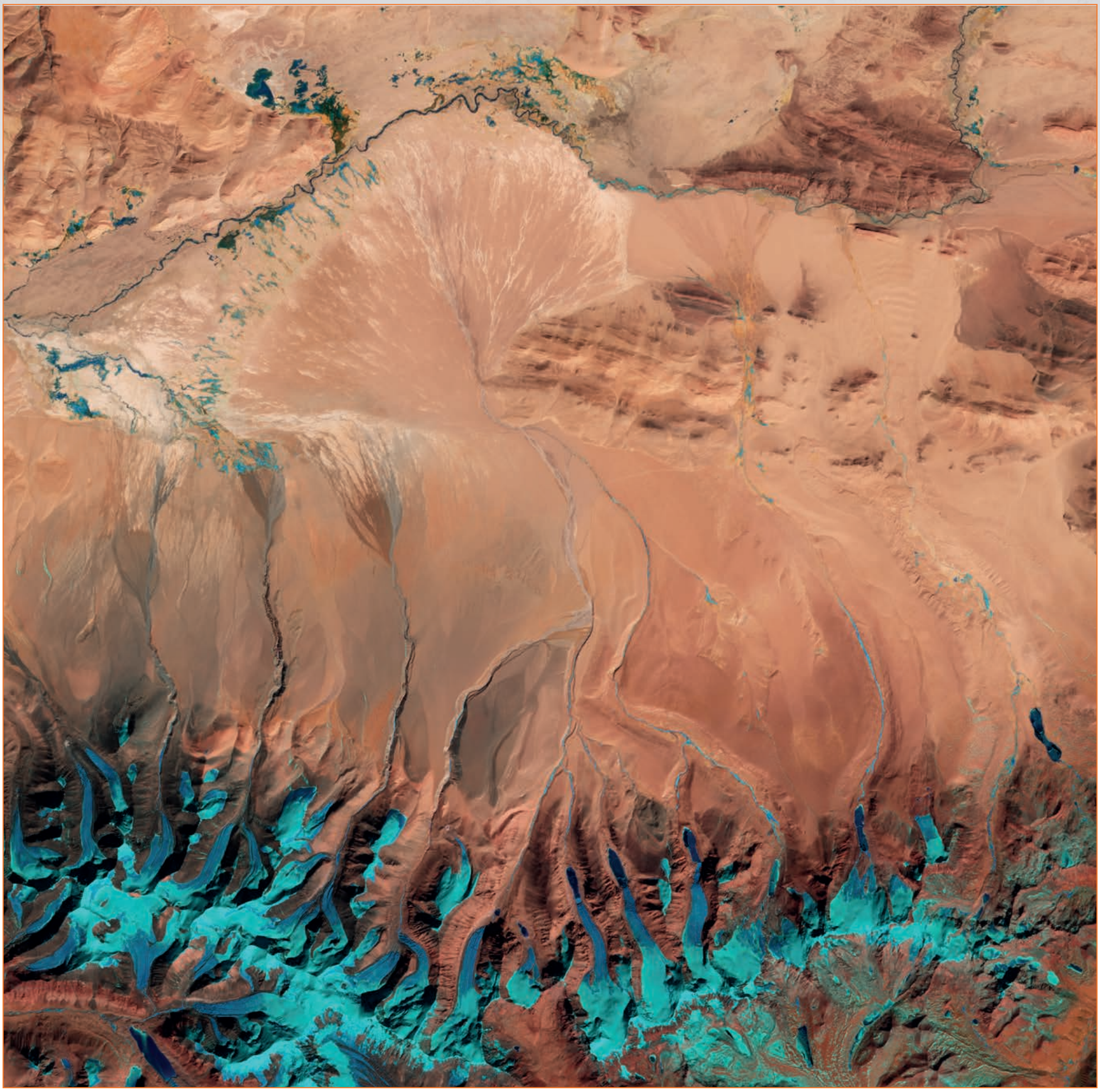


6. Google Earth image with the Glacial Lake Inventory of Bhutan using ALOS (Daichi) Data (light blue). The supraglacial lake object of this assessment report is Wa-007. Google earth image © Google earth. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.
7. TerraSAR-X backscattering intensity image of 02.06.2014 showing many supraglacial ponds in black. Names of the lakes provided according to the Glacial Lake Inventory of Bhutan. TerraSAR-X data © German Aerospace Center (DLR). Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank.



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8. The southern-central edge of the Tibetan Plateau near the border with western Nepal and the Indian state of Sikkim is pictured in this Sentinel-2A image from 1 February 2016. Part of the Himalayas is visible along the bottom of the false-colour image, with the distinct pattern of water runoff from the mountains. At the end of these rivers and streams we can see the triangle-shapes of sediment deposits – alluvial fans – formed when the streams hit the plain and spread out. Sentinel data © ESA. Credits: ESA.

Lake Victoria Basin Health Monitoring

Users:

- World Bank Global Practice on Environment and Natural Resources
- World Bank Country Offices in Bhutan and Nepal
- World Bank Water Global Practice
- Lake Victoria Basin Commission (LVBC)
- National water and environment authorities in each of the five basin countries: Kenya, Tanzania, Uganda, Rwanda and Burundi

EO services provided

- Water quality
- Proliferation of macro-algae
- Index of Sustainability
- Bathymetry
- Topography
- Land use

Service Providers

- ACRI-ST (France)
- Hatfield Consultants (Canada)

Background

Lake Victoria is the second largest lake in the world and supports one of the most important fisheries in Africa. It plays a central role for transport, water resources, and tourism activities in the region. However, the Lake is increasingly subjected to a variety of environmental stresses including harmful algae, toxic chemicals, discharges from vessels, aquatic invasive species, habitat degradation and the effects of climate change. In particular, Lake Victoria has undergone the most severe infestation of water hyacinth over the last two decades with significant negative socio-economic impact on riparian populations which rely on healthy lake fisheries ecosystems for their livelihoods.

The World Bank has been engaged in supporting cooperative management of Lake Victoria for more than a decade. Numerous Bank-led projects and activities carried collection of water quality information, focusing on non-point and point source pollution loading, and eutrophication. Several summary reports regarding these past monitoring efforts are available online, however at present no systematic

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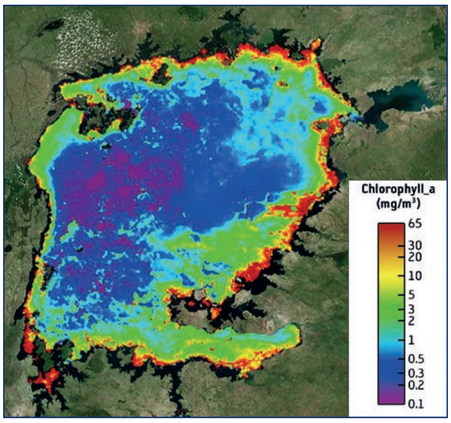

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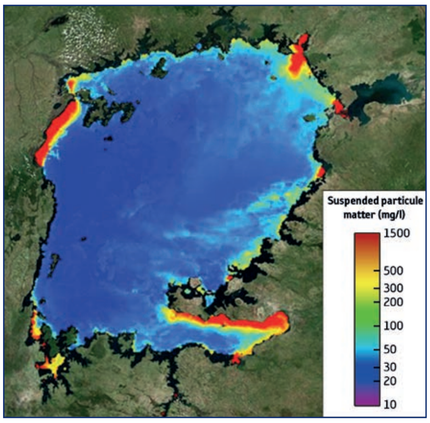

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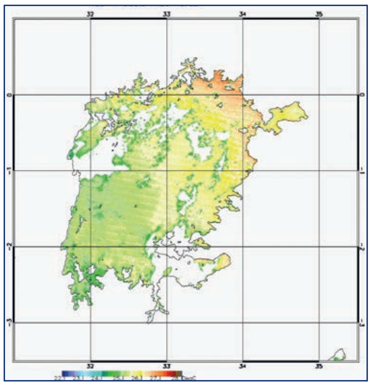


1. Example of the three maps produced in the context of flood hazard mapping for the Amo Chhu river in Bhutan. Geomorphological mapping was based on the interpretation of satellite optical and stereo images (VHRO KOMPSAT-2, HRO RapidEye and Google Earth images) and the ASTGTM2 30 m resolution DEM. Credits: MFB-Geo Consulting GmbH, Gamma Remote Sensing AG & SUPSI-IST for ESA/World Bank
2. Suspended Particle Matter concentration 10-day product derived from MODIS 250m resolution data. MODIS data © NOAA. Credits: ACRI & Harfield for ESA/World Bank.
3. Lake Surface Temperature (MODIS – resolution 1 km) – daily product. Lake Surface Temperature is a combination of short wave LST for night time observation and long wave LST for day time observation. MODIS data © NOAA. Credits: ACRI & Harfield for ESA/World Bank.

geo-spatial information on water quality and macro-algae as well as land use, bathymetry and topography is being collected or used.

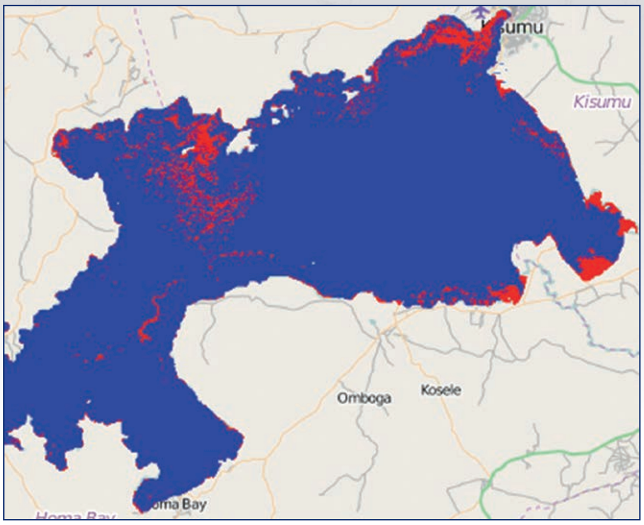
The objective of the ESA project was to demonstrate the potential of available Earth Observation technologies, including Sentinel-1 data, for the monitoring of different stages of anthropogenic impact on the lake's environment. Based on these requirements the project developed the following EO services:

- ecological water quality monitoring (including Chlorophyll-a surface concentration, Suspended Particulate Matter (SPM) and Lake Surface Temperature (LST)),
- monitoring of the proliferation of macro-algae (water hyacinth index from optical data, water hyacinth likelihood index from radar data, and Floating Vegetation)
- sustainability indexes (evolution of land cover – land use (1984 – 2014), evolution of surface occupied by water hyacinth, evolution of pollution release into the lake due to rainfall streaming
- others data products (lake bathymetry, topography, time series of meteorological observations)

All data products are made available through web GIS portal and additionally as Web Map Service (WMS) at http://ocean.acri.fr/Victoria

Water quality of the lake

Water quality parameters such as Chlorophyll-a surface concentration and Suspended Particulate Matter (SPM) concentration have been developed based on MODIS data (Figure 1). Figure 2 showcases the detection of the river plume extent into the Lake (eg. Katonga and Kagera rivers at the North West and Gurumeti inputs in the South East) which is a good indicator for the terrestrial pollutant sources contribution to the lake biological and chemical cycle. Moreover, the Lake Surface Temperature product



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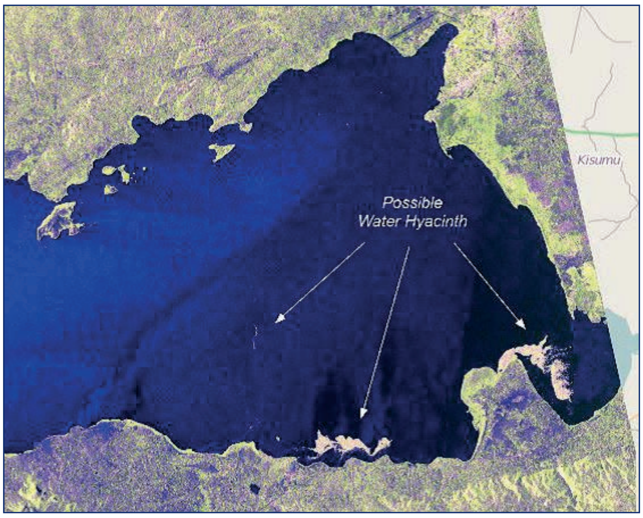

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in combination with Chlorophyll-a information, provided an early warning of algal bloom and eutrophication conditions (Figure 3).

Proliferation of macro-algae

Assessing the floating vegetation cover is difficult using traditional measures. The location of the pockets of macro algae varies a from one day to another and a timely field campaign over the thousands of square kilometres of the

4. NDVI-based detection of floating vegetation. Landsat data © USGS. Credits: ACRI & Harfield for ESA/World Bank.

5. Potential floating vegetation was detected based on radar backscatter intensity and object size through a moving window algorithm. Radarsat-2 data © MDA. Credits: ACRI & Harfield for ESA/World Bank.

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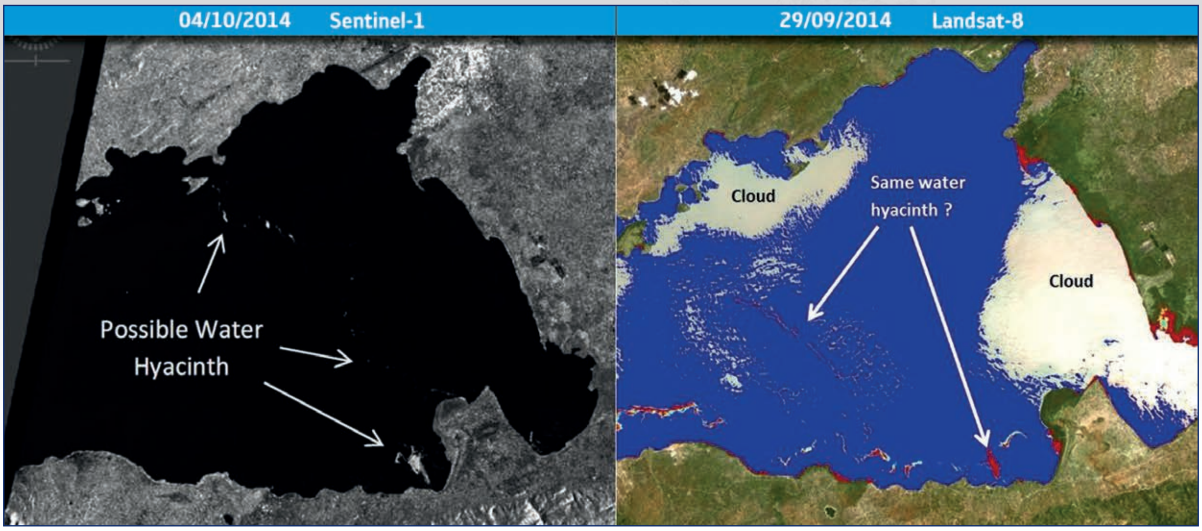

Lake surface areas is very costly, if at all feasible. Remote sensing is the most efficient solution for a large scale view of the vegetation. Figure 4 shows a Floating Vegetation Index based on the optical Landsat data, while Figure 5 uses radar data for detection of the possible Water Hyacinth.

Monitoring of the spread of water hyacinth in Lake Victoria is very important in order to target pollution control measures before large infestations become evident. Based on a dual use of optical/visible imagery (Landsat and Sentinel-2) and SAR (Synthetic Aperture Radar) products (Radarsat-2 and Sentinel-1) several water hyacinth detection products were developed for the Winam Gulf area.

The main purpose of using Radarsat-2 was to assess the potential of radar data integration into the water hyacinth monitoring based on optical sensors. Moreover, an algorithm created for oil spill detection available in ESA's open source Sentinel-1 Toolbox1 has been modified to test applicability of these new data and methods for vegetation detection. The prototype product in Figure 6 represents a comparison of water hyacinth detection by using radar-based surface roughness and the vegetation index (NDVI) derived from Landsat. The radar-based product can be used in parallel/complement to the vegetation index to enhance the mapping of water hyacinth, ie. to overcome the cloud cover. The project demonstrated that SAR data can be used as an additional diagnostic tool for cross-validation of elements identified by the primary optical dataset. With the Sentinel-1 data becoming regularly available, the possibilities mapping of water hyacinth will be therefore further enhanced.

Sustainability indexes

Water quality parameters are often affected by the activities in the watershed. Changes in land use such as land conversions from forest to agriculture can dramatically increase the nitrate fertilizer run off. Similarly, urbanization trends can lead to increased wastewater spill to the watershed. Combining EO indicators (vegetation cover, soil moisture, surface water availability, soil and water retention structures, seasonal erosion indicators) and ground-based information it is possible to identify such land use hotspots. For example, an analysis of anthropogenic pressures on the Winam Gulf indicated that nitrates and phosphates released by agriculture practices are important drivers for the water hyacinth

6. Floating Vegetation Detection (based on Sentinel-1 – resolution 12.5 m) – updated every available observation. Landsat data © USGS. Sentinel-1 data © Copernicus data/ESA. Credits: ACRI & Harfield for ESA/World Bank.

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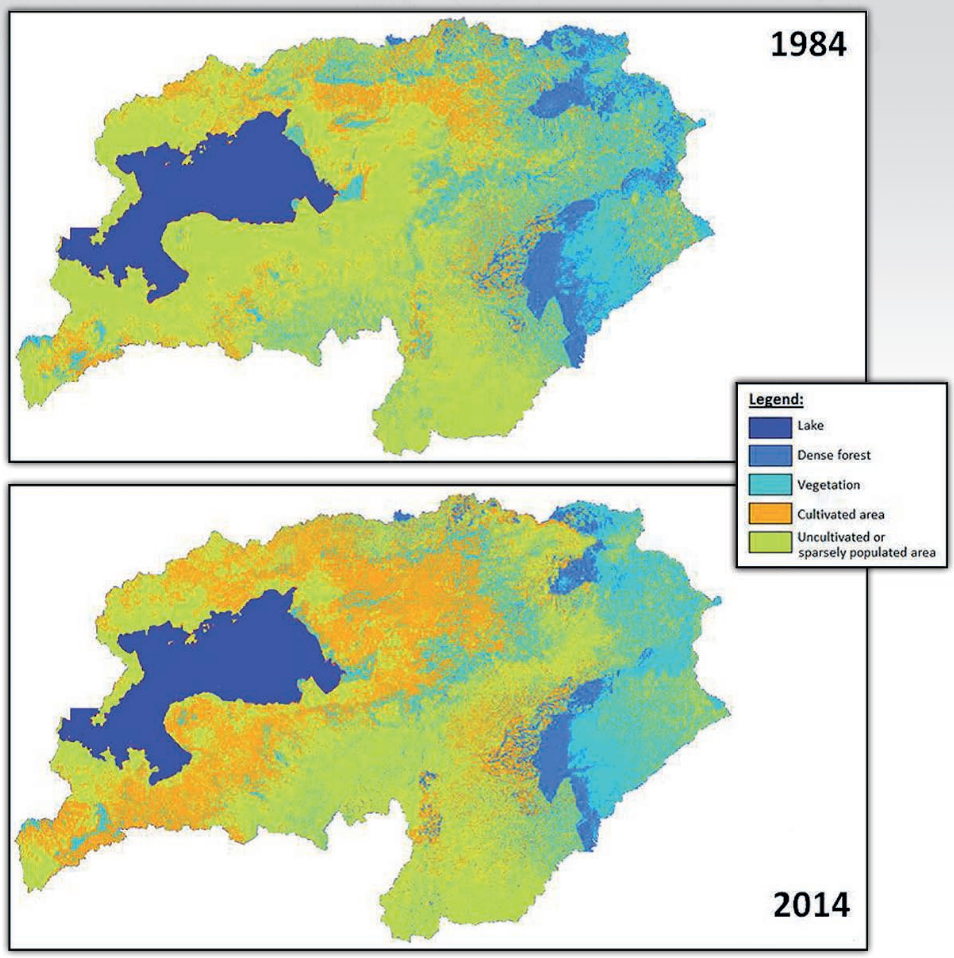


growth. The analysis of land cover – land use (1984 – 2014) conducted based on Landsat data, confirmed that agricultural land is expanding (Figure 7). Over the last 30 years the increase of in cultivated areas amounted to 64% while 24.5% of forest area loss has been detected as well as 14.6% of vegetation area loss.

Results

Earth Observation has a potential to greatly contribute to an assessment of the evolving picture of the health of the Lake Victoria Basin. It allows to establish the links between stressors and impacts – eg. between water quality or water hyacinth infestation and fisheries production, different anthropogenic factors to environmental degradation. Moreover information on how much pollution originates from different point and non-point sources is important for assessing the effectiveness of ongoing investments in cleaner production, sanitation, sustainable land management, among others. Finally, thanks to the development, validation and deployment of the new set of EO products the observation capacity over the lake can be enhanced to deal with existing and new challenges.

7. Land use on the Winam Gulf watershed for 1984 and 2014. Landsat data © USGS. Credits: ACRI & Harfield for ESA/World Bank.

Integrated River Basins Management in Turkey

Users:

- World Bank Global Practice on Environment and Natural Resources
- Ministry of Forestry and Water Affairs, Turkey

EO services provided

- Land use and land use change
- Crop type and acreage mapping
- Irrigated crop area mapping
- Soil erosion potential
- Vegetation productivity and potential degradation indicators

Service Providers

- Geoville (Austria)
- Metria (Sweden)

Background

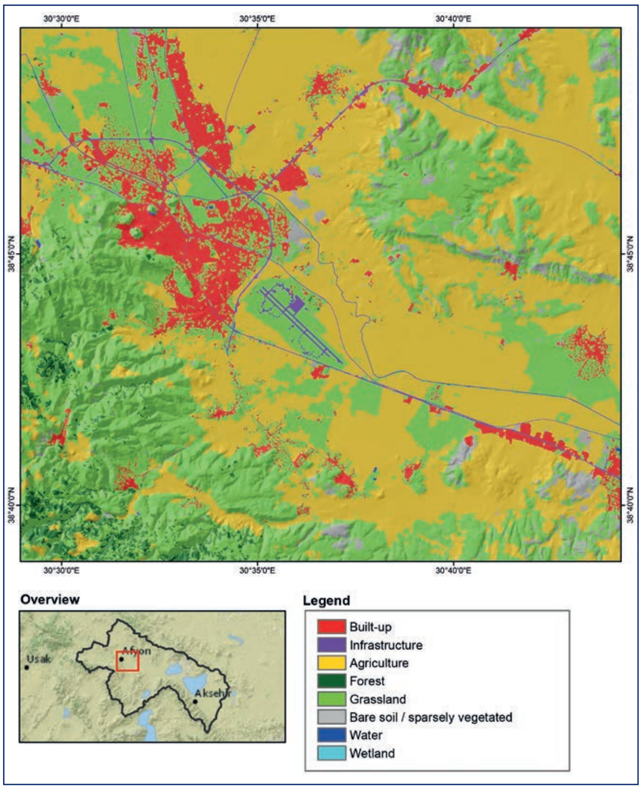
Turkey, a part of Mediterranean Europe's south zone, is sensitive to climate change impacts. The challenge is to mitigate the risk of increased water stress and even water scarcity, particularly in the agricultural sector which is the by the far the biggest water consumer (74%). The Government of Turkey has responded to this challenge by a series of measures aiming at adapting several water policies and practices, and strengthening institutional and technical capacities for sustainable and efficient use and management of water.

The World Bank has been supporting Turkey's water resources management approach by piloting innovative and climate-smart agriculture technologies and promoting integrated basin management practices. The ESA project provided remote sensing services to fulfill the need for spatial data in the Bank project areas on agricultural, forestry, and pasture land uses, as well as information on urban settlements, erosion, land and natural resources degradation, and irrigation systems.

Land use and land cover

The EO services on land use/land cover and change mapping have been developed for the Akarçay River basin in Eastern Turkey for three years 2013, 2009, and 2006 primarily based on high-resolution RapidEye (~5m), SPOT (10m), and on Landsat data (Landsat data were pan-sharpened to 15m and resampled to 5m in order to match the pixel size of the RapidEye data). The leading land use classes included:

- Crop types (eg. cotton, sugar beet, etc.)
- Forest
- Pastures
- Urban areas
- Settlements
- Infrastructures
- Wetland
- Water features



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1. Land cover/land use of Akarçay river basin 2013. SPOT 5 data © CNES, RapidEye data © BlackBridge AG, Landsat-8 data © USGS, DEM © SRTM NASA. Credits: Geoville & Metria for ESA/World Bank.

Water Resources Management

The findings revealed that the land cover/land use composition for 2013 in the basin is dominated by cropland and grassland, which make up about 75% of the total area. Relatively small amount of the land is occupied by the sparsely vegetated bare soil (9%), forest/shrubs (7%) and water/wetland (6%). Built-up areas and infrastructure uptake only 1.6% (Figure 1).

During the entire observation period from 2006 to 2013 about 3.4% of the Akarçay basin area was subject to land cover/land use change. Most of the changes occurred due to class fluctuations between grassland and cropland, on the one hand, and water and wetlands, on the other, partly due to seasonal variations. In total cropland extent has increased by 6272 ha. An area of 11182 ha of cropland was converted to other land use. Built-up areas have increased by 936 ha (Figure 2).

Crop type mapping and irrigated crop area mapping

The crop extents maps were developed for 2006-2009-2013. In addition, crop type classification was provided for 2013 as well as irrigated crop area maps, using as calibration reference crop type information provided by the Turkish stakeholders. The crops were identified as dominated by wheat and barley (78.5% of the total

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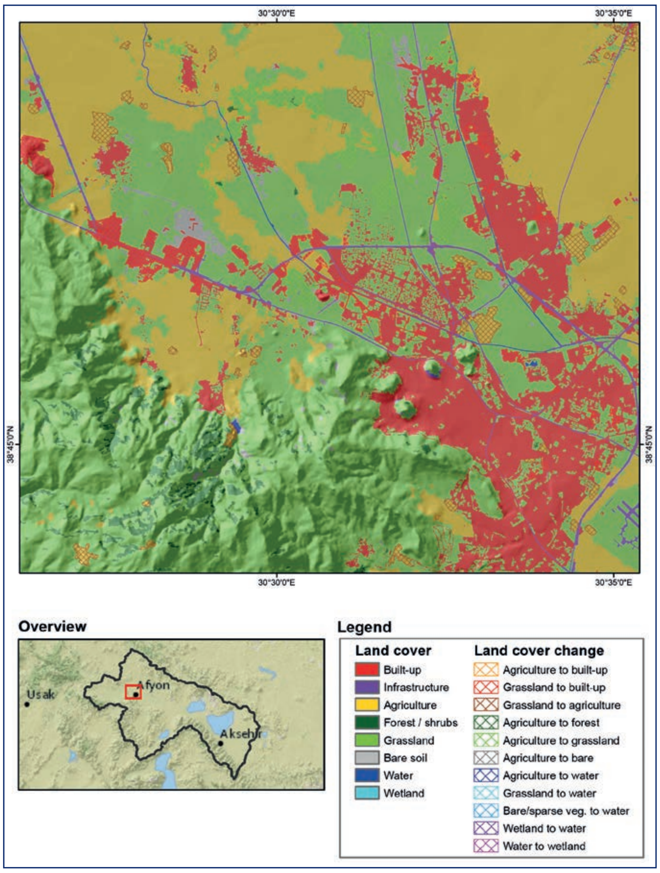

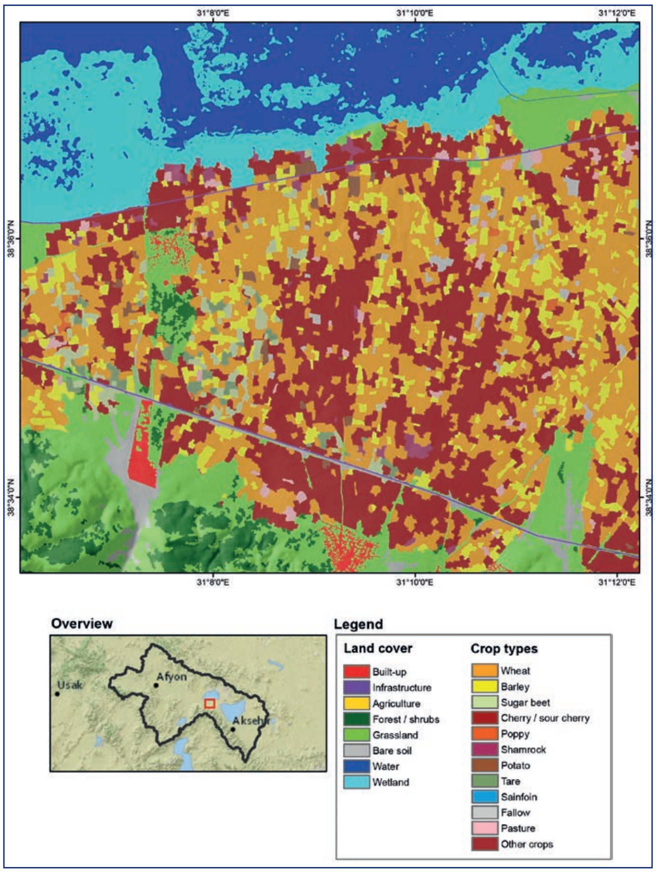

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2. Land cover / land use change map 2013–2009 of Akarçay river basin. SPOT 5 data © CNES, RapidEye data © BlackBridge AG, Landsat-8 data © USGS, DEM © SRTM NASA. Credits: Geoville & Metria for ESA/World Bank

3. The excerpt from the land use as well as crop type map, in the Akarçay river basin, Turkey. The information has been derived based on classification of multi-temporal satellite images in very high to high spatial resolution. SPOT 5 data © CNES, Distribution Airbus DS, RapidEye data © BlackBridge AG, Landsat-8 data © USGS, Crop type reference data © Ministry of Agriculture. Credits: Geoville & Metria for ESA/World Bank.

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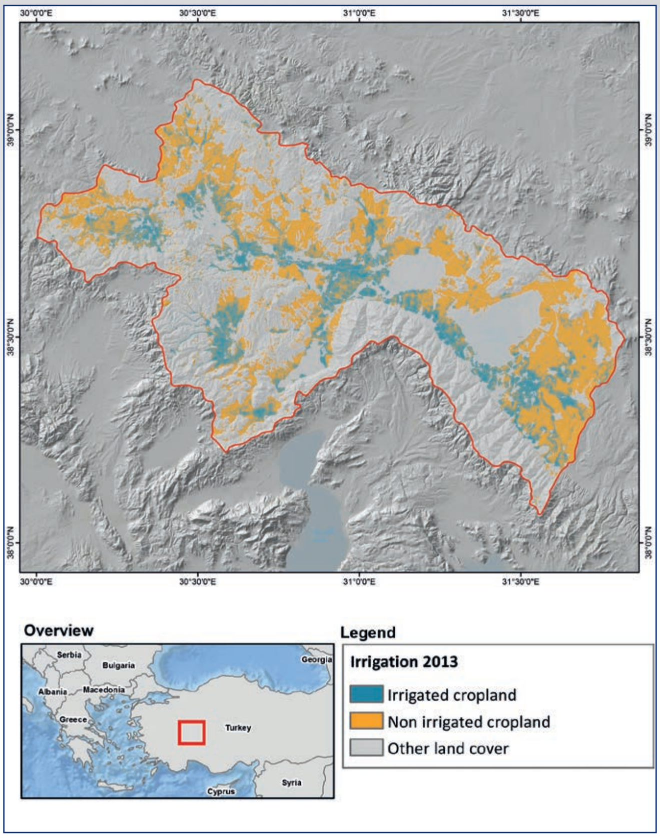

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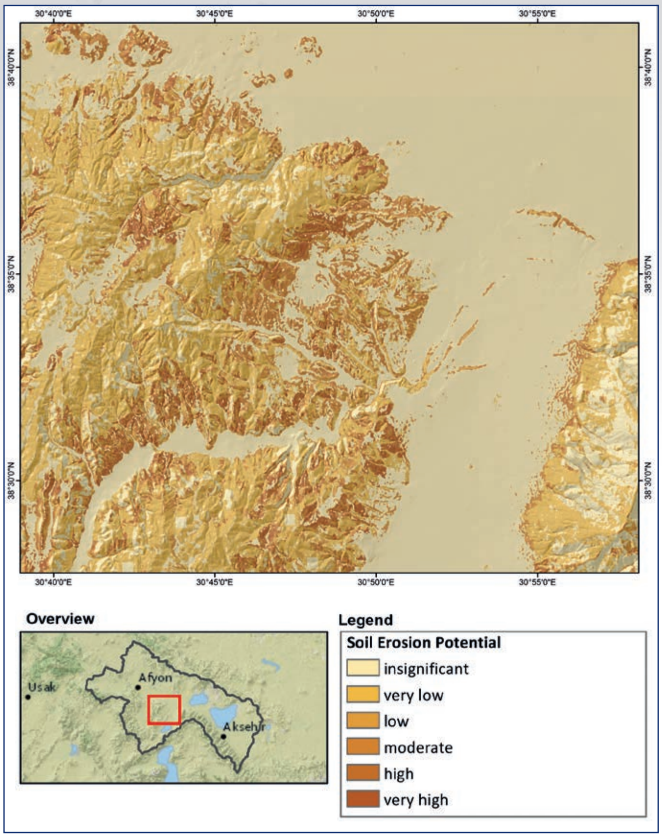

cropland area in the basin), followed by sugar beets and cherry trees (10.5%). Other crops such as poppy, shamrock and potato were also identified (1%) (Figure 3). More than 29% of the overall crop area was identified as being irrigated (Figure 4).

Such crop inventory is essential for policy, food security programs and other agro-environmental health investigations. It can serve as an input to support subsidies, certification systems, or climate-smart agricultural practices. Moreover the basic crop type and extent and irrigated area mapping is one of the input variables to production estimates and yield analysis models as well as other added value services such as water quality or water abstraction by irrigation.

Soil erosion potential and vegetation productivity and potential degradation indicators

The project provided two additional EO based services: the soil erosion potential and vegetation productivity based on the proxy data of Net Primary Productivity (NPP), Rain Use

4. The map of irrigated and rainfed croplands. Cropland has been derived based on classification of multi-temporal satellite images in very high to high spatial resolution. Irrigated areas were mapped using multitemporal NDVI data and functional ecosystem classes. RapidEye data © BlackBridge AG, Landsat-8 data © USGS, CCI land cover data © ESA, Ecosystem functions © Diversity II – ESA, Crop type reference data © Ministry of Agriculture, DEM © SRTM NASA. Credits: Geoville & Metria for ESA/World Bank.

5. The map shows the soil erosion potential based on the Universal Soil Loss Equation. Input data are the land cover/land use map, a terrain model, soil type information from the Harmonised World Soil Database and precipitation data from the Tropical Rainfall Measuring Mission (TRMM). Precipitation © NASA – JAXA, Soil type © FAO/IIASA/ISRIC/ISSCAS/JRC, DEM © SRTM NASA. RapidEye data © BlackBridge AG, Landsat-8 data © USGS, SPOT 5 data © CNES, Distribution Airbus DS. Credits: Geoville & Metria for ESA/World Bank.

Efficiency (RUE), and Soil Moisture Use Efficiency (SMUE).

The soil erosion potential represents the average soil loss in tons per hectare per year. The absolute figures were classified into six classes showing the relative erosion potential. The result shows that it is high on steep slopes and in general low in flat areas (Figure 5).

Vegetation productivity indicators are relevant for river basin management, as they provide signs of the vegetation productivity (NPP – Net Primary Production) for different seasons and in relation to rainfall and soil moisture, as well as land use changes and trends. The indicators were developed based on ENVISAT MERIS data, which have been recorded from 2002 (July) to 2012 (March) at a spatial resolution of 300m. They cover the vegetation years 2003 – 2011, starting with the rainy season in 2003 and ending with the start of the rainy season in 2011 (Figure 6).

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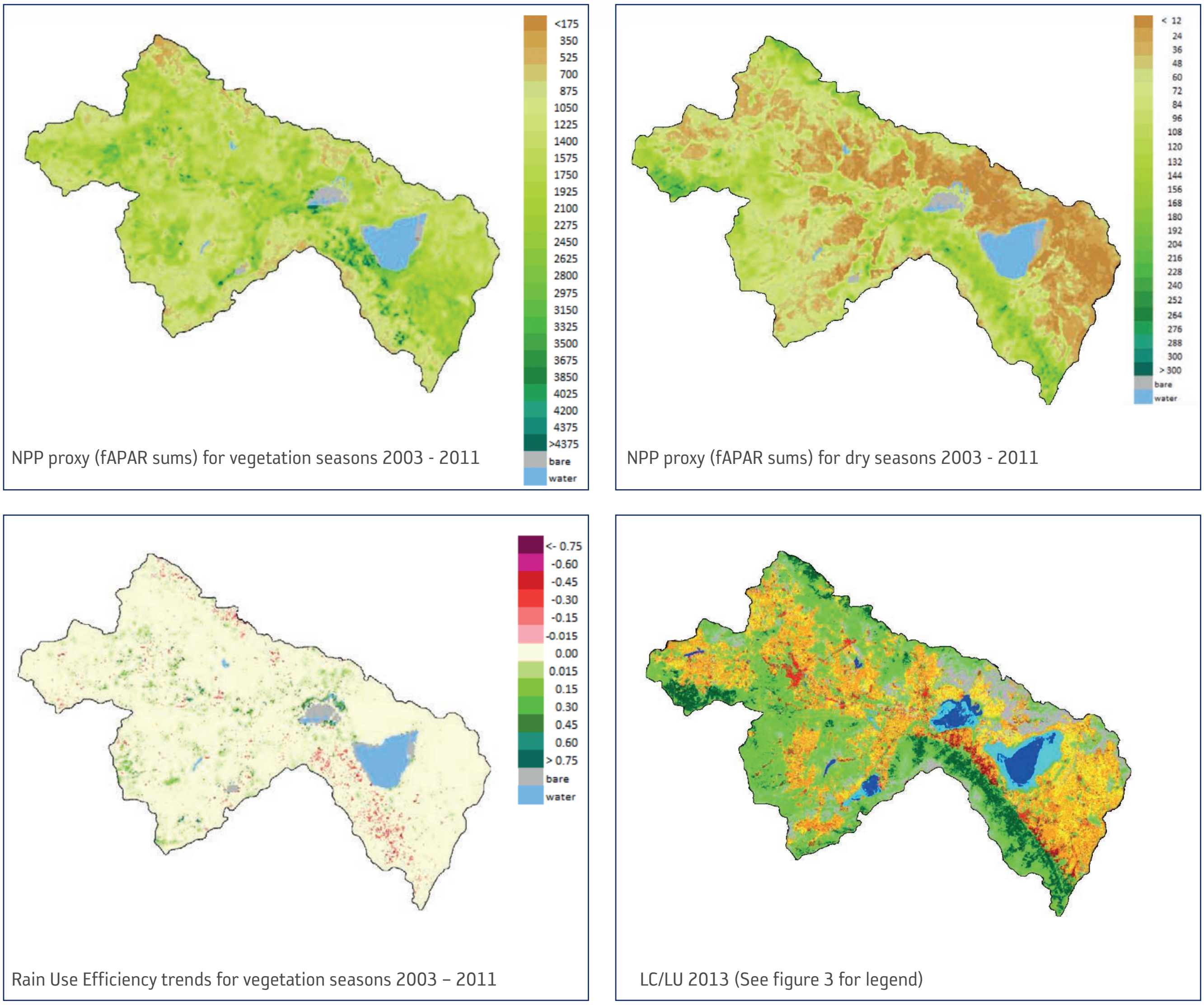


NPP proxy (fAPAR sums) for vegetation seasons 2003 - 2011

NPP proxy (fAPAR sums) for dry seasons 2003 - 2011

Rain Use Efficiency trends for vegetation seasons 2003 – 2011

LC/LU 2013 (See figure 3 for legend)

6. Comparison of seasonal NPP proxies, Rain Use Efficiency trends and land cover/use 2013 with the outline of the Akarçay river basin. The figures in the legend represent average fAPAR (Fraction of Absorbed Photosynthetically Active Radiation) values from 2003 to 2011. Credits: Brockmann Consult, Geoville for ESA Diversity II.

Characterisation of long-term watershed changes in Tanzania

Users:

- World Bank Water Global Practice

EO services provided

- Land cover / land use and its changes, focusing on irrigation patterns and water courses
- Mapping of degraded land

Service Providers

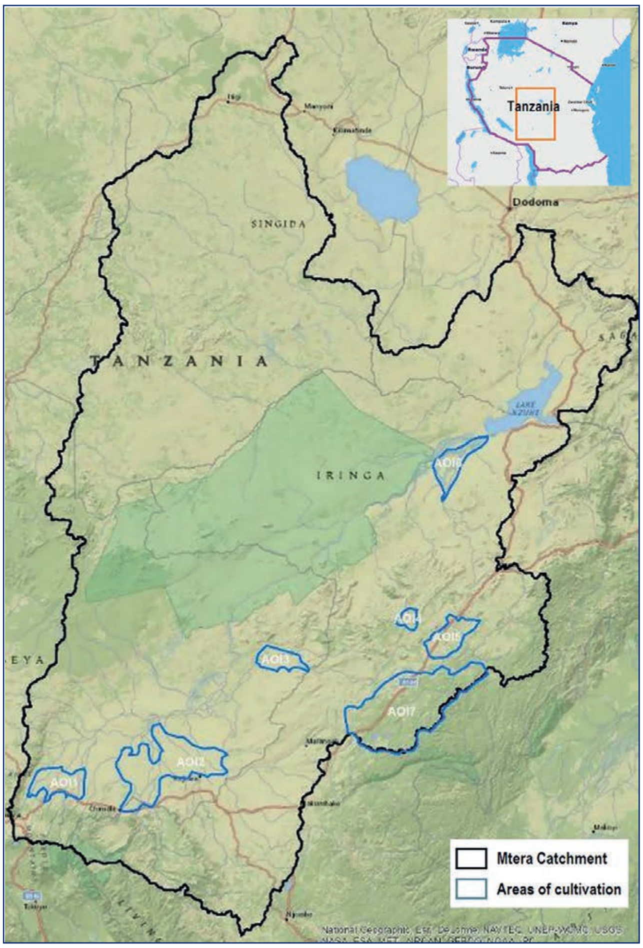
- Martin Critchley & Associates (Ireland)

Background

The main objective of the EO support project was to use EO data to map land use and land cover changes in the Mtera-Kidatu catchment of Tanzania. The Mtera-Kidatu catchment feeds the Mtera dam which was built from 1975 to 1979 for the purpose of regulating water level downstream at the Kidatu Hydro-electric Dam. Since the dam was built, its water levels have steadily declined. A report produced by the World Bank in 1995 attributed the low level of water to drought, increasing irrigation upstream and poor operation of the reservoir. Additional low water levels occurred in 2000 and 2011.

To resolve causal connections between the declining water levels and the occurrences in the catchment the present research by the World Bank has mainly concentrated upon climatic and dam management issues. However, there is extensive agriculture in the catchment which includes rain fed crops as well as irrigated crops. Most irrigated crops are the result of government-approved schemes, although there is a suspicion of illegal irrigation. In addition to these issues there is also a question of un-regulated grazing, especially the Usangu wetlands which form an important buffer to the Mtera catchment. Between 2007 and 2009 a large number of pastoralists were present in the Usangu wetlands and these may have resulted in over grazing and extra extraction of water. The pastoralists were removed in 2010.

EO data was used to provide the characterisation of changes taking place in the watershed over the last 2–3 decades, and results were presented in a form suitable for use in the present World Bank catchment study. The work was structured in the following steps: 1) rapid mapping of extent of irrigated areas using medium-resolution optical imagery (Landsat TM); 2) basin-wide study of land use changes using Landsat TM imagery; 3) Detailed mapping



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1. Study area (Mtera basin) showing areas of cultivation where more detailed analysis was performed.

of land use changes in the Kapunga area using high-resolution optical imagery (SPOT series, 1.5 m resolution), including settlement changes; 4) analysis of the land degradation, and 5) investigation of options for further analysis of crop growth patterns over time using medium-low resolution optical imagery (MODIS/MERIS).

Land Use Changes and Irrigation Patterns

An initial visual analysis of the satellite imagery revealed four main types of arable land within the Mtera basin. These are (see also Figure 2):

1. Modern large-scale schemes that comprise farming units established with the aid of international financing. The main crops are soy and rice. These areas only use water during the rainy season and are probably less of an issue for water loss in the basin in the dry season. Examples are the Kapunga, Mbarali and Madibira rice farms. The Kapunga scheme is the largest in the basin.
2. Improved traditional systems, i.e. traditional systems that have received government- or donor-assisted interventions to improve the headworks and water control structures. Mixed rice and cash crops are present, with apparent use river water in both rainy and dry seasons.
3. Traditional systems, which comprise village irrigation, based on the diversion of perennial or seasonal flows, used mainly for the production of rice, vegetables and other relatively high-value crops. Increasingly these

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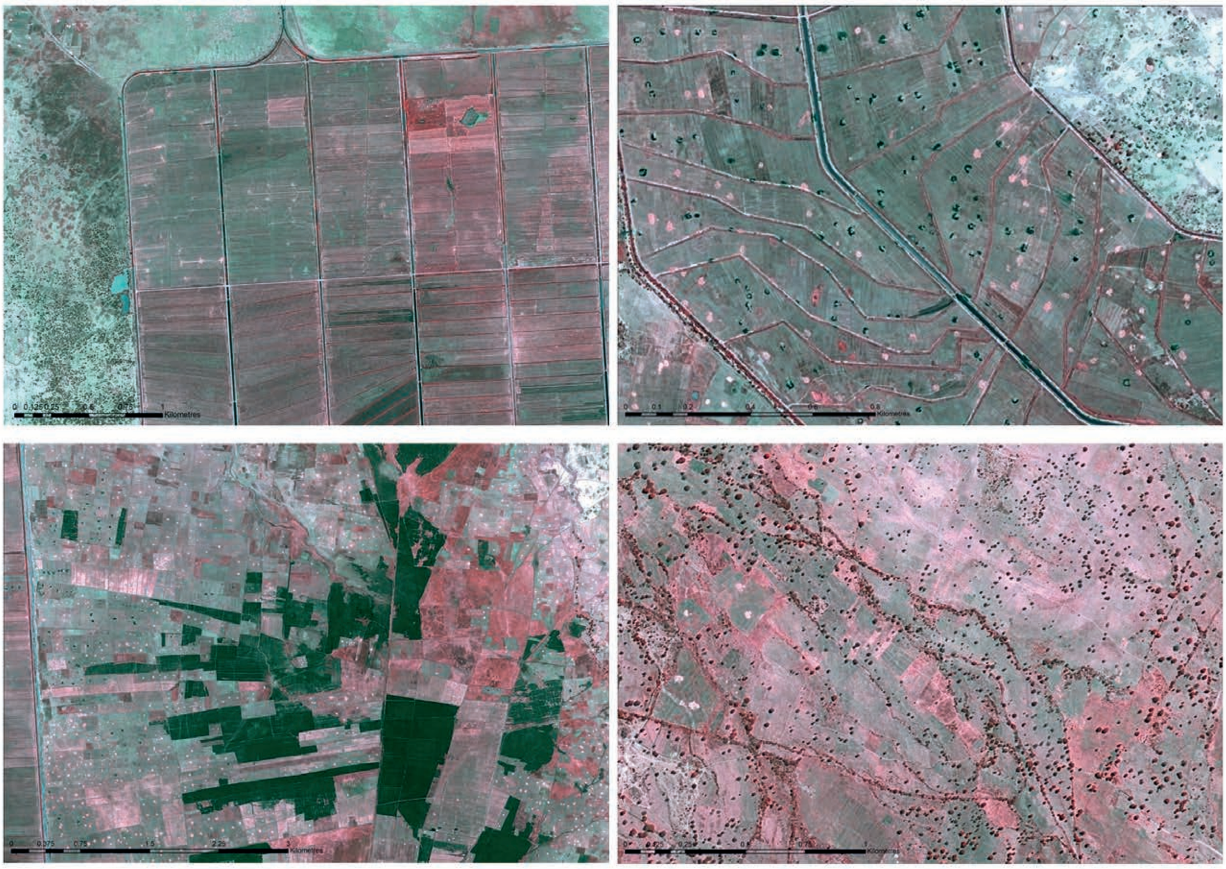

2. Types of arable land in the Mtera basin. Top left: large-scale irrigation, Kapunga. Top right: small-scale irrigation, Kapunga. Bottom left: unplanned irrigation, east of Kapunga. Bottom right: mixed rain-fed arable land and pasture agriculture. Landsat data © NOAA. Credits: Martin Critchley & Associates for ESA/World Bank

informal (unplanned) irrigation areas are found adjacent to the formal schemes, and are made up by a mix for cash crops and garden crops.

4. Informal river-fed garden crops for local consumption, which are usually closely intermixed with enclosed pasture for grazing.

The distribution of irrigated arable crops was undertaken using the Landsat TM for the six points in time: 1986, 1992, 1998, 2004, 2008 and 2013. An initial classification was performed using object-based image segmentation, classification, followed by visual refinement. Three types of irrigated land cover types were mapped: large-scale

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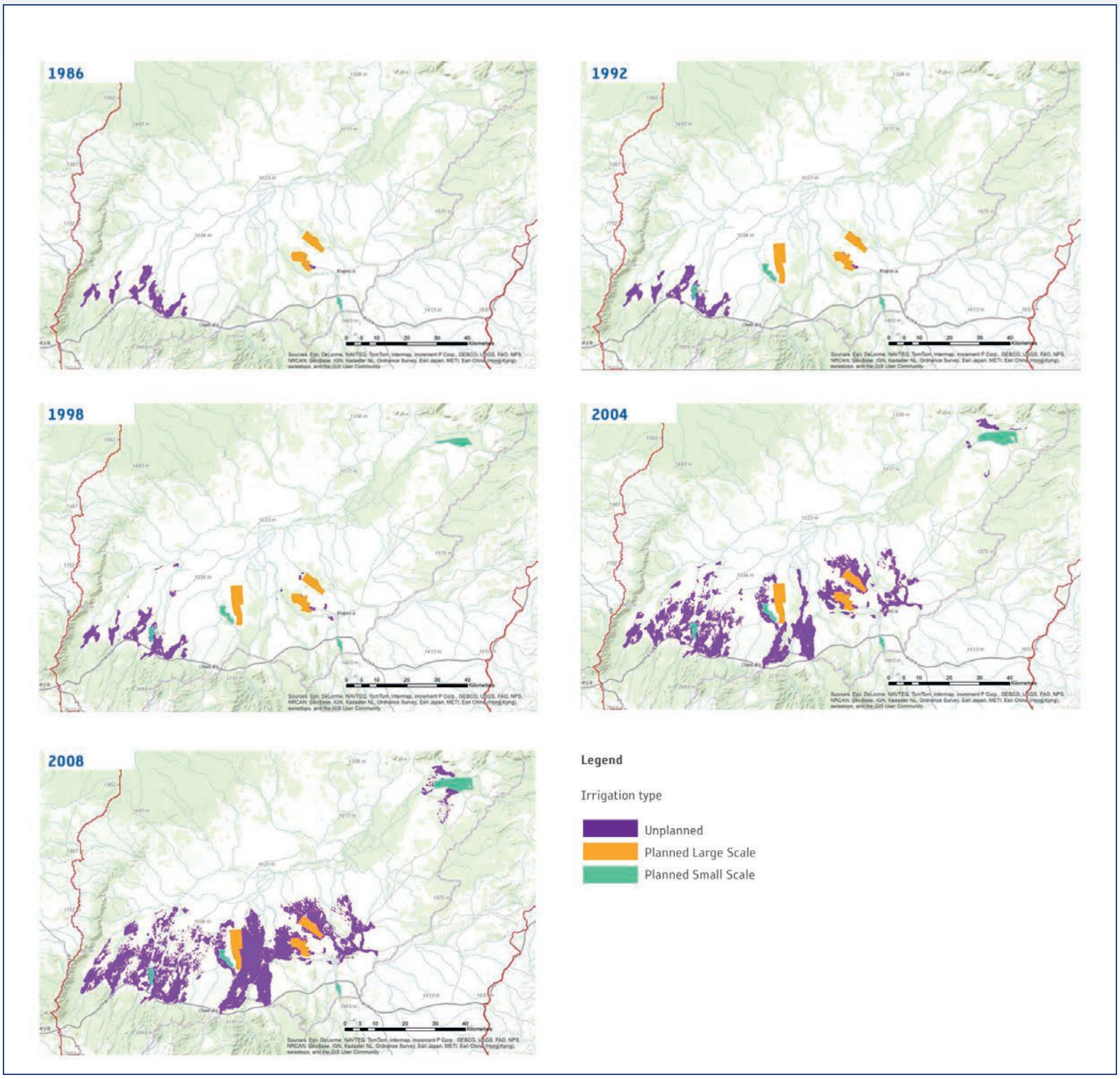

3. Evolution of irrigated land around the Usangu wetlands. Credits: Martin Critchley & Associates for ESA/World Bank

planned, small-scale planned and informal/unplanned. The large majority of the irrigated lands are located in the southern part of the catchment, along the rivers feeding the Usangu wetlands (Figure 3). In 1986, the only commercial irrigated crops were two schemes near Rujewa.

Using the classification of irrigated areas it is possible to analyse changes in the irrigation patterns over time from 1986 to 2013 (Figure 4). There was a doubling of planned large-scale irrigated land over this time period (from approx. 4,500 ha to 8,750 ha). Similarly, small-scale planned irrigated areas showed an almost sevenfold increase in area, from 1,300 ha to approx. 8,000 ha. Most dramatically, unplanned irrigated areas showed a tenfold increase from around 11 thousand ha to 101 thousand ha. The planned large-scale irrigated land showed a rapid increase in area between 1986 and 1992 and then a less steep increase after 1992. Planned small scale irrigated area show a steady increase between 1986 and 1992. There was little increase in unplanned irrigated areas during the period 1986 to 1998 but a rapid increase from 1998 onwards. The increase after 1998 averages nearly 6000 ha per year. The time lag between the implementation of planned irrigated schemes and unplanned irrigation would suggest that unplanned irrigation is stimulated by the planned schemes. There is also visual evidence from the satellite imagery that the unplanned irrigation in part has tapped into the outflow channels of the planned schemes.

Water courses for the different points in time were also mapped, using on-screen digitising. These can be grouped into natural water channels and man-made channels for irrigation. Figure 5 shows their distribution, further divided into major, medium and minor courses. High-resolution imagery was only available for the main Usangu area and thus temporal analysis of water channels was only performed there. Overall, changes in river lengths are not large and are probably due to small variations in river flows between the considered dates. Major irrigation channels are those built for the planned irrigation schemes. There were a total of 151 km of major channels in 1986 and these increased to 284 km in 1984 but with no increase afterwards. These new major courses correspond to the building of the Kapunga scheme in 1992. Medium and minor-sized irrigation channels are either found leading off from the main planned irrigated areas (probably as

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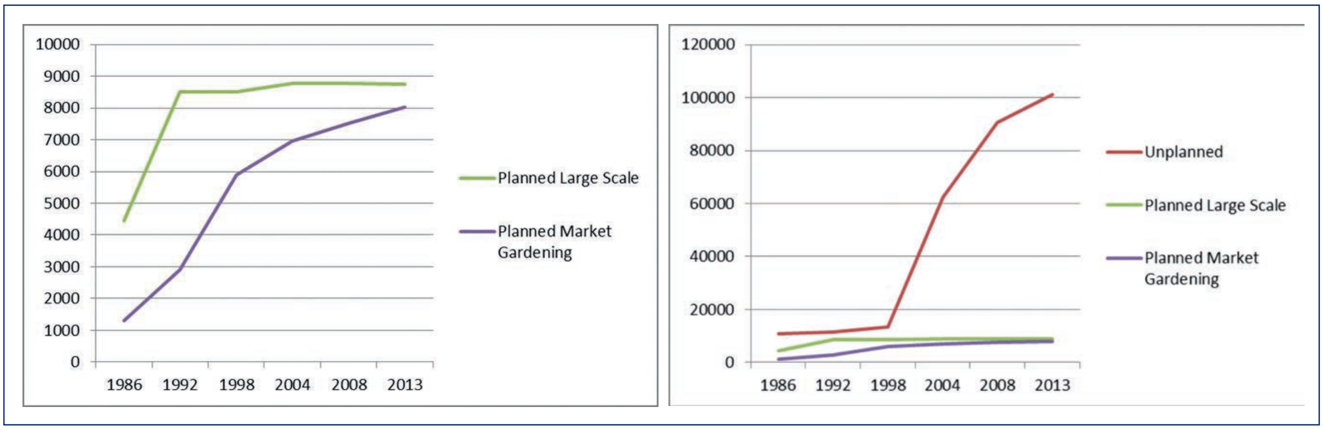

4. Evolution of irrigated land total areas from 1986 to 2013. Credits: Martin Critchley & Associates for ESA/World Bank

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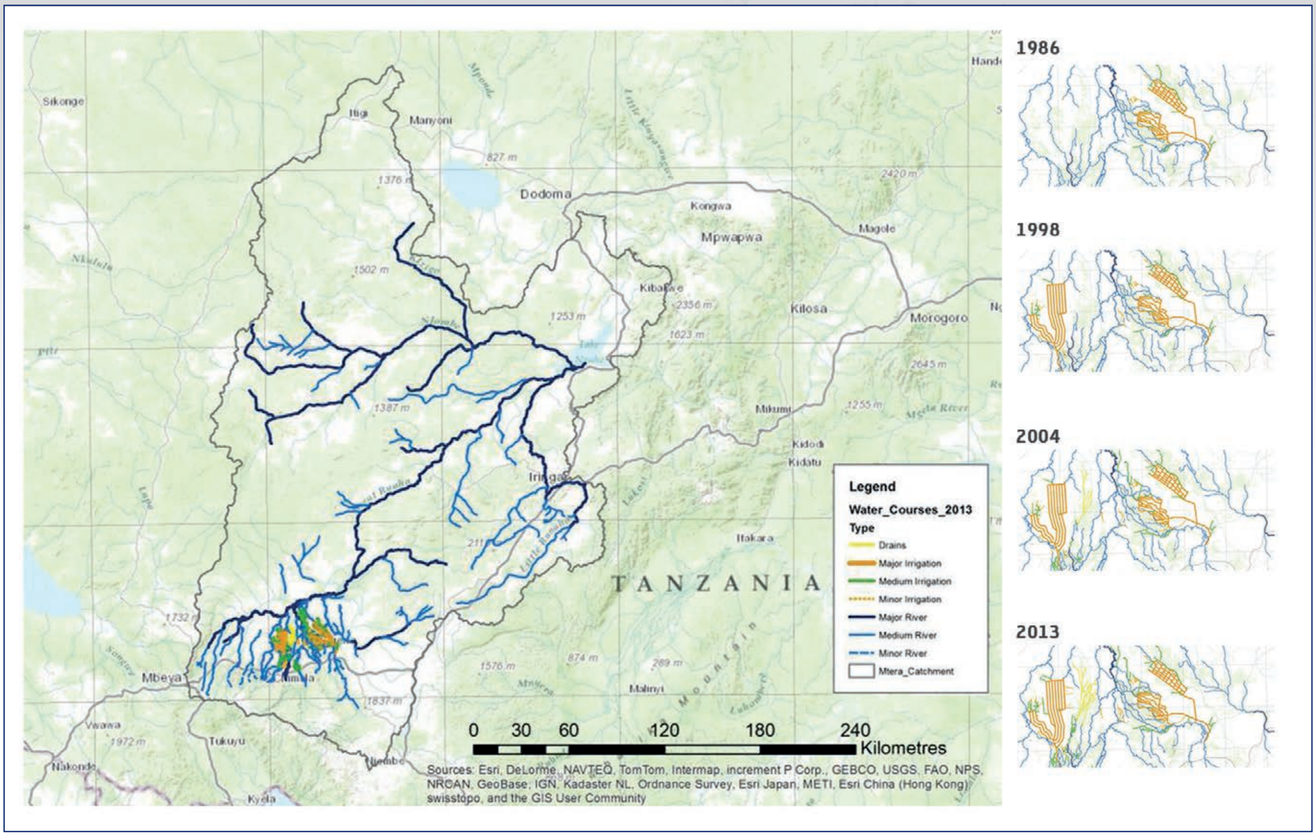


breaches into the major channels) or lead water from the rivers into areas of unplanned or informal irrigation. The medium channels show a large increase (from 77 km to 146 km) between 1998 and 2003, corresponding to a period after the construction of the Kapunga scheme. This would suggest that the building of planned irrigated schemes stimulated the unplanned schemes, albeit with a time lag of 5-10 years after the planned schemes.

Drains are mainly found in the former wetland areas to the east of Kapunga, where they appear to drain excessive water from the soils to allow for informal cultivation. The total length of these drains also increased post the construction of Kapunga.

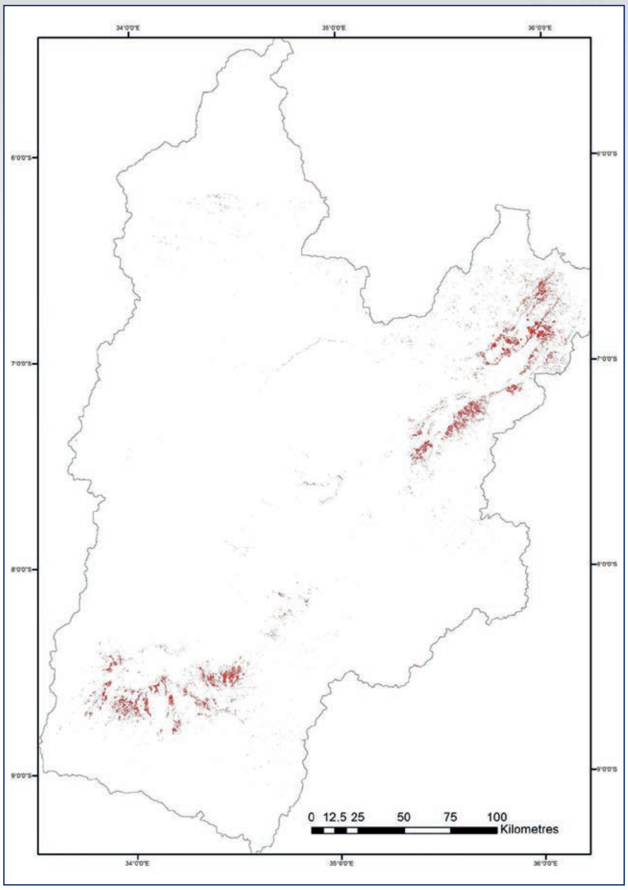
Similarly, a mapping of urban areas was also performed. At catchment level, the areas of urban fabric are too small to allow their monitoring for each year. Only Google Earth 2013 imagery was available in high enough resolution to map the whole catchment using on-screen interpretation. Multi year mapping of urban fabric was only possible for the Usangu area (using SPOT imagery). Analysis showed an increase in urban fabric in the Usangu area from 2,824 ha in 1986 to 3,833 ha in 2013.

5. Mapping of water courses in the Mtera basin for 2013. The succession of images on the right shows in detail the evolution of the water courses in main Usangu area. Credits: Martin Critchley & Associates for ESA/World Bank

Degraded Land

Degraded land was mapped using NDVI, brightness and soil indices of wet season Landsat TM imagery. Figure 6 shows the distribution of degraded land for 2013. In 1995, the only degraded land was found in the northeast, near the Mtera dam. In 2000 there was an increase in degraded land near Mtera but also the start of some degradation in the SW close to the Kapunga irrigated areas. In 2007, degradation increased near Mtera and Kapunga and a new of degradation started in the central part of the catchment. The central area appears to improve in 2013 but the Mtera and Kapunga areas show increased degradation. Overall, degraded land shows little change in area between 1995 and 2000, but big increases between 2000–2007 and 2007–2013. Much of this increase was in the southwest, in the Usangu area.

An additional exercise was undertaken to see if traditional Maasai settlements (boma) have increased in proximity to degraded lands. Only the high resolution 2007 and 2013 SPOT imagery could be used to detect these settlements. A distance analysis showed that out of the 1742 detected boma, 1183 are within 100 m of degraded land in 2013.



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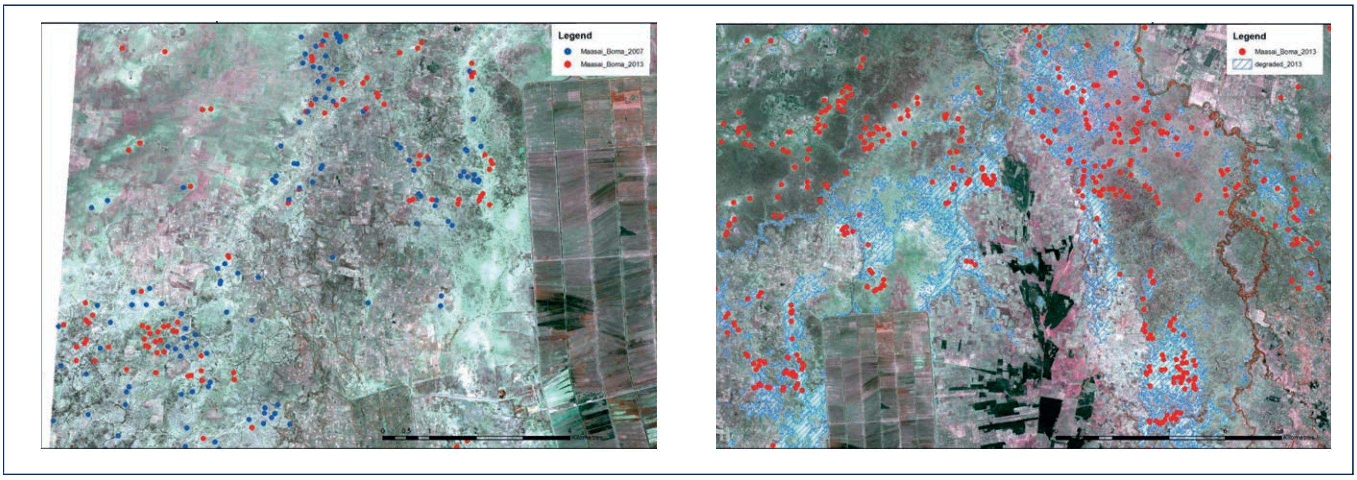

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6. Distribution of degraded land in 2013. Credits: Martin Critchley & Associates for ESA/World Bank

7. Left: the growth in number of the Maasai boma from 2007 (blue) to 2013 (red). Right: locations of the Maasai boma (red) in relationship to degraded land (blue hatched areas). Credits: Martin Critchley & Associates for ESA/World Bank

Results

The study has demonstrated the use of Earth Observation data for monitoring land use in the catchment of hydroelectric power generation reservoirs. The main results show that land use patterns changed over the period 1986–2013 especially adjacent to major areas of planned commercial irrigation. Whilst planned commercial irrigation doubled in area during the period, most of the change were between 1986 and 1992, with little new development after that. Conversely, unplanned (informal) irrigation started to increase in 1998, some 5–10 years later than the installation of the commercial schemes. Between 1998 and 2013, the unplanned (informal) irrigation grew 500%, with doubling of the total length of associated irrigation channels. There is evidence that some of the informal irrigation took place in former wetland areas with drainage channels being developed to allow crops in these areas.

A dramatic 10-fold increase in degraded land between 1995 and 2013 was suggested from wet season imagery. However, caution should be given to these results unless there is further investigation. Only two images were used for each year studied (dry season and wet season) and a better analysis might be obtained from more frequent (monthly) imagery. In addition analysis of monthly rainfall records and seasonal burning may also need to be incorporated in the analysis.

The study of settlement patterns was limited by the resolution of the imagery used (mostly SPOT 10 m/20 m and Landsat 15 m/30 m resolution) coupled with the dispersed settlement patterns and small size of houses. For the Usangu area, the analysis shows an approximately 33% increase in urban fabric and there is suggestions that some of the new urban areas were built adjacent to the planned commercial irrigation schemes. Similarly, mapping of traditional settlement requires very high resolution imagery the analysis of these images indicates a 25% increase in the number of Maasai boma between 2007 and 2014 in a limited study area. Furthermore, the analysis shows that many Boma were close to degraded land in 2013.

The EO information was used as a crucial input to a World Bank analytical study on water resources management in southern Tanzania, and is part of the World Bank policy note Tanzania's Water, Hydropower and Climate Future. The EO data supplemented the records of land and water rights for the studied area, which were outdated and incomplete due to illegal and informal irrigation development. The only possible way to obtain the same data would be to do detailed and costly land surveys. Without the impartial assessment made possible by satellite information, the study outcome would have been very uncertain and questionable. Many developing countries face similar problems of incomplete records of land use, where EO analysis provides a cost-efficient method to update these. Such data are crucial for sustainable land and water management.

"The EO data filled in a gap on actual irrigation area, which was not available from any surveys or land rights record in Tanzania. Without the EO data the results of the study would have been very uncertain and the whole study would have been put in question. The EO data created an undisputed fact about actual irrigation area (and indirectly thereby also of water use) that has already been referred to numerously in the past."

Rikard Lidén, Senior Hydropower Specialist, Water Practice, World Bank

Water Resources Management

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8. The map of water courses and major irrigated areas. Credits: Martin Critchley & Associates for ESA/World Bank
Images show the World Bank webstory about support to irrigation systems development available at http://www.worldbank.org/en/news/feature/2013/08/30/irrigation-development-helps-tanzanian-farmers-thrive and Tanzanian local communities tilling rice paddies on an irrigation project and cultivating crops. Tanzania. Photo: Scott Wallace / World Bank

Support to REDD Program in Latin America

Users:

- World Bank Global Practice on Environment and Natural Resources
- CONAF (Corporación Nacional Forestal) in Chile
- Forest Carbon Partnership Facility (FCPF)
- Forest Investment Program (FIP)

EO services provided

- Forest / forest change mapping
- Land use / land use change mapping
- Forest fragmentation indicators

Service Providers

- GAF (Germany)

Background

The impact of infrastructure expansion on tropical forests is currently of particular importance in South America. There are large infrastructure projects planned or taking place as a way to improve communication and stimulate economic growth. A clear example of this is the "Initiative for the Integration of the Regional Infrastructure in South America" or IIRSA, which aims to promote the development of transportation, energy and communication to enhance the connectivity of South American countries. IIRSA includes large-scale projects to build roads, waterways and ports. However, the cumulative impacts of these developments still have to be understood, especially when it comes to the negative effects of infrastructure development on deforestation through illegal logging. There is already substantial literature indicating that road construction and improvement, eg. construction of new roads and waterways, impacts extensive forest areas. In this context, geospatial information can be a useful tool for identifying, analysing and monitoring the causes of deforestation and forest degradation and provide essential evidence to respond to range of forest management issues. This applies to:

- identifying cases where infrastructure development may affect important forested areas,
- assessing and locating areas where deforestation is taking place because of infrastructure development,
- evaluating the direct and indirect impact of infrastructure development on forests, including degradation,
- providing information for an informed forestry dialogue that supports national forest policies.

Forest, land use mapping and forest fragmentation assessment

Two areas of interest were selected to demonstrate the state-of-art monitoring systems for assessing impact of infrastructure and agriculture expansions on deforestation: northern part of Isla Grande de Chiloé in Chile and the area of extreme dry broadleaved forest ecosystem in Argentina (so called 'Gran Chaco') close to the border of Paraguay. For both areas six forest change maps have been produced for the years 2007-2013, 2000-2013, as well as between 2000-2007 mainly based on the high-resolution optical satellite imagery from the RapidEye system.

Figure 1 presents the land cover/land use change map for the Argentinian service case which is located in the Chaco forest region that covers a total area of 21.7 million. Four provinces (Chaco, Salta, Santiago del Estero and Formosa) that make up 88% of the Chaco Ecoregion have poverty rates with low access to basic services or infrastructure. As a result, the communities living in those provincial areas are disproportionately dependent on forest products for their livelihoods, consuming more than 50 percent of the total fuel wood in the country and exerting the pressures

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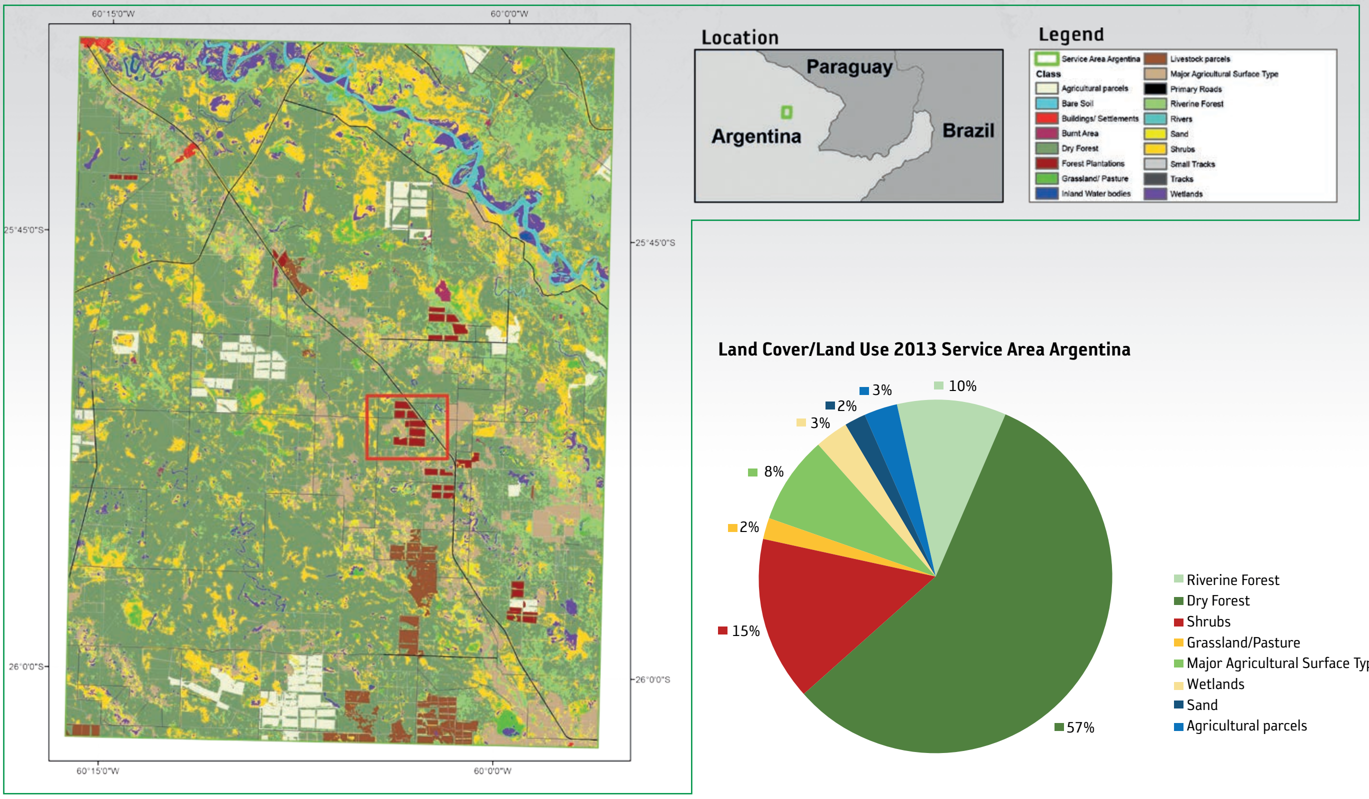

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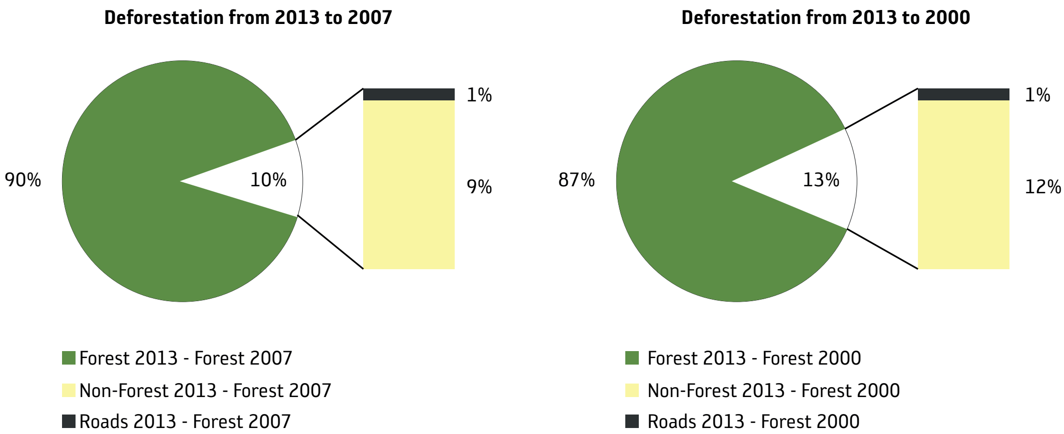

1. Land use/land cover statistics 2013 Service Area Argentina in 'Gran Chaco', an extreme dry broadleaved forest ecosystem in Argentina close to the border of Paraguay. RapidEye data © BlackBridge. Credits: GAF for ESA/World Bank.
2. Deforestation from 2013 to 2007 and 2013 to 2000 for the Service Area Argentina. Credits: GAF for ESA/World Bank.

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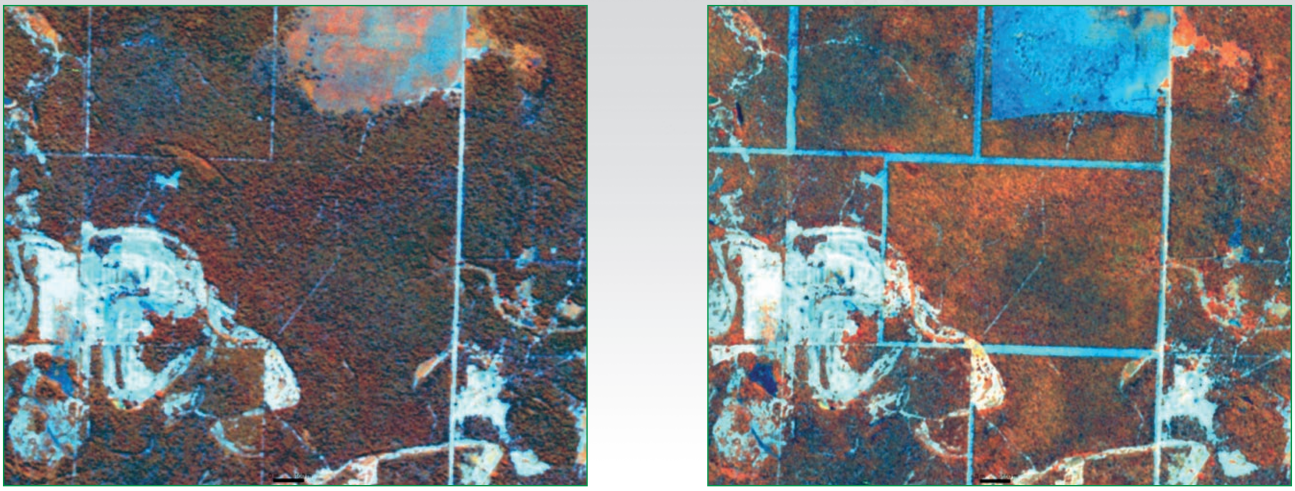

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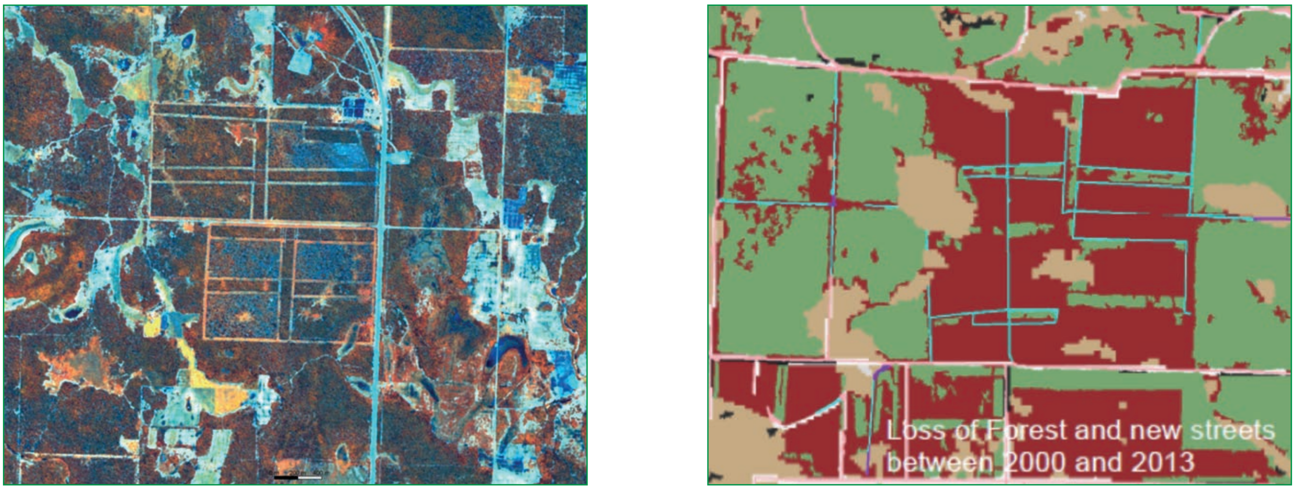

on the remaining natural resources. In addition the area is under pressure of agricultural commodities producers.

The study found that the entire service area is dominated by forest cover, which is subdivided into dry forest (which covers over the half of the area) and riverine forest (which covers almost 10%). Shrubs account for 14% of the area, while agricultural area covers only 7.5%. Between 2007-2013, approximately 10% of the forested land was lost mainly due to agricultural use, settlements and road construction (an overall of 774ha of new roads have been identified) (Figure 2). Newly established agricultural patches have been clearly identified through their rectangular shape and their specific vegetation coverage (Figure 3).

The second area in Chile (Chiloé Island) shows no significant changes in the monitored land surface. Overall

3a. Left: RapidEye satellite image acquired in April 2013 (left), RapidEye satellite image acquired in November 2013 (right), the red to brown areas are forested, blue lines are roads or tracks. The figure shows an example of the forest loss assessment due to agriculture expansion in project area in Argentina. Landsat data © USGS, RapidEye data © BlackBridge. Credits: GAF for ESA/World Bank.

3b. The figure shows an example of the forest loss assessment due to agriculture expansion in project area in Argentina. RapidEye data © BlackBridge. Credits: GAF for ESA/World Bank.

since 2000 deforestation reached 7%. Between 2007 and 2013 only 4% of forested area had been lost. Regarding infrastructure development, newly constructed roads/ tracks have been identified (nearly 418ha), however, the forest suffered little or no fragmentation (Figure 4). Moreover more than 3800ha of new forested area have been identified as forest plantations.

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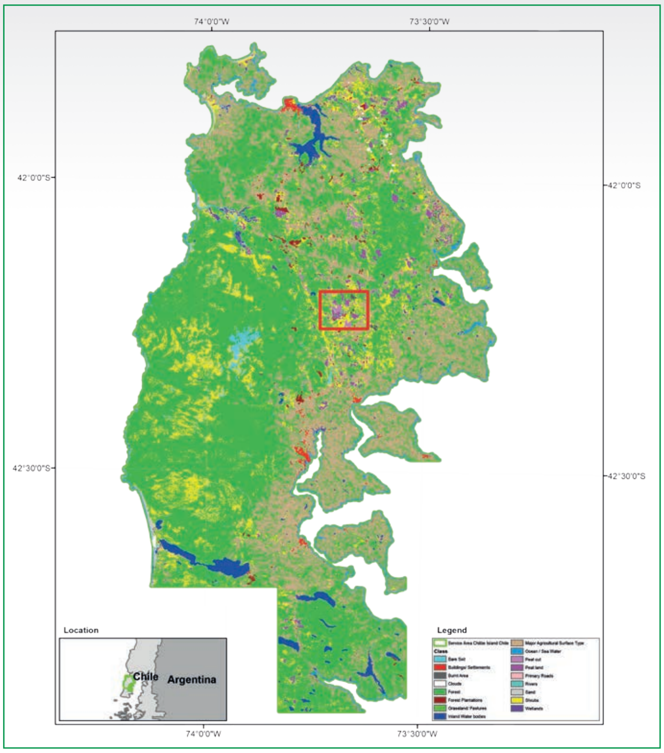
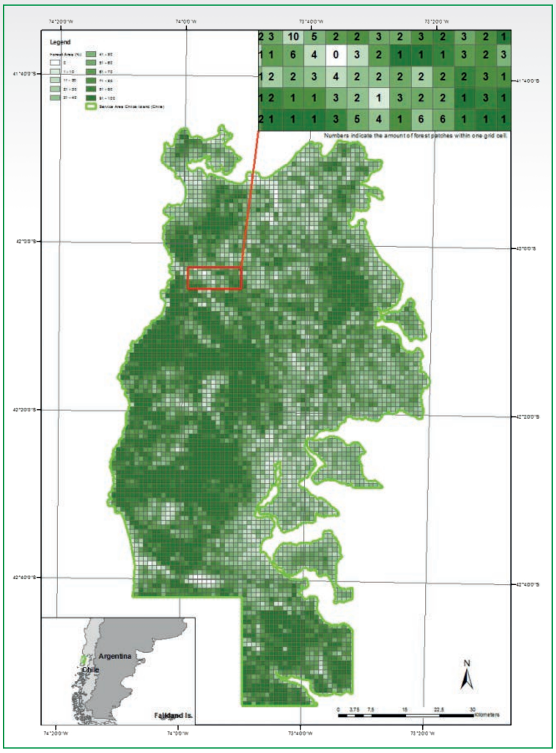
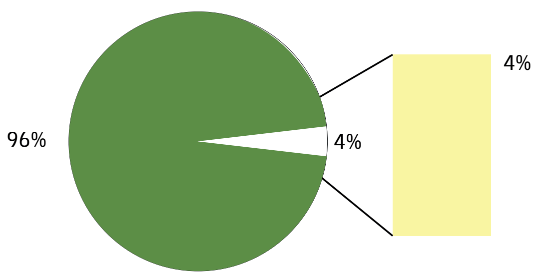




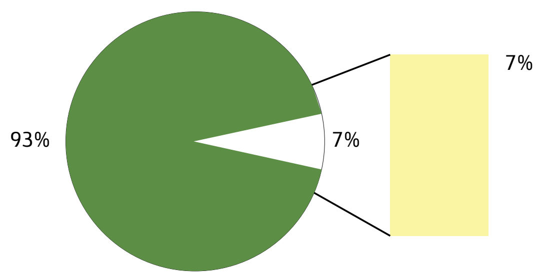
Deforestation from 2013 to 2007



Forest 2013 - Forest 2007

Non-Forest 2013 - Forest 2007

Deforestation from 2013 to 2000



Forest 2013 - Forest 2000

Non-Forest 2013 - Forest 2000

4. Deforestation statistics from 2013 to 2007 and 2013 to 2000 as well as forest fragmentation map for the Service Area Chiloé Island, Chile. Credits: GAF for ESA/World Bank.

Sustainable Land Management and Plantation Planning in Mozambique

Users:

- World Bank Global Practice on Environment and Natural Resources
- World Bank Maputo Country Office
- International Finance Corporation
- Portucel
- UT-REDD Mozambique
- FCPF Mozambique Task Force

EO services provided

- Forest / forest change mapping
- Land cover / land use mapping

Service Providers

- RSAC Ltd. (United Kingdom)
- RSS – Remote Sensing Solutions GmbH (Germany)

Background

The interest in private wood production in Mozambique is increasing steadily since mid-2000s. Several studies estimated that 7 million ha of land could be considered available for forest plantations development in central and northern regions. 'Available' land has typically been defined in terms of environmental sensitivity criteria and the absence (or acceptable mitigation) of social and land use conflicts. However, while commercial forestry is considered a potential contributor to GDP growth in Mozambique, the unsustainable land use planning can be a particular concern. This is because the customary (community) land use (eg. without a formal registration) is long established and practiced. As a result, it is often difficult to fully identify the actual land use by local communities, leading to overestimation of land availability. To this end, the World Bank is supporting the Government of Mozambique with a technical assistance to promote sustainable economic development of forestry sector which conforms to sound environmental and social practices. Additionally, the International Finance Corporation (IFC) participates in the development of investments relating to pulpwood plantations.

To assess available land some critical baseline information is required, such as existing forest cover and land uses. This study focused on the Namarroi and Ile Districts of Zambezia Province, northern Mozambique, which have been under consideration by investors for pulpwood production. For these two provinces some initial analysis of potential plantation sites has been completed in the past based on very high (2m) resolution remote sensing (SPOT) data acquired in 2009. However the knowledge gaps still existed in terms up-to-date information and trend analysis. Therefore, the ESA project complemented these past studies with information acquired for three points in time with the 10m (SPOT) and 5m (RapidEye) spatial resolution the minimum mapping unit of 0.5ha (forest mapping) or 0.25ha (land cover mapping) for 2000-2006 and 2013. Moreover, a map the pre-Civil War land cover situation has also been provided in order to reveal additional information on the land cover changes that occurred during the Civil War between 1977 and 1992.

Forest mapping

The analysis of forest cover concentrated on four main aspects: forest area and type classification, forest density, forest area changes and habitat fragmentation. The forest cover was mapped with minimum mapping unit (MMU) of 0.5ha using SPOT-2 (2006), SPOT-4 (2000, 2006), SPOT-5 (2006) and RapidEye (2013) data (Table 1).

In Mozambique, the predominant forest ecosystem is the Miombo, which covers about two-thirds of the country north of the Rio Limpopo. Other ecosystems include mopane in the semi-arid regions of the hinterlands (in the valleys of Limpopo and Zambezi) and the undifferentiated forests on the coast of the central region. For the purpose of this study two forest classes were classified: Miombo woodland and forest plantation (Figure 1) and provided in the form of geoinformation data products for two districts in the Zambezi Province (which were selected by the Government to identify and allocate formerly

Table 1

Type of map	Classes	Year / period	EO data basis	Minimum mapping unit	Geometric accuracy
Forest type	- Miombo woodland - Forest plantation - [Non-forest] - [No data]	2000	SPOT-4	0.5ha or better	<1 pixel
		2006	SPOT-2, SPOT-4 and SPOT-5	0.5ha or better	
		recent past (2011-13)	RapidEye	0.5ha or better	
Forest density	- Miombo woodland dense - Miombo woodland open - Forest plantation dense - Forest plantation open - [Non-forest] - [No data]	2000	SPOT-4	0.5ha or better	<1 pixel
		2006	SPOT-2, SPOT-4 and SPOT-5	0.5ha or better	
		recent past (2011-13)	RapidEye	0.5ha or better	
Forest fragmentation	- Patch - Edge - Perforated - Small core (< 100ha) - Medium core (100-200ha) - Large core (>200ha)	2000	SPOT-4	0.5ha or better	<1 pixel
		2006	SPOT-2, SPOT-4 and SPOT-5	0.5ha or better	
		recent past (2011-13)	RapidEye	0.5ha or better	
Forest area change	- Deforestation - Reforestation - Forest plantation decrease - Forest plantation expansion - No change - [No data]	2000 to 2006	SPOT-2, SPOT-4 and SPOT-5	0.5ha or better	<1 pixel
		2006 to recent past (2011-13)	SPOT-2, SPOT-4, SPOT-5 and RapidEye		

degraded and deforested areas for the establishment of plantations).

The study found that the past development of forest plantations in the Namarroi and Ile Districts is experiencing slow but steady growth. However the Miombo forest is sustaining dramatic changes the dense Miombo woodland area has decreased by 33.5% between 2000 and 2013, the area of the open Miombo woodland shows even higher change of -43.3%. Most of those changes are attributed to the expansion of the smallholder agriculture. Only negligible portion of natural forest has been converted to

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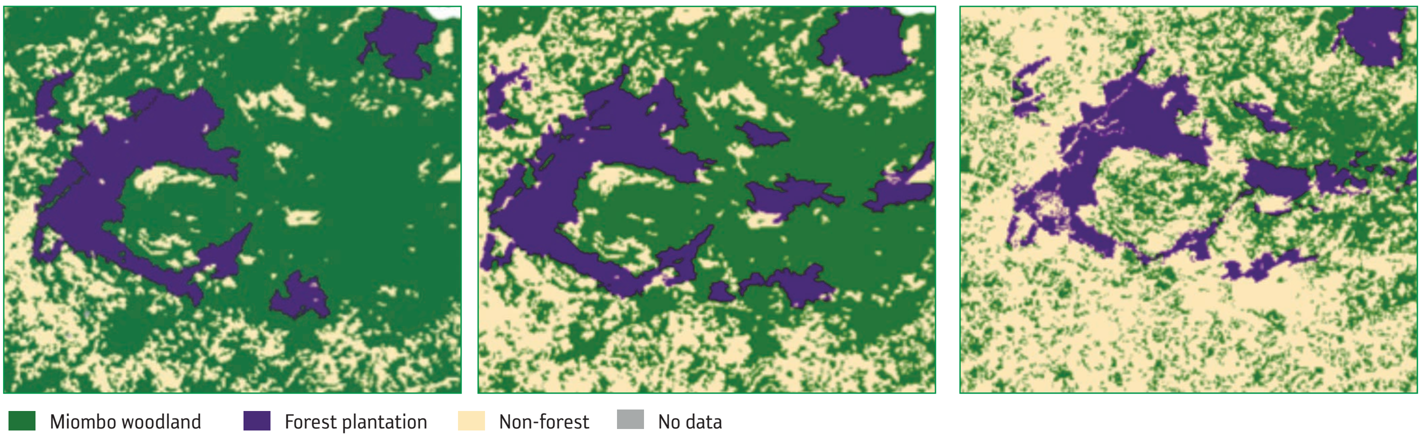

Table 1. Summary of the mapping products developed including land use classes, MMU, mapping/monitoring period and satellite data used.

1. Excerpt from the forest type map for 2000-2006-2013 showcasing the Miombo forest and plantation development. SPOT data © CNES, RapidEye data © Blackbridge. Credits: RSAC Ltd. & RSS for ESA/World Bank.

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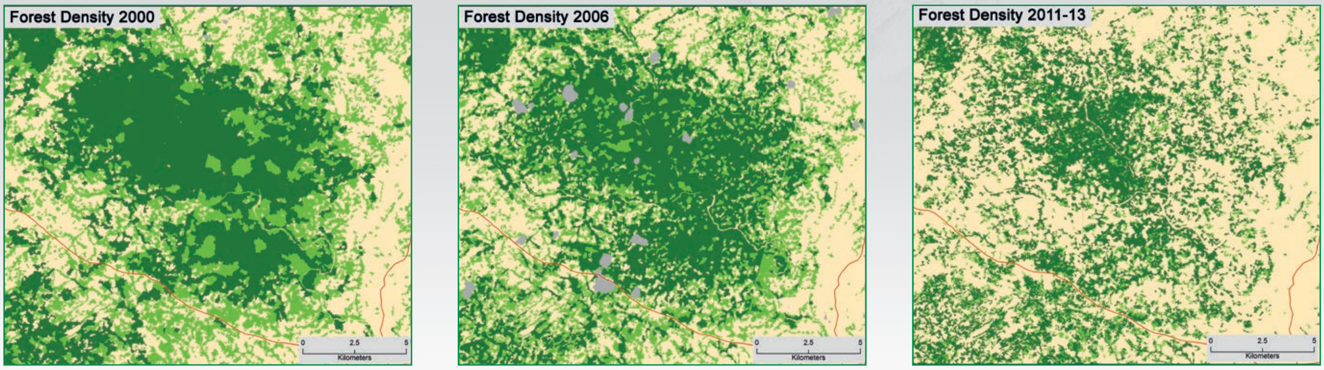

open forest plantation. Moreover, the forest fragmentation maps show a striking picture of forest disturbance. Large core forest areas have more than halved in the area of interest since 2000, whilst even small core areas have seen an overall decrease. These reductions are balanced by increases in the perforated, edge especially patch categories (Figure 3).

To assess the total change in forest area during the periods 2000-2006 and 2006-2011-13, a post classification change detection method was applied. Based on the derived forest cover maps the annual net rate of deforestation have been calculated (Figure 4).

Land cover

According to recent CIFOR study (Center for International Forestry Research) the underlying causes of deforestation and forest degradation in Mozambique include (i) technological factors (inefficient use of wood fuel, low

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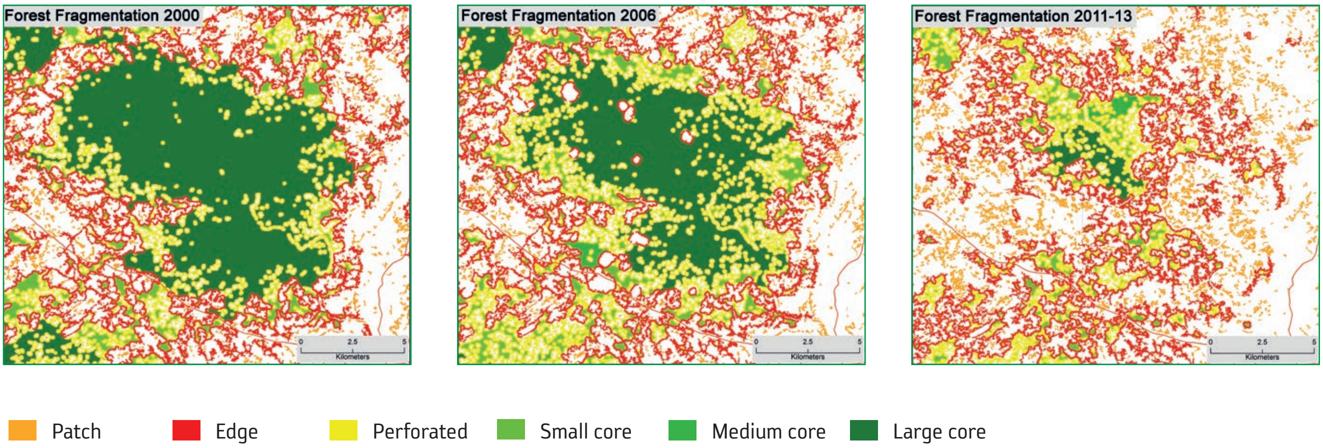
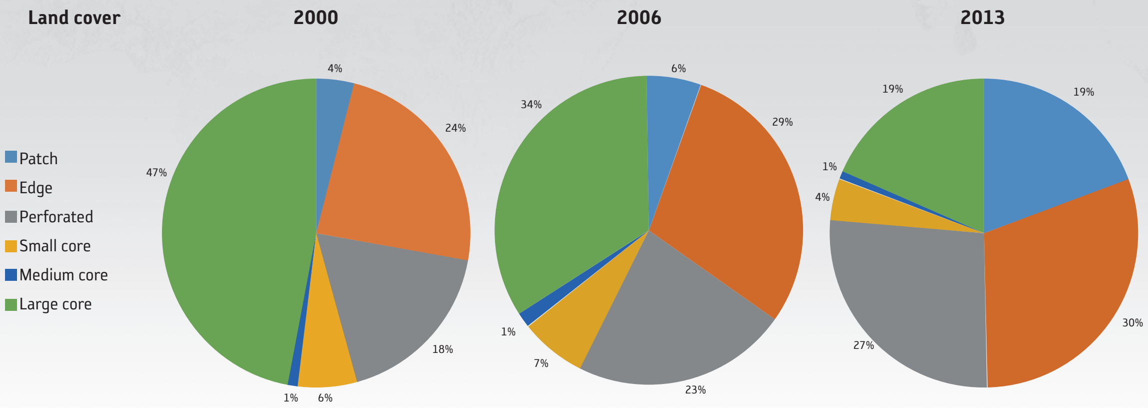


2. Detailed view of the forest density classification for three time steps (2000, 2006 and 2011-13). Clearly visible is how patches with low Miombo woodland density increase between 2000 and 2006. Between 2006 to 2011-13 large areas of Miombo woodland finally disappear. For Miombo forest two forest density classes, dense and open, were defined based on definitions developed by leading CIFOR (Center for International Forestry Research). SPOT data © CNES, RapidEye data © Blackbridge. Credits: RSAC Ltd. & RSS for ESA/World Bank.

3a. Detailed view of the forest fragmentation analysis for the three time steps (2000, 2006 and 2011-13). Clearly visible is how large core and small core Miombo woodland areas strongly decrease between 2000 and 2011-13. On the other hand, there is an increase in the perforated, edge and patch categories. Credits: RSAC Ltd. & RSS for ESA/World Bank.

3b



agricultural land-use intensity); (ii) demographic factors (high demand from urban areas); (iii) economic factors, such as those related to export markets for agricultural commodities (sesame seed, tobacco and cotton) and timber; and (iv) institutional factors, especially weak law enforcement capacity.

Examination of the land cover maps for 2000, 2006 and 2013 confirm some of these trends. Forest is no longer a dominant land cover in the both Districts. In the most recent change interval (2006-2013), the majority (83%) of deforested land was converted for subsistence agriculture. The second most common transition (10%) was from forest to 'scrub/grassland' which is suggestive of land reverting to unmanaged grassland or regenerating forest after initially being used for agriculture.

3b

Results

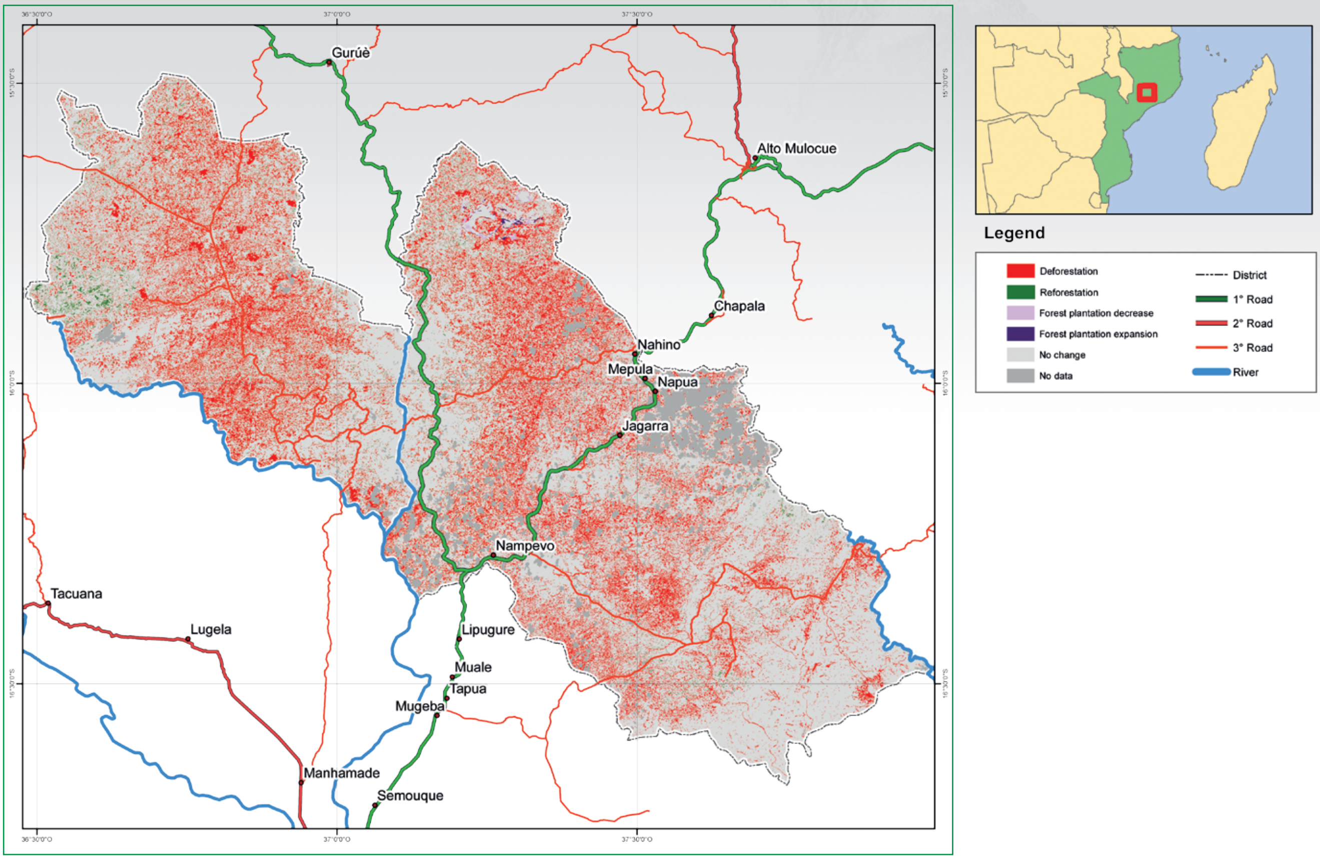
One of four objectives of Mozambique's REDD+ Strategy is to convert non-forest areas and degraded forests to forest plantations and to promote agroforestry systems in agricultural areas. The National Reforestation Strategy and the Strategic Plan for Agricultural Development (PEDSA) 2010-19 is aiming at the promotion of the commercial forestry sector, as well as smallholders plantations. Therefore the availability of up-to-date and accurate information to enable landscape level decision making is necessary to reconcile different land use strategies.

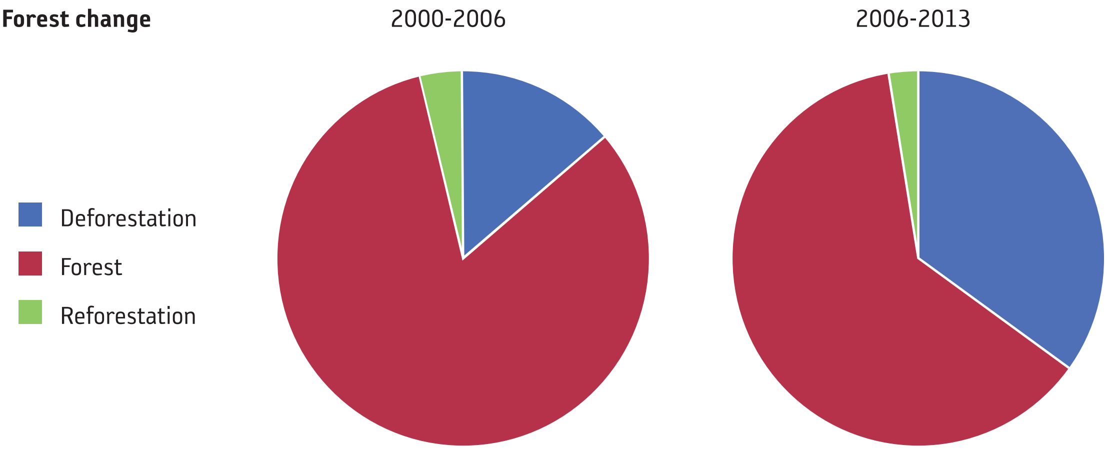
The study has confirmed that community land use patterns in northern Mozambique are dynamic, with cultivation activities moving from machamba to machamba year to year. This means that a snapshot of cultivated land does not show the full extent of a community's territory, since other cultivable land is 'dormant' at the time but to which farmers will return in future years. In other words a community's 'footprint' can generally be considered to be larger than its active extent at any one point in time.

3b. Summary of forest fragmentation 2000,2006 and 2013 and Example of the five main fragmentation categories derived from the Landscape Fragmentation Tool. Credits: RSAC Ltd. & RSS for ESA/World Bank.

4

ILE and NAMARROI Districts - Forest Change 2006-2011-13



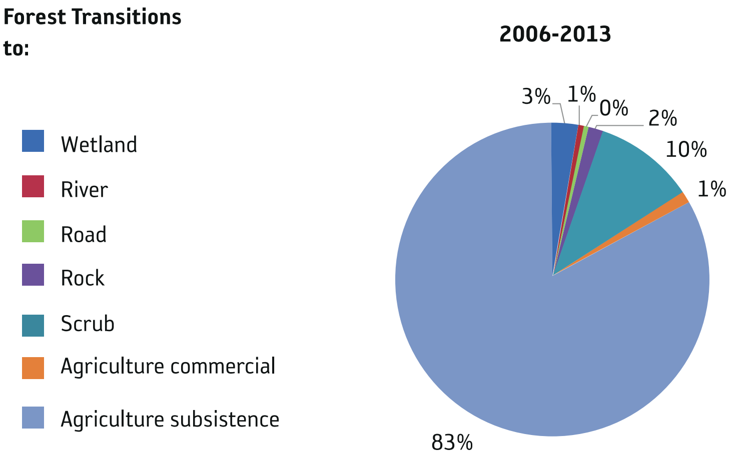


2000 to 2006	**- 1.44% p.a**
2006 to 2013	**- 4.20% p.a**

4. Summary of forest change: 2000-2006 and 2006-2013. Credits: RSAC Ltd. & RSS for ESA/World Bank.

This yields important conclusions. Plantation forestry development on a commercial scale usually requires substantive blocks of contiguous land to ensure economic viability (commercial agriculture usually occupies plots of around 500ha or larger). Whilst substantial areas of scrub or grassland (~60,000ha) exist, the high frequency small size pattern of community land use in Ile and Namarroi Districts is full of active community lands (agriculture and settlements), thus providing little large-scale homogeneous plots for plantation development. Moreover, it has to be noted that most of the existing agriculture developments have taken place on land that appears to have been deforested since 2006, which by many environmental standards would not be considered a sustainable practice.

Land use maps provided in this case study demonstrate to the users how EO can help to support a socially and environmentally sustainable plantation sector, complementing data on silvicultural suitability. The service could be seen as a tool to prove that decision makers have exercised due diligence before proceeding with planned developments.



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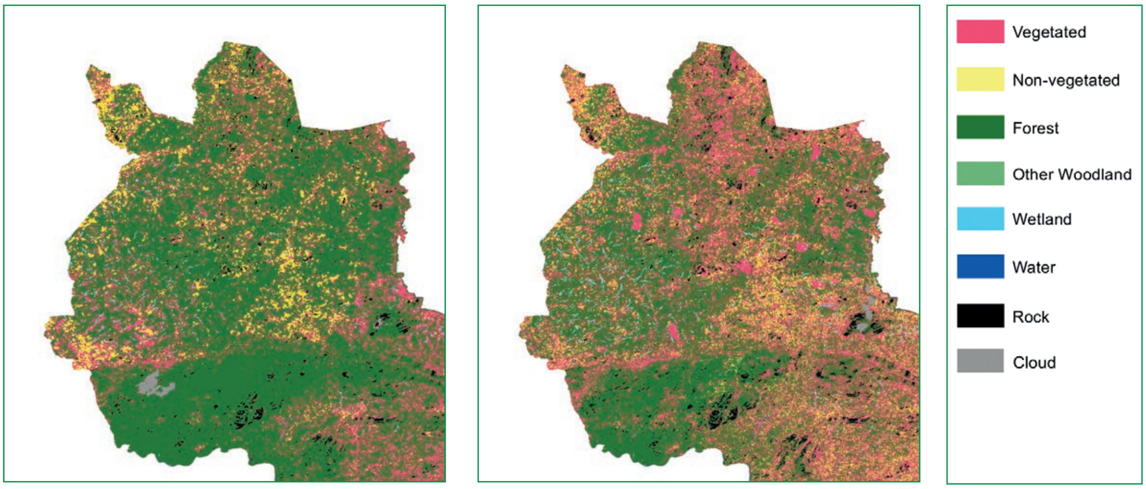

5. Detail of 2006 and 2013 land cover in the north of the Namarroi district shows large continuous areas have been deforested in the period 2006 to 2013 likely for commercial agriculture. SPOT data © CNES, RapidEye data © Blackbridge. Credits: RSAC Ltd. & RSS for ESA/World Bank.

Monitoring urbanization in Latin American Metropolitan Areas

Users:

- World Bank Global Practice on Social, Urban, Rural and Resilience

EO services provided

- Land use and land use change mapping
- Transportation network mapping
- Urban vegetation mapping

Service Providers

- IABG (Germany)

Background

Many Latin American countries are developing with the typical characteristics of the urbanizing economies such as an increasing industrial development, city population, land sealing as well as corresponding social and ecological problems (i.e. agricultural land uptake, natural areas encroachment, rural-urban consolidation, slums development. Newly-developed areas are often (illegally-built) squatter settlements in high-risk locations (eg. steep hill slopes, riversides) and without connection to public infrastructure. Moreover, the region-specific phenomenon is the concentration of industry and service provision in metropolitan areas which are often the state capitals. These emerging megacities are extremely fast growing urban environments that need to be better monitored over time concerning their growth patterns. However, the lack of a widespread reliable up-to-date geoinformation is a challenge to coherent and consistent analysis. In this context remote sensing plays an increasing role as a way to diagnose the state and trends of urban growth. It allows to characterise the spatial development in the greater metropolitan areas, identify the range of factors related to land-use, housing, and transport, and serve as an input to recommend specific measures that can

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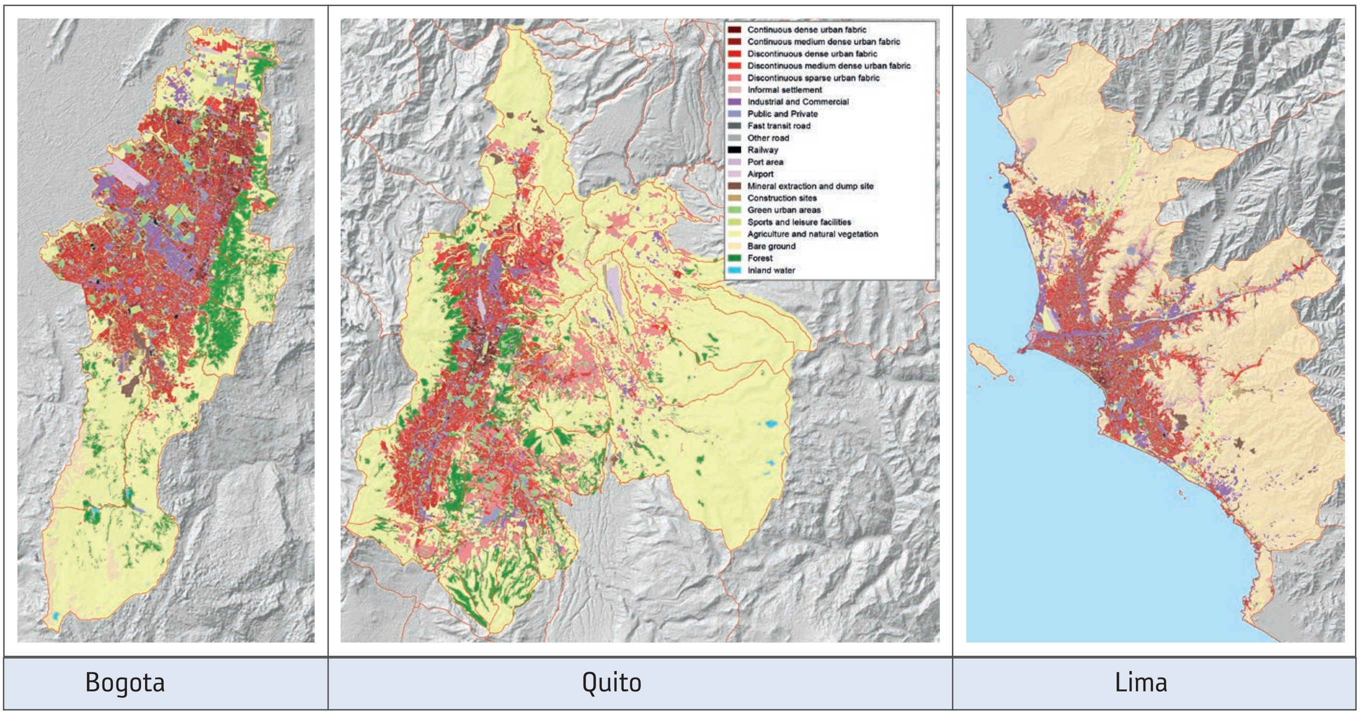
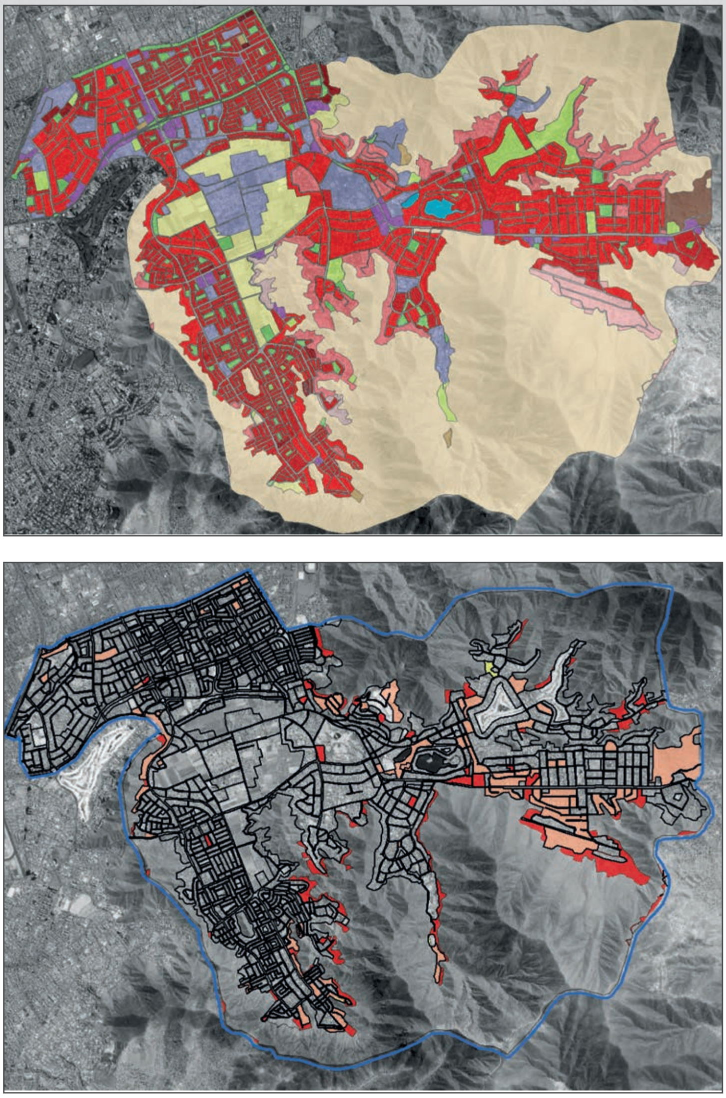


1. Baseline urban mapping product (2013). Data © Airbus DS. Credits: IABG for ESA/World Bank.

Urban Development

2



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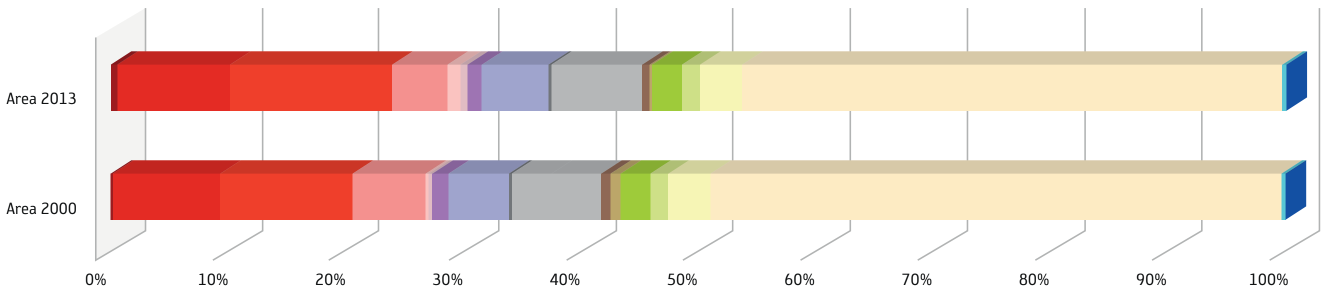


2. Baseline urban mapping of la Molina district, Lima, 2013. Data © Airbus DS. Credits: IABG for ESA/World Bank.

3. Example of land cover changes and derived statistics from 2010 to 2013 for la Molina district. Data © Airbus DS. Credits: IABG for ESA/World Bank.

4

support a more sustainable development pattern (from a transport perspective).

The World Bank is currently leading a number of analytic studies and project preparation activities through the urban transport regional program of knowledge services (PKS). It will support specific analytical activities in several countries including Argentina, Mexico, Brazil, Peru, and Colombia. The EO demonstration services have been set up to provide information for three metropolitan areas: Bogota, Quito and Lima.

Land use and land use change

The main information requirement for the project was to produce maps that show changes over time in the extent and form of the built-up areas to follow-up with diagnostic for slums, infrastructure planning, and land use change patterns . The land use map layer was prepared based on SPOT 5/6 data (1.5–2.5 m resolution) for 2013 and SPOT4 / Landsat-7 (2.5–15 m resolution) for 2000 reaching thematic quality of 96% or better (Figure 1). The data provided important insight into the patterns of urban growth. Figures 2 and 3 showcase a detailed analysis of change patterns for the Lima district of la Molina. The project also provided the retrieval of the road networks, demonstrating the feasibility of mapping of roads of 3–10 m width (Figure 4).

Urban vegetation

While there is a widespread recognition that compact urban development increases the productivity of urban services provided to the population (transport, electricity, sewage, etc.) sustainable development practices do require the presence of green urban areas. For this project the green urban spaces were identified, and characterized as low and high vegetation areas at the 0,1 ha mapping unit (Figure 5).This type of information is important in quantifying the value of the ecosystems serving urban areas (i.e. to which extend the street trees, lawns/parks, urban forests, cultivated land, wetlands, etc. support flood protection measures by increasing the surface run-off or contribute to the mitigation of the urban heat island effects by regulating temperature and filtering the air).

4. Road axes and derived classification. Data © Airbus DS. Credits: IABG for ESA/World Bank.

5

Results

The new mapping products were used by the World Bank in developing a policy dialogue with the different cities' administrations. For example, in the case of Lima, this information supported investigation of the impact of the metropolitan railway expansion on the city compaction and additional sprawl. One of the advantages of the EO-based information is in the consistency of results across different metropolitan areas which allows comparing the cities and look at correlations between spatial development and development policy choices.

5. Urban vegetation classification: high vegetation (dark green), low vegetation (light green) and large individual trees (green circles). Data © Airbus DS. Credits: IABG for ESA/World Bank.

Mapping of South Asian Cities

Users:

- World Bank Global Practice on Social, Urban, Rural and Resilience, South Asia Unit
- World Bank Country Offices in Bangladesh, Sri Lanka, Pakistan and Afghanistan

EO services provided

- Land use/cover and change mapping
- Potential slums

Service Providers

- GISAT (Czech Republic)

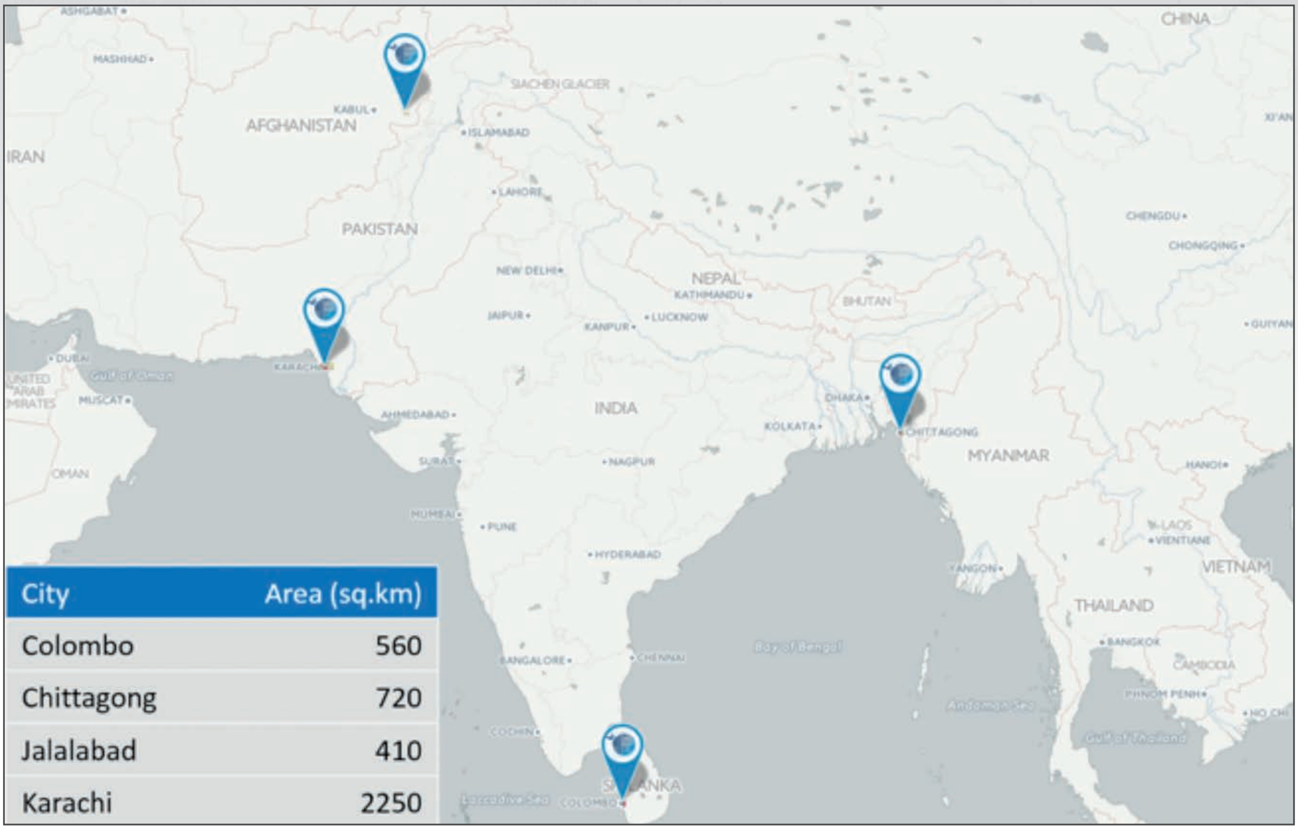
Background

The South Asia Region is poised for rapid urbanization over the next two decades. The ongoing shift from agricultural to industrial sectors is characterized by massive demographic movements. However while urbanization is expanding rapidly, slums now account for one fourth of all urban housing in the region. Moreover they are often located in the disaster prone and poorly communicated areas.

Sustainable urban management and planning requires insight into the spatial growth of built-up areas and their structure in order to identify trends and prioritise actions and resources provided through various infrastructure development projects. However lack of spatial data on both major and minor urban territorial attributes such as transportation networks, land use, formal – informal settlements, density of built-form, flood plains, among others, often impairs appropriate long-term planning and decision making.

In an effort to understand the urban dynamics, the World Bank South Asia urban team has undertaken a number of country urbanization reviews to identify country-specific needs and priorities. The team has completed studies in Nepal, India, Bangladesh, and Sri Lanka, as well as Pakistan, and Afghanistan highlighting urbanization trends at a macro-level and "growth nodes" which are primary and secondary cities in each of the countries. Several urban areas in the South Asia Region have been further analyzed under the ESA project to provide spatial-explicit information about current status and previous development of land use / land cover in the area. High and medium resolution satellite mapping were combined with Bank's database on social and economic indicators, environmental attributes, and demographic information, imrpving the understanding of the urban growth trends in the region.

City facts	
Jalalabad, Afghanistan	With population of more than 200,000, Jalalabad is the second-largest city in eastern Afghanistan as well as the center of its social and business activity. Located at the junction of the Kabul River and Kunar River near the Laghman valley, Jalalabad is the capital of Nangarhar province.
Chittagong, Bangladesh	Chittagong is the main seaport and second largest city of Bangladesh. It is located at the estuary of the Karnaphuli River in south-eastern Bangladesh. The city proper has an estimated population of over 4 million people, while the Greater Chittagong metropolitan area has a population of 6.5 million. It is one of the fastest growing cities in the world.
Karachi, Pakistan	Karachi is the largest and most populous metropolitan city of Pakistan and its main seaport and financial centre, as well as the capital of Sindh province. The city has an estimated population of 23.5 million people as of 2011, and a density of nearly 6,000 people per square kilometre.
Colombo Sri Lanka	Colombo is the largest city and the commercial, industrial and cultural capital of Sri Lanka. It is located on the west coast of the island and adjacent to Sri Jayawardenepura Kotte suburb or the parliament capital of Sri Lanka. Colombo is a busy and vibrant place with a population of about 750,000 in the city limits.



City	Area (sq.km)
Colombo	560
Chittagong	720
Jalalabad	410
Karachi	2250

Land use/cover and change mapping

Jalalabad, Chittagong, Karachi and Colombo have been selected to demonstrate the added-value of Earth Observation data to collect in-depth information about urban dynamics.

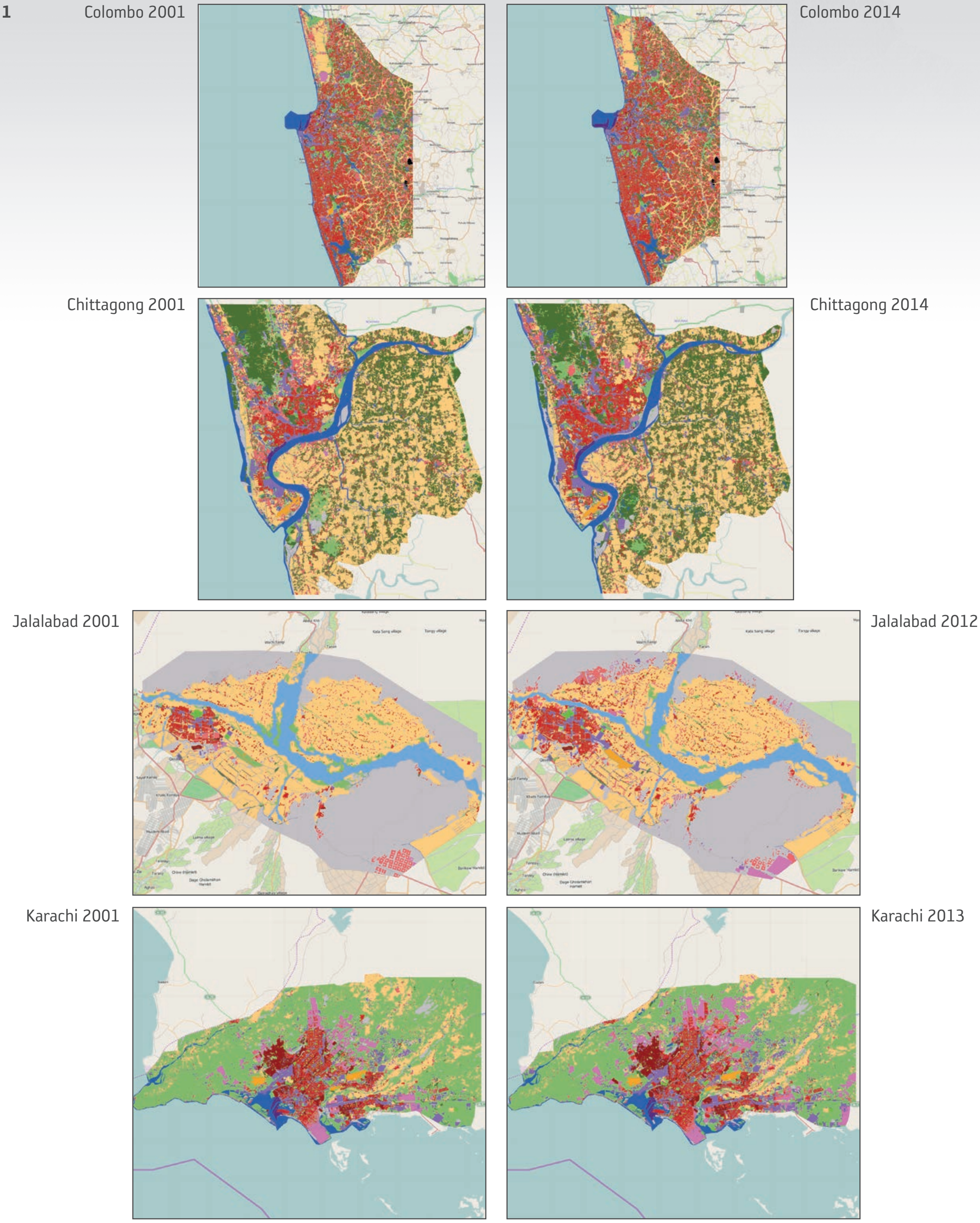
Land use/cover and changes mapping products have been provided for the two reference periods: 1999-2001 and 2012-2014. The processing methodology includes a semi-automatic OBIA (Object-Based Image Analysis) classification, supported by post-classification CAPI (Computer-Aided Photo-Interpretation) approach on top of satellite imagery. A semi-automatic detection and visual interpretation of changes between the two periods follows to obtain the change layer and, subsequently, the other land use/cover map.

Main benefit of EO-based land accounting is linked to its capacity to describe and quantify development of land use classes in time. Figure 1 provides an insight into urban land use structure and evolution within the four cities. Comparison of urban footprint extent, at different points in time, in the maps above, give an indication of spatial axes of urban development. The bar charts below support understanding patterns of urban growth. Significantly different proportions of continuous (111) and discontinuous (112) urban fabric between 2001 and 2013 were detected in Chittagong. In Jalalabad increase of share of construction sites (130) is apparent. Karachi experienced extraordinary proportion of construction sites compared to other cities.

Figure 3 indicates relative structural comparison of all land use changes at city levels. From comparison it is evident that (except Chittagong) proportion of urban-related changes represented by flows of urban residential sprawl, urban development/functional change and sprawl of industrial and commercial sites dominate over non-urban changes/flows. Going deeper

Land use/cover of all four selected cities in both periods

1



1. Land use/ cover map and structure of urban classes in years 2001 and 2013 (100% = Total urban area for given year) for all four cities. Reference Imagery: Ikonos © DigitalGlobe, Pléiades© Astrium. Credits GISAT for ESA/World Bank

Urban Development

Legend

- Formal high density residential - (S.L. > 50%)
- Formal low density residential - (S.L.: 10% - 50%)
- Commercial, Industrial and Transport Units
- Harbour
- Roads
- Airport
- Construction sites
- Urban greenery
- Agricultural land
- Forest
- Other Natural and Semi-natural Areas incl. Wetlands
- Vacant land not obviously being prepared for constr.
- Water bodies
- Potential slums
- Roads

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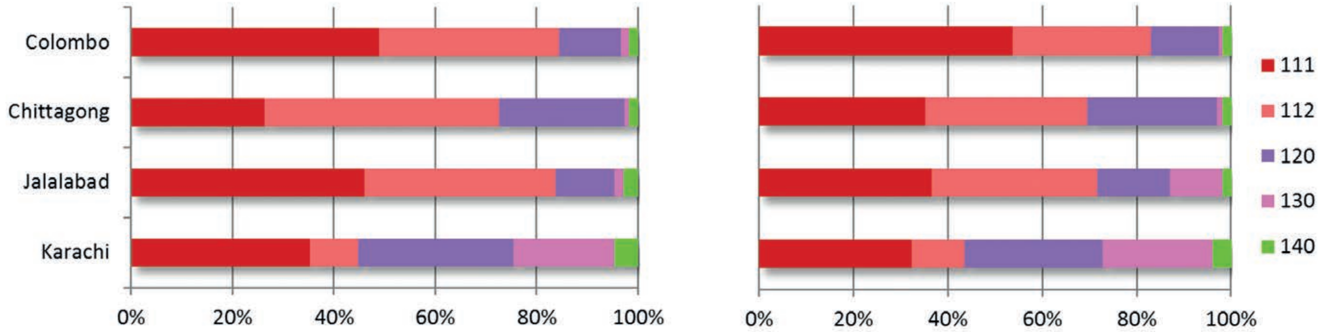

into detail, in Karachi and Jalalabad the residential sprawl significantly predominates over the rest of urban-related changes while in Chittagong and Colombo it is predominated by development and functional change (though not significantly).

As opposed to conventional statistical records, which usually provide only net estimates (saldo), land accounting based on EO-derived land use statistics enables in-depth analysis of internal structure of changes (area increase = formation, area decrease = consumption) for each land use class. Thus information provided (see figure 4) supports the policy questions like: What is share of non-urban classes which were consumed by urban extension in each city? Which classes were formed at expense of non-urban classes and what is their share in each city?

2. Land use/ cover map and structure of urban classes in years 2001 and 2013 (100% = Total urban area for given year) for all four cities. Reference Imagery: Ikonos © DigitalGlobe, Pléiades© Astrium. Credits: GISAT for ESA/World Bank.

Urban Extension 2001-2013

3

3. Distribution of urban development: urban land use changes (urban extension and internal changes) between 2001 (T1) and 2013 (T2) for Colombo, Karachi, Chittagong and Jalalabad. The lower bar chart shows relative urban extension (i.e. with respect to total urban area in 2001). Credits: GISAT for ESA/World Bank.

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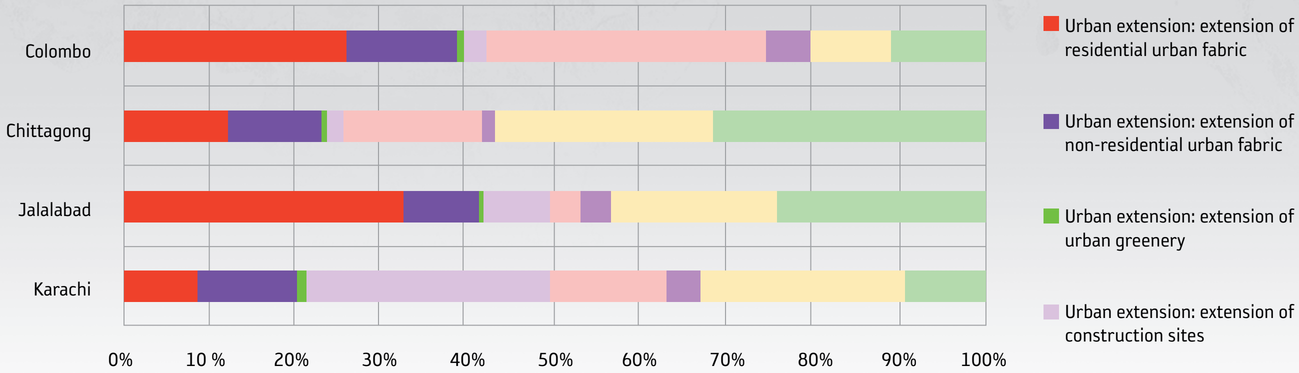

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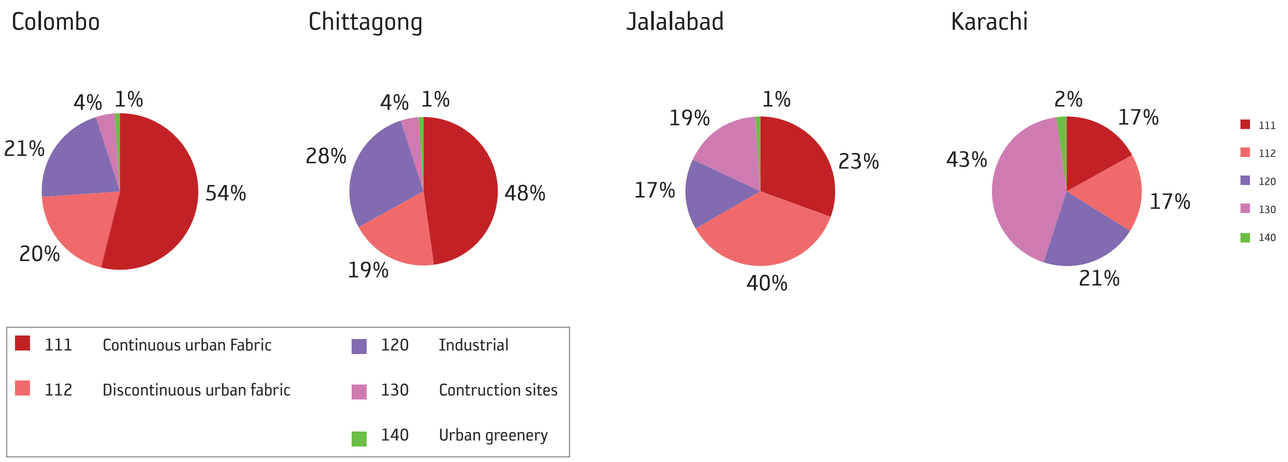
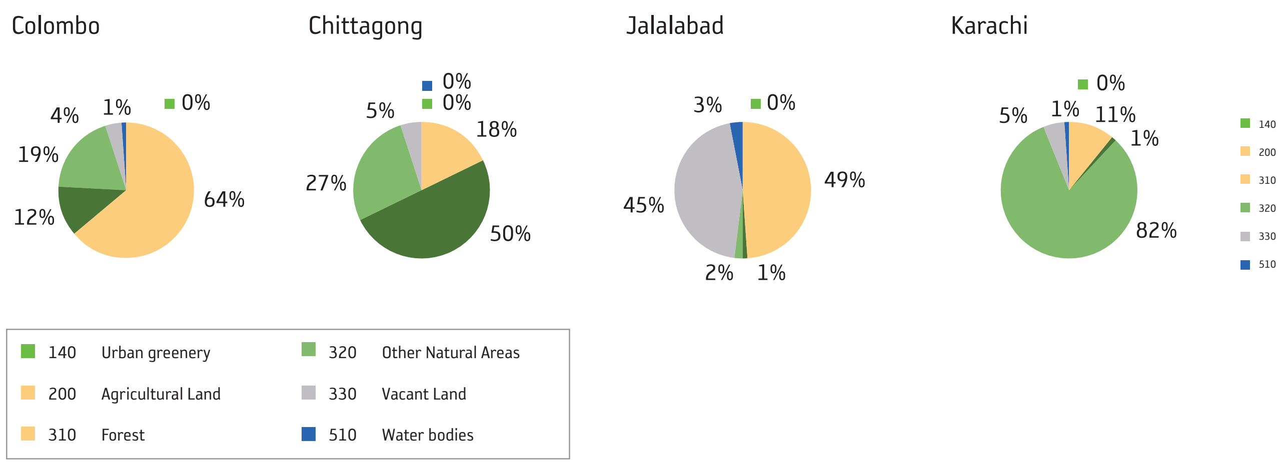
Formation



Consumption



4. Relative structure of Land cover flows. Credits: GISAT for ESA/World Bank.

5. Structure of urban extension (formation and consumption) in different cities. Credits: GISAT for ESA/World Bank.

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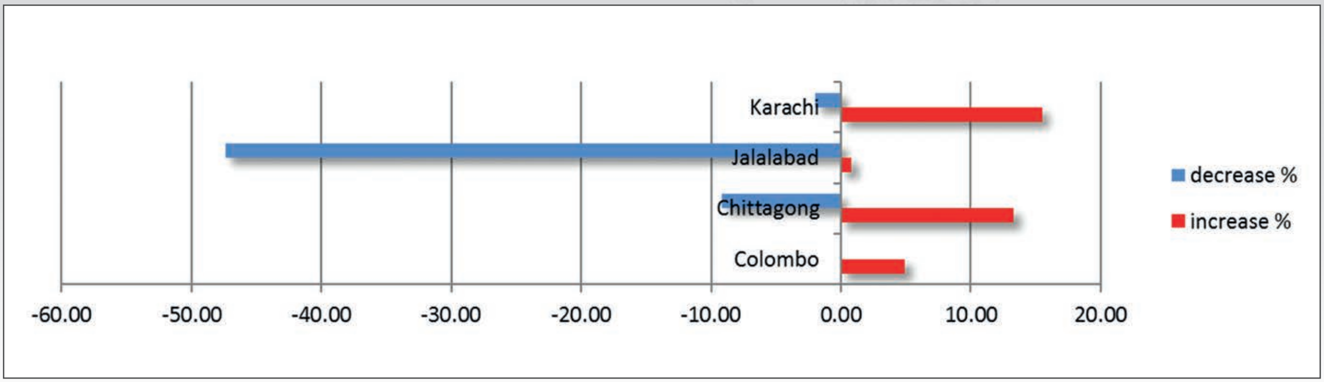


Potential slums

Figure 4 provides an example of results related to the potential slum area identification and monitoring. It is apparent that in Chittagong the net change of the latter amounts to no more than 5% increase if scaled according to area of original potential slum in 2001. Spatial analysis of changes though shows that almost 10% of original potential slums were rebuilt and 13% (scaled to original extent in 2001) was newly created.

Totals of potential slum area changes are listed in the table below. In absolute numbers, Karachi has witnessed the most significant extension of potential slum areas during the observed period, which differs from other cities on order of magnitude.

	Increase (sq.km)	Decrease (sq.km)	Net change (sq.km)
Colombo	0,18	0	0,18
Chittagong	0,08	0,06	0,02
Jalalabad	0	0,26	-0,26
Karachi	11,42	1,42	10

SLUM MAPPING

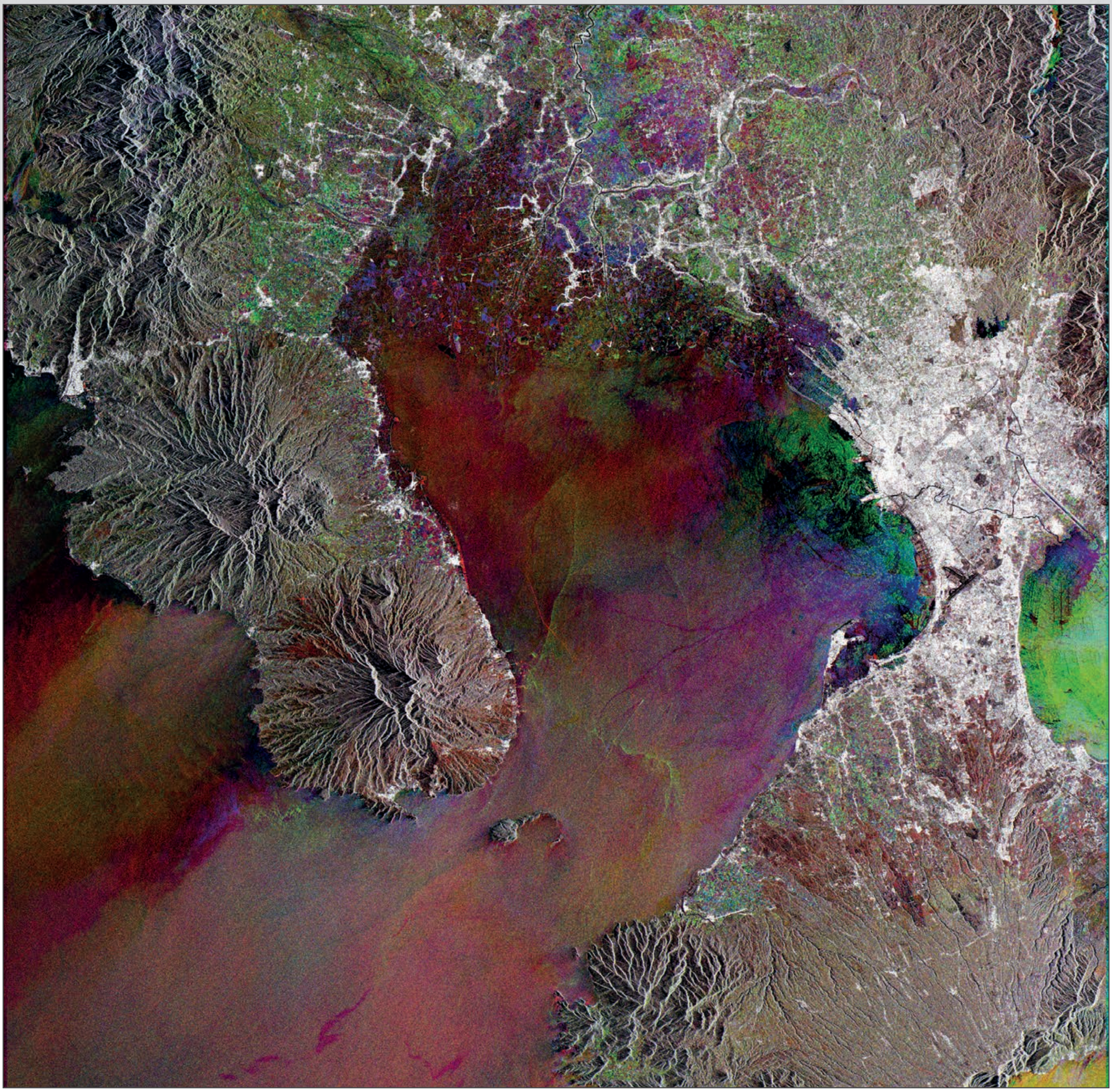
Although Earth observation techniques have a big potential for mapping/monitoring of slum areas, it is important to understand the limitations as well. Slums differ in their de facto and de jure characteristics from country to country or even from city to city. Slum areas vary from shanty houses to professionally-built dwellings that deteriorated into slums because of poor-quality design or construction. Thus general definition of slum areas provided by UN-HABITAT gives only a general guidance based on their main characteristic and as such it is difficult to use these open definitions for setting up operational mapping and monitoring. In short, slum areas are result of a complex function of environmental and socioeconomic factors that cannot be fully assessed using satellite image analysis only.

For this project the "Potential Slum Areas" have been identified based on their physical appearance only. Other key characteristic, like poverty level or informality of land tenure, are not taken into account as they cannot be detected by EO means. Instead local verification of identified areas is necessary to validate and confirm the results.

Table 1 - Totals of potential slum area changes.

5. Development of informal settlement – potential slums (100% = potential slum area in 2001)

7



7. Manila, the capital city of the Philippines, and its surrounding metropolitan area forms one of the most densely populated urban areas in the world. In this multitemporal Advanced Synthetic Aperture Radar (ASAR) composite red relates to an acquisition on 04 November 2004, green to one on 2 July 2003 and blue to one on 19 March 2003. Envisat data © ESA. Credits: ESA.

Informal Settlements and Urban Growth Patterns in Metro Manila

Users:

- Department of Social Welfare and Development (DSWD)
- National Mapping and Resource Information Authority (NAMRIA)
- Manila Observatory, Department of Remote Sensing, Informality and Land Use
- Quezon City Administration, Office of Congressman Kit Belmonte
- Homeless People's Federation of the Philippines

EO services provided

- Land use and land cover mapping
- Change detection and time series analysis
- Informal settlements mapping

Service Providers

- GIM – Smart Geo Insights (Belgium)

Background

The Philippines is one of the fastest urbanizing countries in East Asia. Metro Manila (MM), the country's national capital, is its primary urban agglomeration. Together with its peri-urban areas, Metro Manila accounts for 30% of the country's population and 50% of economic output, while occupying less than 4% of the national territory.

Metro Manila confronts many challenges, including rising poverty, proliferation of informal settlements (ISF) and high risks from natural disasters (mainly floods). The fragmented and piecemeal approach to Metro Manila planning has undermined the efficient and sustainable use of limited resources and the overall quality of life of its residents. To address these issues the World Bank has set up a range of initiatives on urban renewal, flood management and informal settlements upgrading to help the Government realize Metro Manila's long term 2030 vision for city development.

The ESA project provided insights concerning development of informal settlements and urban growth patterns in the metropolitan area. The objective was to help raise awareness, facilitate policy decisions (including land use decisions) and resolve challenges related to informal

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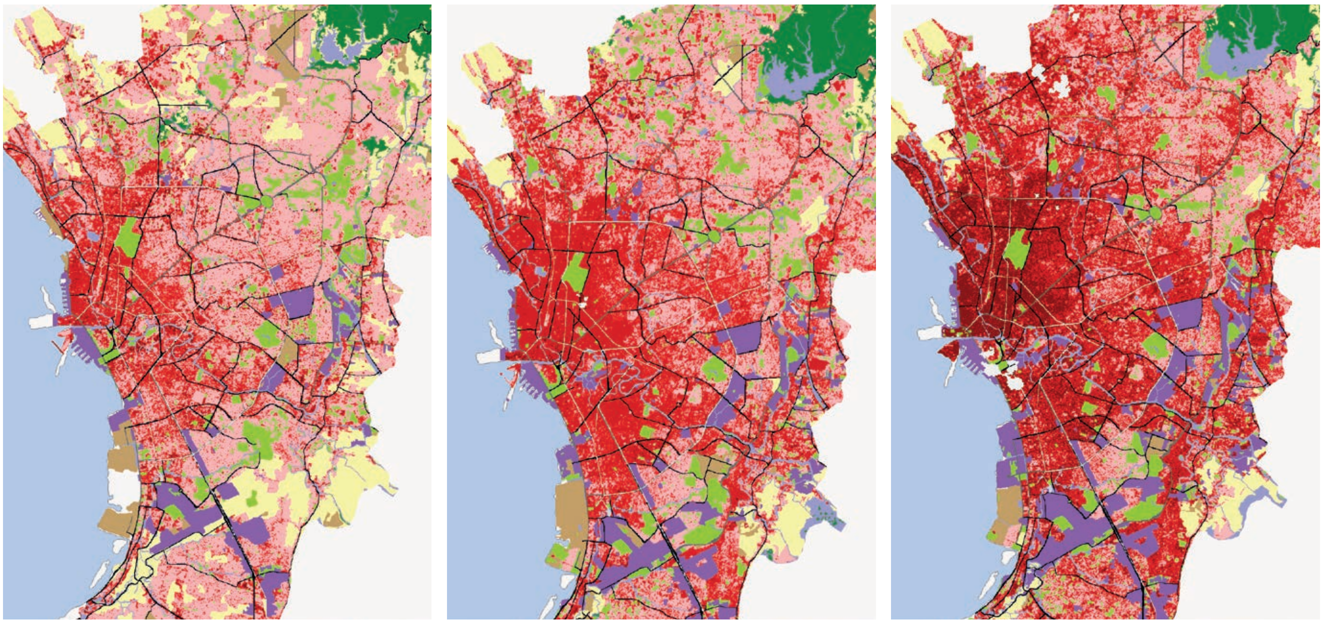


1. Land Use Land Cover maps for 1990, 2000 and 2010 as well as land use classes evolution statistics. Imagery from SPOT 1/HRV © CNES 2014. Credits: GIM for ESA/World Bank.

settlements and the urban poor's vulnerability to natural disasters and climate change in the National Capital Region of the Philippines.

Urban mapping and land use maps

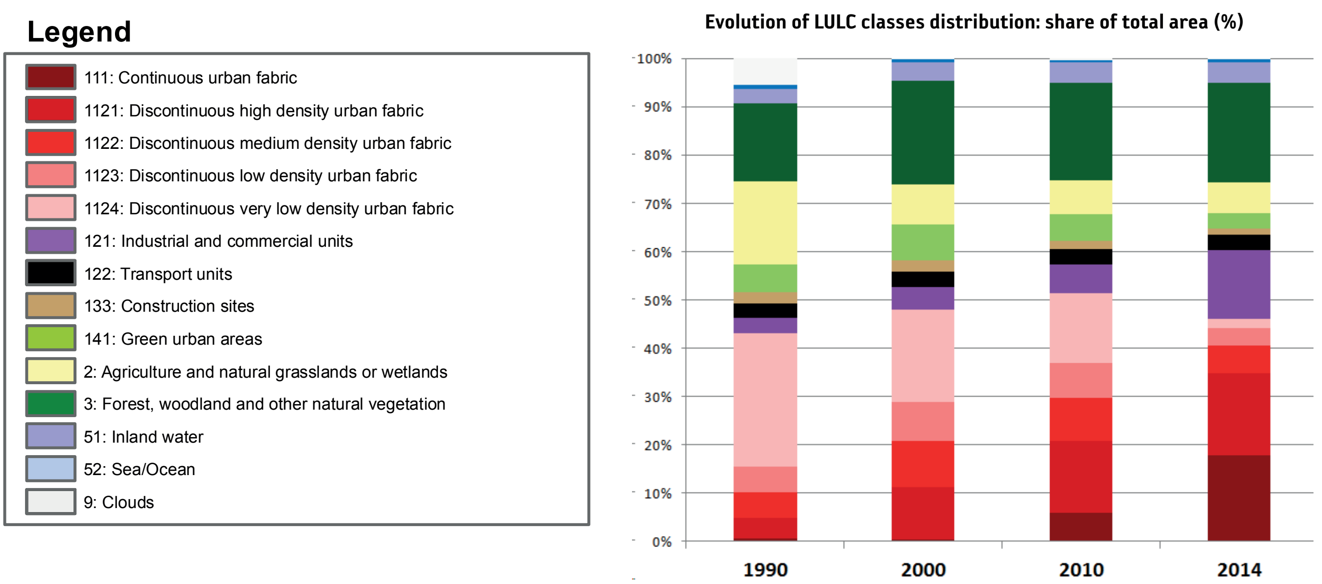
The mapping was aimed to characterise the land-use and its evolution with a focus on identifying and quantifying the spatial attributes of informal settlements in relationship to hazardous zones, residential, commercial, industrial, transportation networks, and utility system. For this level of analysis very high resolution (VHR) satellite imagery was used including a combination of SPOT-1, SPOT-2, SPOT-4, and Pléiades-1A satellites. The mapping products were developed for four points in time: 1990 – 2000 – 2010 – 2014:

- Land use and land cover maps for 1990, 2000, 2010 and 2014 (Figure 1 and 2)
- A range of dynamic assessment products over a period of several decades (Figure 3 and 4)

The results enhanced the understanding spatial development of the city over the last 25 years, and identified the key processes driving current expansion. A comprehensive and consistent overview of land consumption and conversions patterns highlighted specific hotspots and patterns. This information led to further analysis of drivers in conjunction with prevailing urban planning policies.

Informal settlements mapping

Informal settlements mapping is an important element for understanding the magnitude, spatial distribution and evolution of urban poverty. Typically the access to such information is however limited in terms of time series, methodological consistency, and disaggregation concerning the location, density and vulnerability of informal settlers. To fill in that gap the ESA project generated detailed informal settlements mapping by exploiting VHR multispectral imagery for the detection



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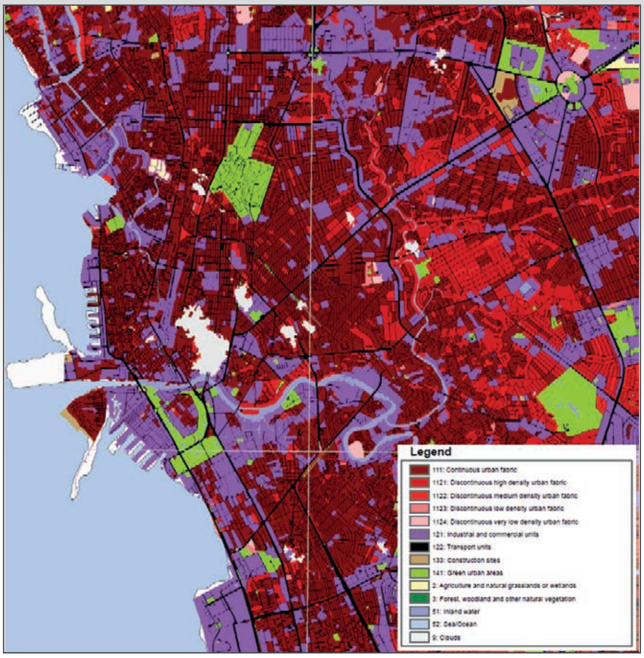

"To be able to [identify lands within Metro Manila which can be utilised for socialized housing], the Joint Committee has to determine the location of informal settlers in the Metro and the status of their land. The map of the slum areas in Metro Manila is crucial to our goal of promoting on-site and in-city settlements for the huge number of informal settler families in our country."

– Sen. Joseph Victor "JV" Esercito and Rep. Alfredo "Albee" Benitez, Chairpersons of the Joint Committee on Housing of the Philippine House of Representatives and the Senate.

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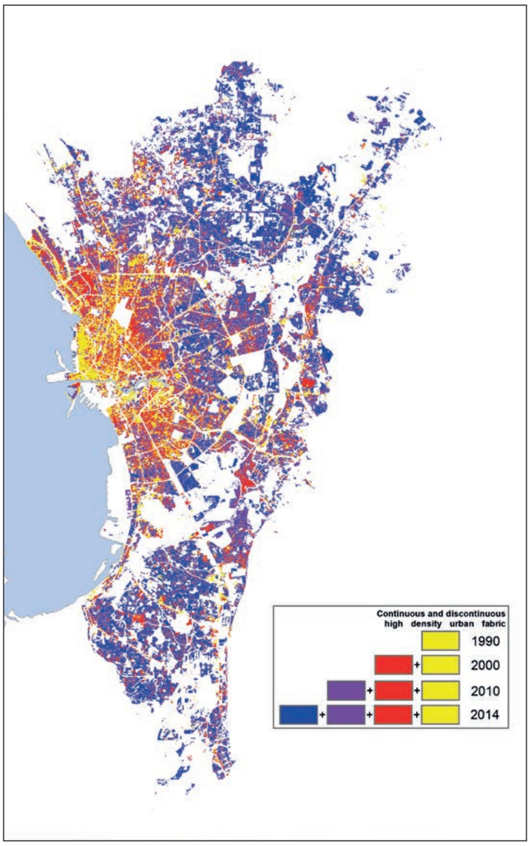

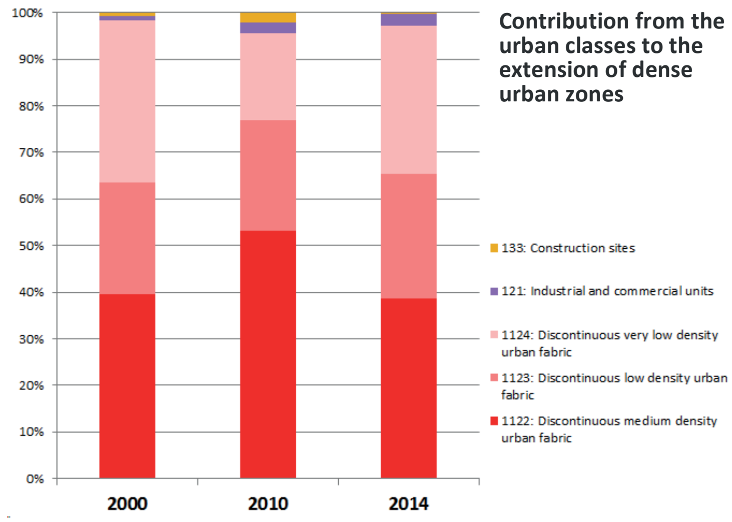

2. Land Use Land Cover maps for 1990, 2000 and 2010 as well as land use classes evolution statistics. Imagery from SPOT 1/HRV © CNES 2014. Credits: GIM for ESA/World Bank.
3. Sprawl of the dense urban zones (1990-2000-2010-2014). SPOT 1/2/4 imagery © CNES, Pléiades imagery © Airbus. Credits: GIM for ESA/World Bank.

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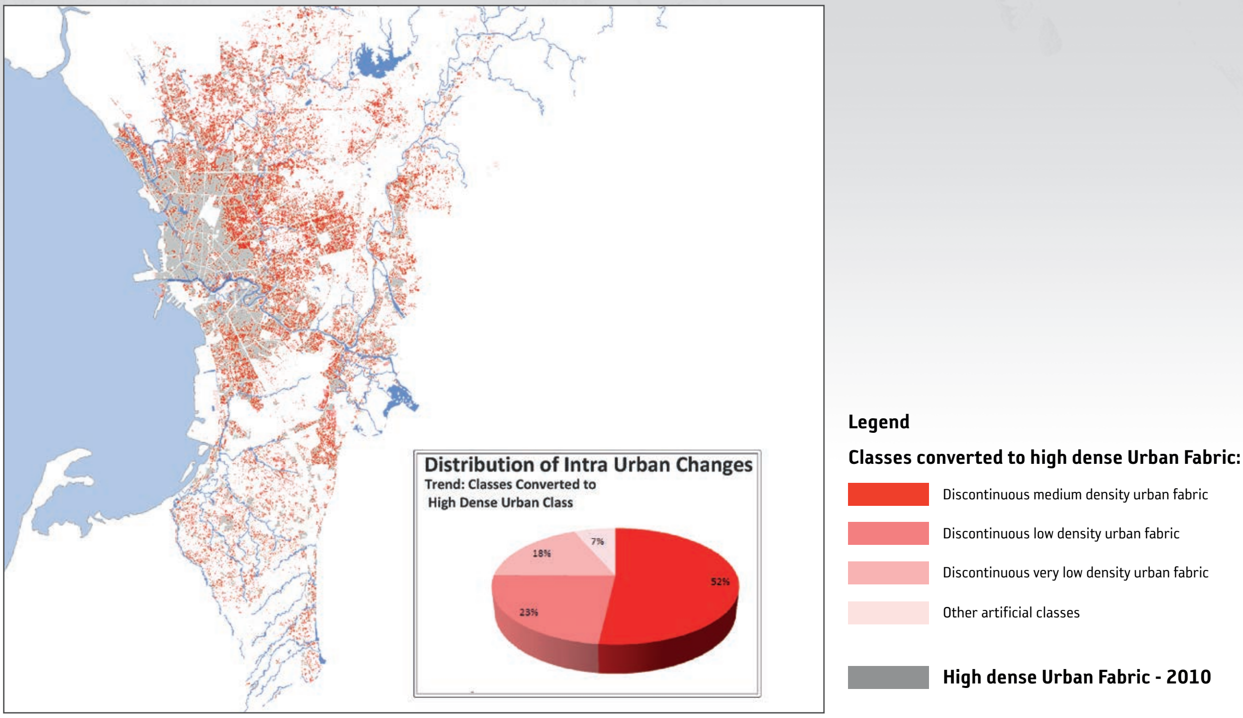

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and delineation of all settlements and the extraction of physical attributes such as individual housing structures inside the slums (Figure 5). An objective typology was developed on the basis of the slums location and physical attributes (buildings size, density, presence of vegetation, roads, etc.) (Figure 6)

Results

The informal settlements map was considered by the World Bank as a major breakthrough. The slum mapping effort of this scale and at that level of accuracy and completeness has been unprecedented and conclusively revealing, for the first time, the magnitude of the informal setlement phenomenon in the city (amount, distribution, links to specific land use classes). Consequently, a number of concrete opportunities for further exploiting these geospatial layers were identified.

4. Urban densification 2000 – 2010 and distribution of changes. SPOT 2 / 4 data © CNES. Credits: GIM for ESA/World Bank.
5. Individual objects inside a high dense informal settlement. 2014. Pléiades imagery © Airbus 2014. Credits: GIM for ESA/World Bank.

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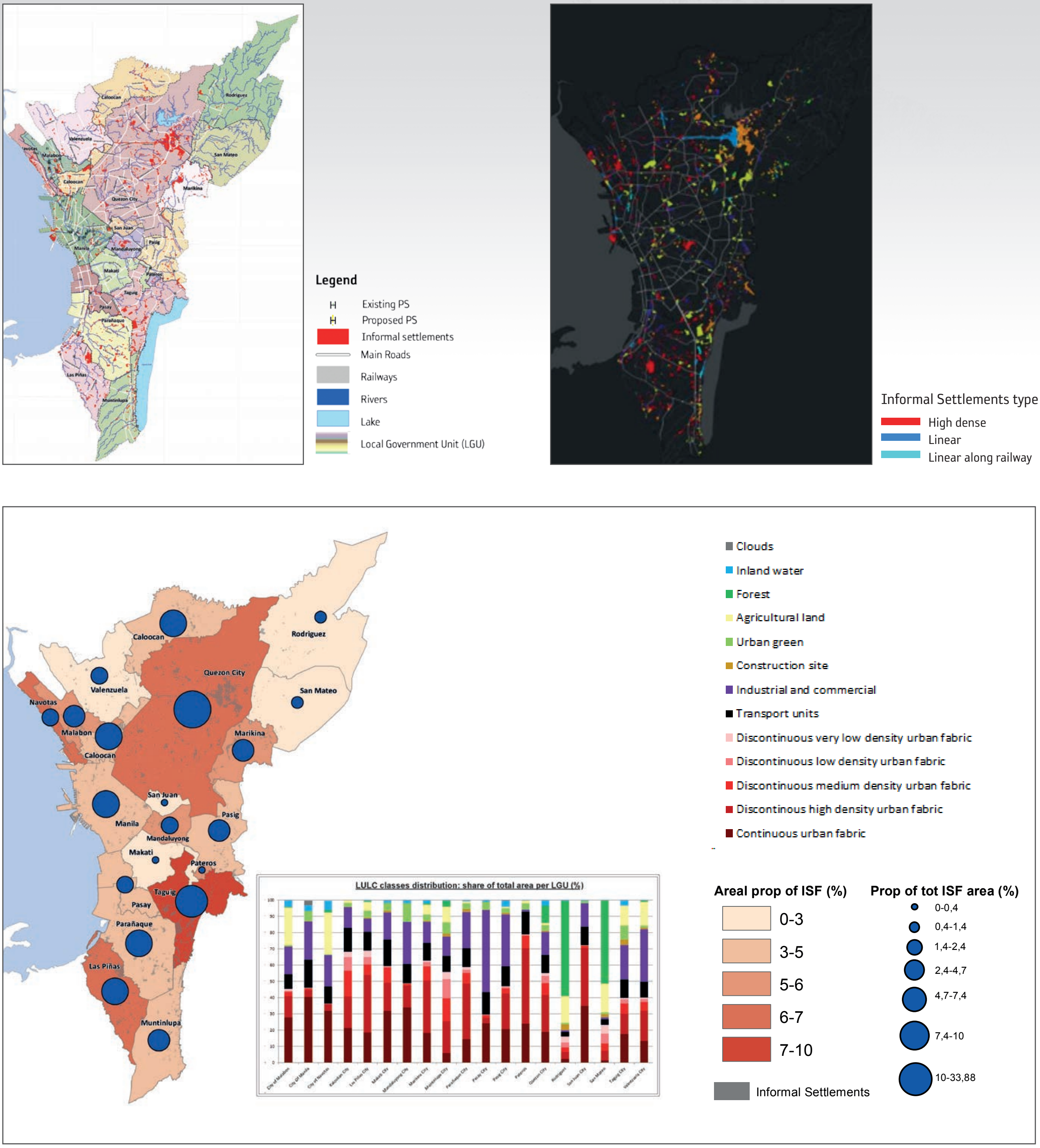
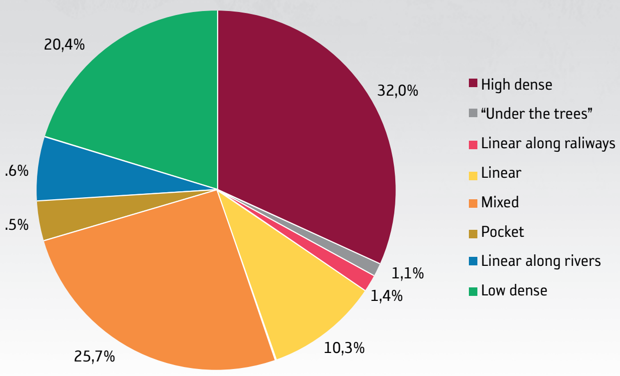


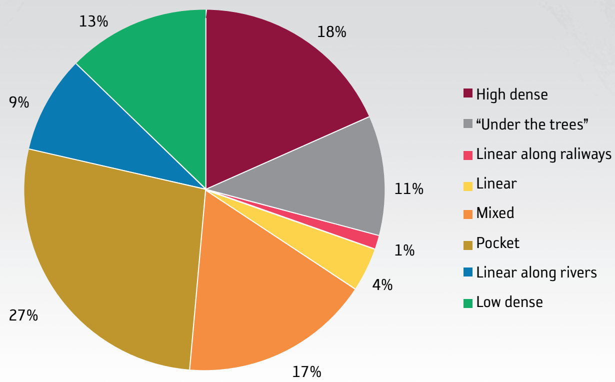
6. Metro Manila informal settlements location and extent, types of slum and their distribution. 2014. Pléiades imagery © Airbus 2014. Credits: GIM for ESA/World Bank.

Urban Development

Proportions per slums types (%) - Areas



Proportions per slums types (%) - number of slums



"We have found out of the 270 randomly selected Primary Sampling Units in the three Local Government Units, very few were actually errors of commission. The other interesting thing is that the number of households within the designated structures within a PSU in most cases doubled or often, tripled. I think these are all very useful lessons when thinking about how populations are captured from space in dense and complex urban environments."

– Gayatri Singh, Urban Specialist, World Bank, on the on-site validation exercise of the satellite-based informal settlement map.

Earth Observation to Support Climate-Related Health Risk Assessment in Africa

Users:

- World Bank Climate Change Solutions Global Practice

EO services provided

- Climate-related health risk assessment in Africa
- The EOCHA Data Portal

Service Providers

- Meteorological and Environmental Earth Observation (MEEO) (Italy)
- International Research Institute for Climate and Society (IRI) (USA)
- Manchester Metropolitan University (MMU) (United Kingdom)
- Department of Epidemiology of the Regional Health Service - Lazio (DEP) (Italy)

Background

Climate change impacts many of the environmental variables that lead to disease outbreaks. Regardless of the species affected, the effects can ultimately impact the health, livelihood, and economic security of humans.

Determining the exact degree to which climate change impacts diseases is challenging. Disease risks to humans, animals, and plants are determined by interconnected environmental variables that affect incidence, transmission, and outbreak. For example, there is a multitude of factors that determine disease transmission, such as species interactions, vegetation, land degradation, food resources, population, and baseline health of species.

A number of studies have explored the potential effect of environmental variables on infectious diseases in animals and humans. Collectively, these reviews highlight that climate may influence virtually all components of disease systems: the pathogen (eg. influencing the development rate, or survival outside the host or vector), the host (through the immune response, or changes in host distribution), and the vectors (arthropod vector development is tightly linked to climatic parameters such as temperature and humidity). In addition, climate change and climate variability may strongly influence disease by indirect effects such as movements of hosts resulting from floods or heat waves, or climate induced changes in land use or land cover.

It is possible to make some inferences about how climate change will impact diseases in any given region with an understanding of how certain diseases are sensitive to the environment. The current capacity to predict the actual impact of climate change on disease can be improved with the coupling of remote sensing, ecological, and epidemiological data.

Climate-related health risk assessment in Africa

The correlation between climate conditions and the effects on the animals and human being health is well known. The quantification of this correlation is still, however, under investigation especially in remote areas where the meteorological and climate information are hard to be collected. Earth Observation data, associated with epidemiological data about diseases, outbreak and other kind of social-health data, are relevant to analyse the impact and the cause-effect dynamics linking meteo-climate parameters to human and animal health. Furthermore, thanks to the large amount of climate data made available by EO systems, it is possible to predict the risk for those regions where the climate conditions are particularly favourable to disease vectors development and diffusion.

The scope of the “Earth Observation for Climate-related Health risk in Africa” (EOCHA) project was to provide an effective web based platform to collect meteorological

Climate Change Adaptation

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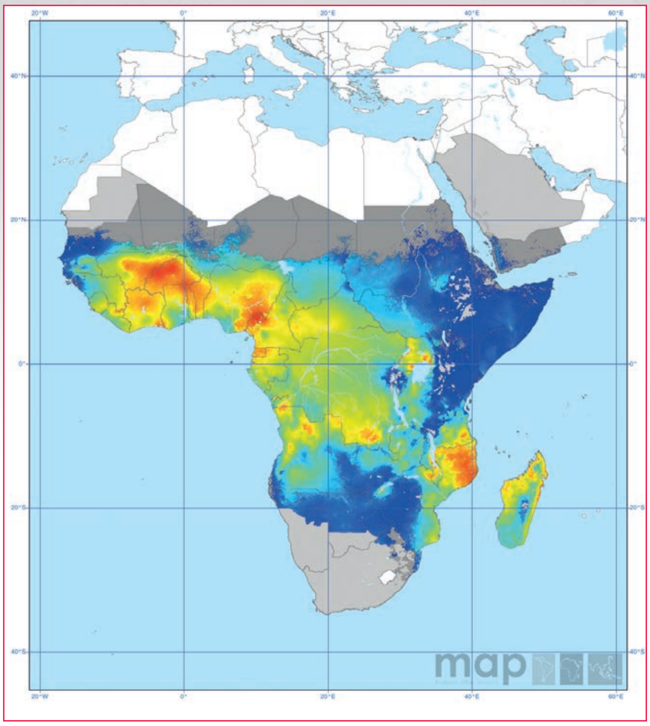
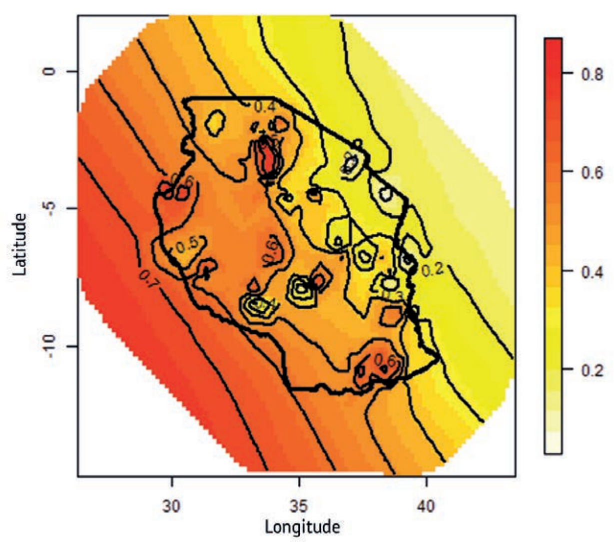


and climate parameters from heterogeneous data sources (satellite, in-situ, model) fully dedicated to climate-health analysis with a particular focus on Rift Valley Fever, Epidemic malaria, Meningitis and Chikungunya in Sub-Saharan regions.

The project aimed at assessing the effectiveness of EO technologies to support the accurate identification of favourable climatic conditions for the development of disease vectors. As a result with the created EOCHA Data Portal, the Climate-Health experts can find in a single location the best quality data, the proper documentation and the suitable tools to implement their applications.
To demonstrate the application in practice, a case study related to the distribution of plasmodium Falciparum as a proxy for Anophele mosquitoes diffusion in Tanzania, with data ranging between 2000 and 2011, has been implemented and made available through the EOCHA Data Portal.

Open source data on plasmodium Falciparum parasite rate have been collected from the Malaria Atlas Project database (Oxford University), a wide collection of information containing monthly geo-referenced data on the number of positives and the number of tested subjects, coming from heterogeneous sources. The meteo-climatic variables have been selected on the basis of experts' suggestions and literature review, and have been collected from the EOCHA data portal. Monthly averages have been computed. The statistical analysis has been performed at the maximum allowed detail, i.e. spatial points, and results will be aggregated to the user-required level.



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1. The spatial distribution of Plasmodium Falciparum malaria endemicity map in 2010. Credits: Malaria Atlas Project, University of Oxford.
2. Spatial distribution of plasmodium Falciparum over Tanzania: white to red zones represent areas with increasing estimated posterior probability of being infected. Credits: MEEO, MMU, DEPLAZIO, IRI for ESA/World Bank.

The statistical model chosen for the analysis was based on the Bayesian approach where the outcome variable represents the posterior probability for a human subject to be affected by plasmodium falciparum and the likelihood is assumed to follow a binomial distribution: longitude, latitude and altitude are assumed to have a linear effect, while rainfalls and temperature are assumed to have a non linear effect (i.e. second order random walk). The map in Figure 2 shows the posterior probability fitted by the specified model on the prediction grid over Tanzania region.

The EOCHA Data Portal

The created EOCHA Data Portal (http://eocha.services.meeo.it) facilitates the access to heterogeneous datasets providing in a one-stop-shop the access services and basic data mining tools necessary to explore geospatial data i.e. in the context of the disease early warning systems (Figure 3). The Portal is based on the Multi-sensor Evolution Analysis (MEA) technology - an Earth Observation and geospatial data analysis tool empowered with OGC (Open Geospatial Consortium) standards and open source technologies to enable Big Data access and processing services. The system is easy to understand regardless of language barriers. The use of pictogram icons for specific functions has been designed to enhance the user experience.

Key World Bank sectors can benefit from such climate-related health risk assessment including Agriculture and Rural Development, Environment, and Health, Nutrition and Population in the regions that are afflicted by both high burdens of infectious disease and climate change – notably, Africa, South America, East Asia and the Pacific.

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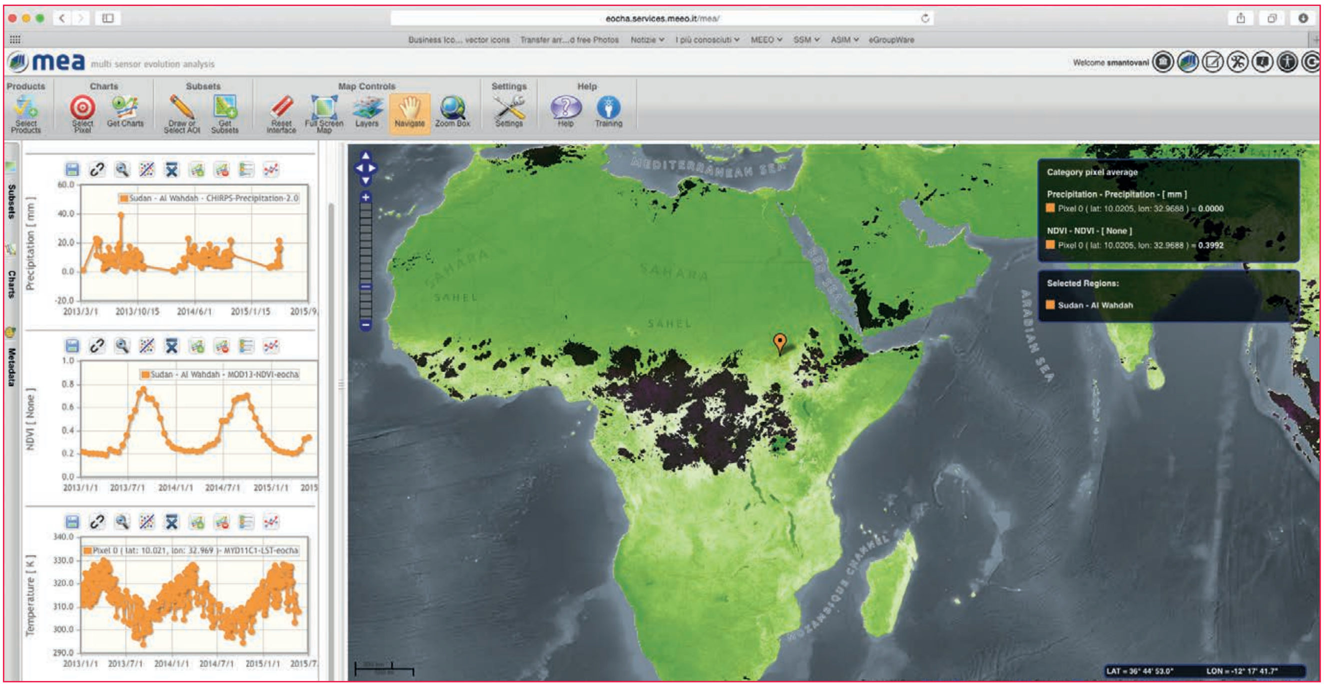
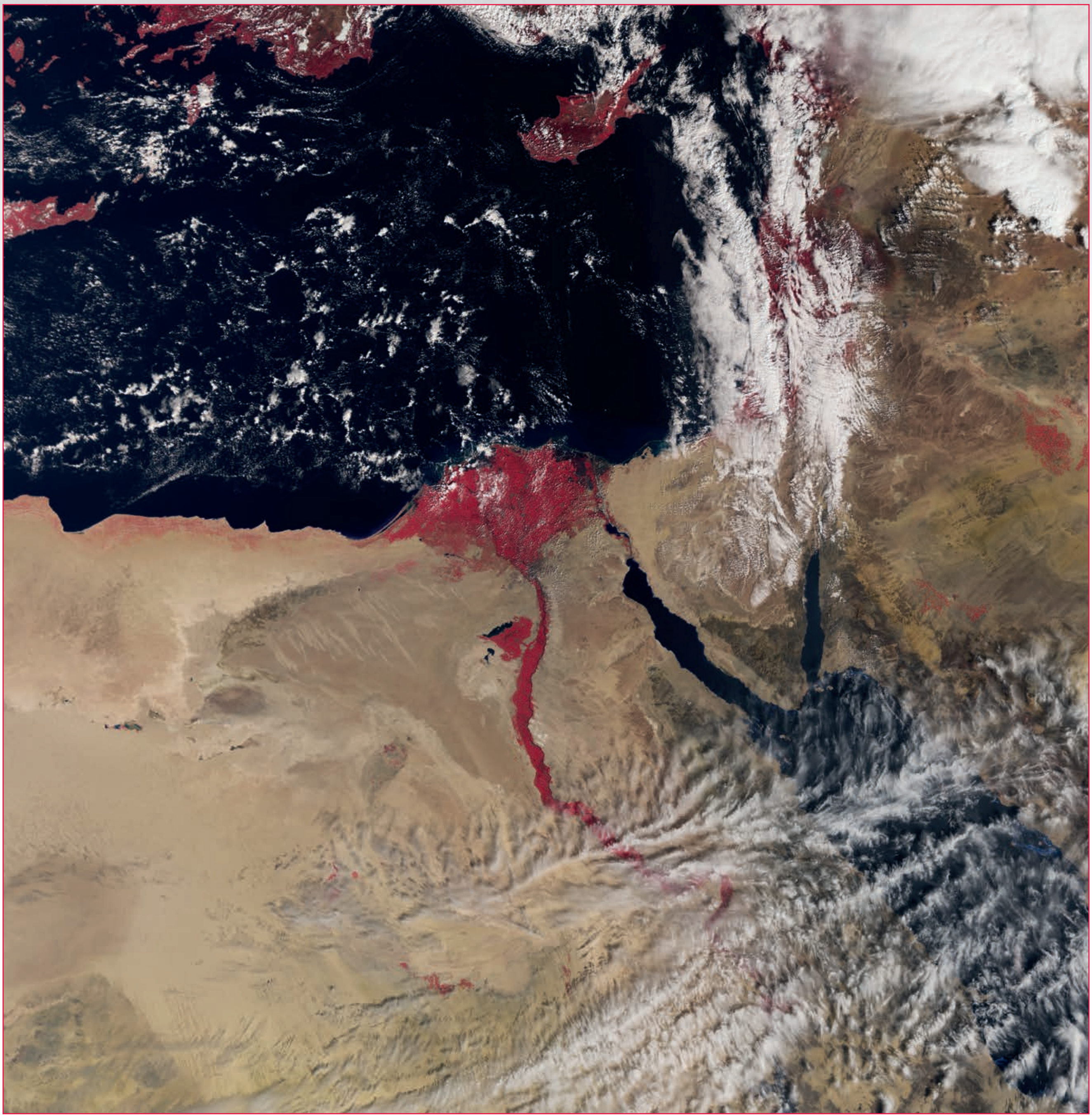


3. The spatial distribution over Africa and time-series in Sudan of precipitation (CHIRPS - Climate Hazards Group InfraRed Precipitation with Station data), vegetation index (NDVI) and temperature (Land Surface Temperature). Credits: MEEO, MMU, DEPLAZIO, IRI for ESA/World Bank.



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4. The new Sentinel-3A satellite recently began providing data from orbit. This very early image recorded on 3 March 2016, takes us over the River Nile and Delta and the surrounding desert areas of northeast Africa and parts of the Middle East. ne of the suite of sophisticated instruments that will measure Earth's oceans, land, ice and atmosphere, Sentinel-3's Sea and Land Surface Temperature Radiometer (SLSTR) measures the energy radiating from Earth's surface in nine spectral bands, including visible and infrared. The instrument improves on the capabilities of the Advanced Along-Track Scanning Radiometer carried by the Envisat satellite of 2002–12, including a wider swath of 1400 km, new channels and a partly higher spatial resolution. Sentinel data © ESA. Credits: ESA.

EO Information for Hydromet and Climate Services

Users:

- Pilot Program for Climate Resilience

EO services provided

- Sea Level Anomaly products
- Sea Surface Temperature products
- E-learning module "Satellite Earth Observation (EO) and its Application in Climate services Investments"

Service Providers

- Hatfield Consultants (Canada)
- Terradue 2.0 (Italy)

Background

Many developing countries are highly vulnerable to adverse impacts of climate change as well as extreme weather events. Understanding climate variability, climate change trends, and their impacts and associated risks is crucial for the development of suitable adaptation measures and enhanced climate resilience.

The World Bank has recognized climate change as a development issue and committed to fostering innovative approaches, knowledge exchange and shared learning in this area. In particular provides a support developing countries in their efforts to become resilient to climate change while promoting their sustainable growth. However the availability and limited access to climate-and earth observation data and services for climate smart-planning is a common drawback in many countries. In addition to budgetary constraints, developing countries often have a low density of hydrometeorological monitoring stations and weak capacity to use real-time information from both ground- and earth-observation systems. These and other factors impede countries' abilities to enhance their resilience. Data collection needs to be improved to foster development climate services, warning systems, weather-based insurance products and other climate-related products to support climate resilient planning.

The World Bank Climate Change Knowledge Portal (CCKP) (http://www.climateknowledgeportal.worldbank.org) is a key component of the Bank's Open Data Initiative and serves as a hub for climate data, reports, tools, and country dashboards. The goal of the ESA project was to support the CCKP portal by integration of the EO-based climate datasets and development of an Earth Observation (EO) e-learning module to enhance climate smart planning practices. The climate datasets adapted to CCKP as a Web Mapping Service were based on the ESA Climate Change Initiative's (CCI) data products: Sea Level Anomaly, and Sea Surface Temperature.

Sea Surface Temperature products

Changes in sea surface temperature can alter marine ecosystems in several ways. For example, variations in ocean temperature can affect what species of plants, animals, and microbes are present in a location, alter migration and breeding patterns, threaten sensitive ocean life such as corals, and change the frequency and intensity of harmful algal blooms such as "red tide." Over the long term, increases in sea surface temperature could also reduce the circulation patterns that bring nutrients from the deep sea to surface waters. Changes in reef habitat and nutrient supply could dramatically alter ocean ecosystems and lead to declines in fish populations, which in turn could affect people who depend on fishing for food or jobs.

Prior to the 1980s measurements of sea surface temperature were derived from instruments on shorelines, ships and buoys. Since the 1980s most of the information about global SST has come from satellite observations. Instruments like the Moderate Resolution Imaging Spectroradiometer on board (MODIS) onboard NASA's Terra and Aqua satellites orbit the Earth approximately 14 times per day (Figure 1).

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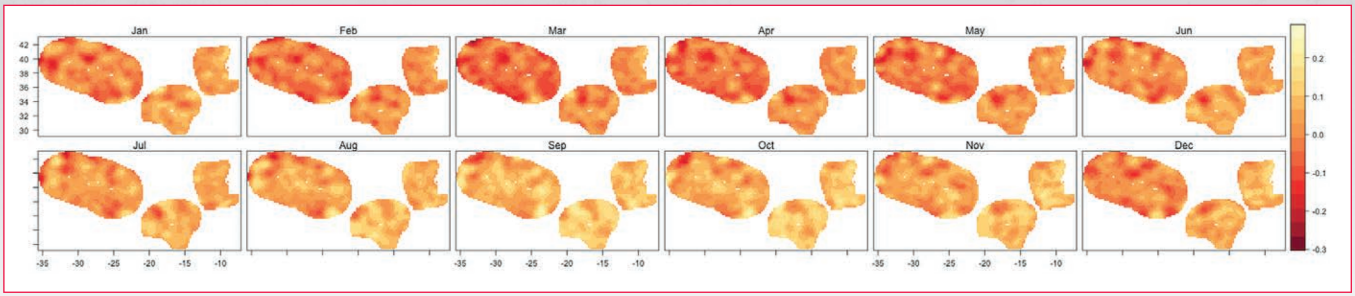

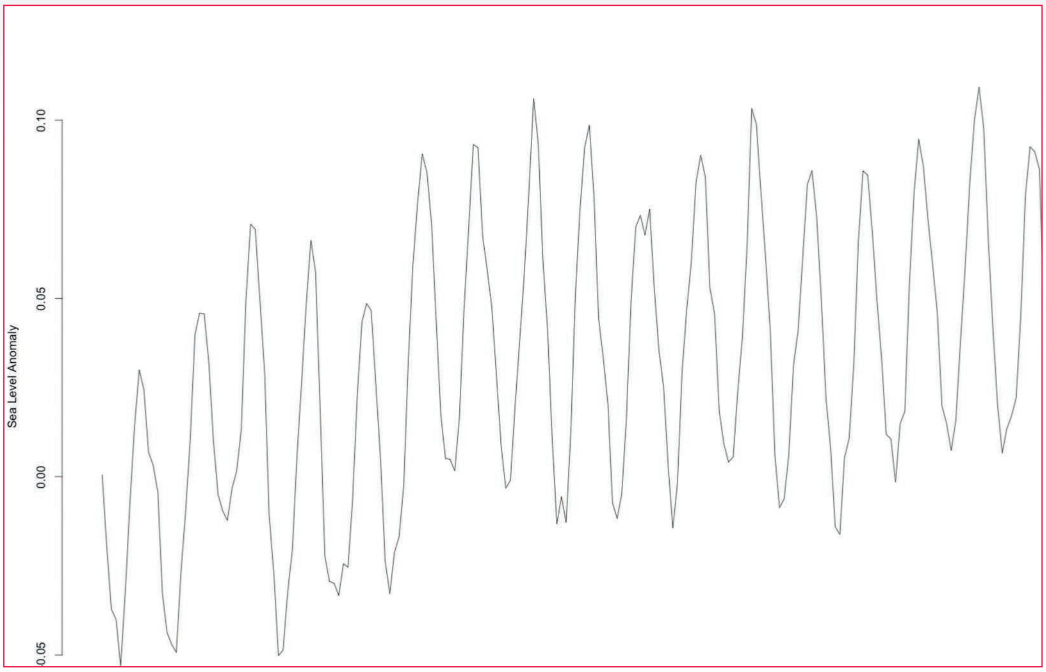

Sea Level Anomaly products

The global mean level of the oceans is an indicator of climate change. It incorporates the reactions from several different components of the climate system. Precise monitoring of changes in the mean level of the oceans is vitally important for understanding not just the climate but also the socioeconomic consequences of any rise in sea level.

For nearly twenty years now, the global mean sea level has been routinely measured over the whole oceanic domain with high-precision satellite altimetry, and such observations show clear evidence of global mean sea level rise (+3.2 +/-0.6 mm/yr). The rise in the level of the oceans is far from uniform. In fact, while in certain ocean regions the sea level has indeed risen (by up to 20 millimeters a year in places), in others it has fallen an equivalent amount. These regional differences, observed by altimetry satellites, mostly reflect sea level fluctuations over several years (Figure 2).

1. The data were produced part of the ESA Sea Surface Temperature Climate Change Initiative project: GHRSST Level 4 OSTIA Global Foundation Sea SurfaceTemperature Analysis (UKMO-L4HRfnd-GLOB-OSTIA). Credit : UK Met Office for ESA/World Bank. The adaptation to CCKP and Exclusive Economic Zones territories by Terradue available at https://github.com/Terradue/eowb-cckp

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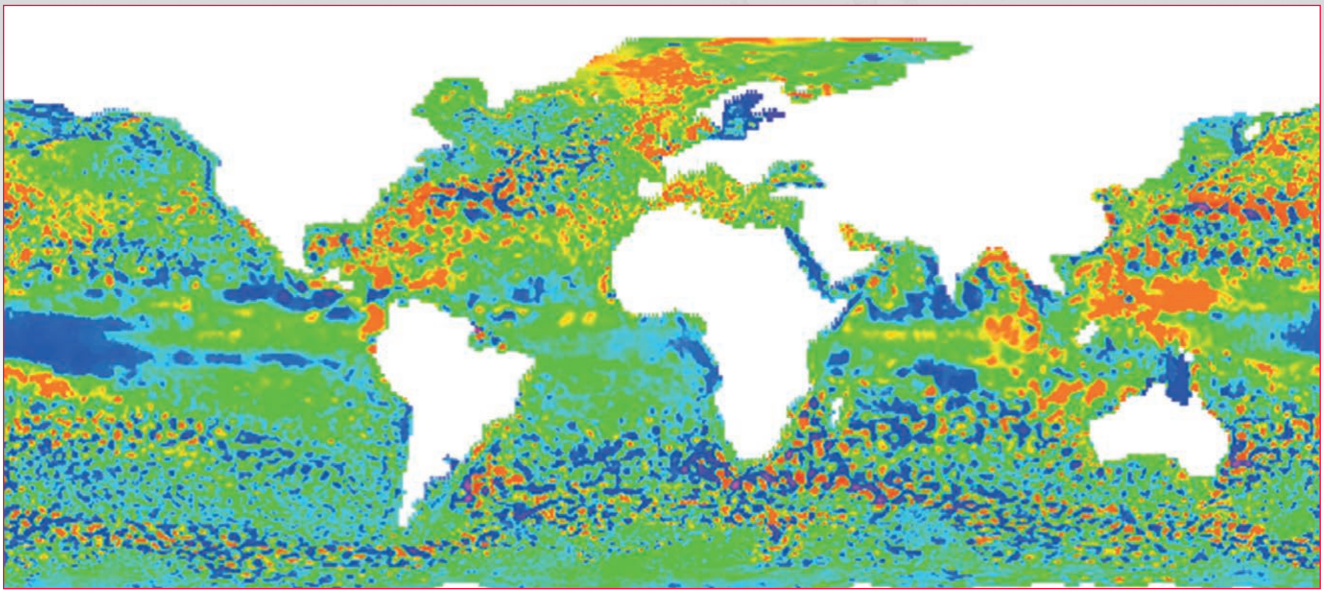

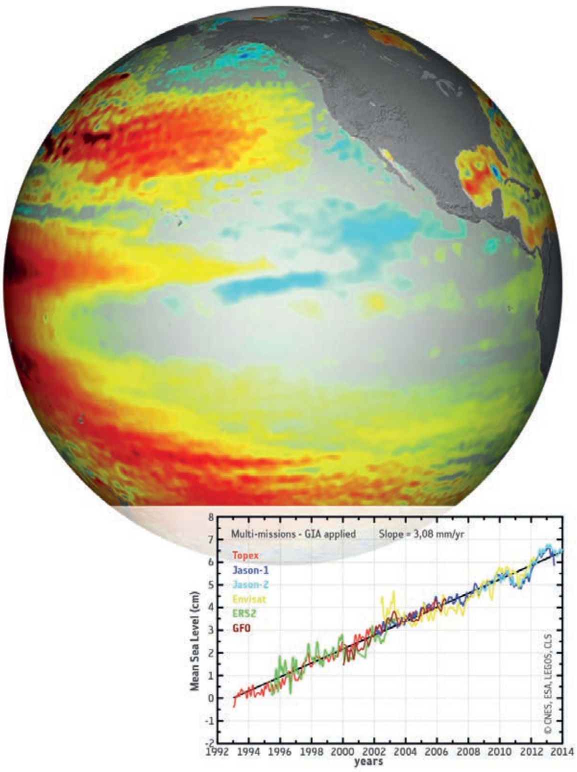

E-learning module "Satellite Earth Observation (EO) and its Application in Climate services Investments"

When choosing and designing investments into climate resilience practices and climate smart planning, satellite-based Earth Observation systems can provide valuable inputs into a variety of areas, including:

- establishing baselines against which changes can be detected and mitigation measures can be determined,
- managing and protecting valued ecosystems to counteracting overexploitation of resources, desertification and land degradation, and to support sustainable agriculture and biodiversity conservation,
- managing marine and coastal ecosystems to mitigate the negative impact of both natural and anthropogenic effects in sensitive habitats,
- managing and monitoring of water resources to predict flood and landslide events, plan for drought and water scarcity, track water pollution and ecosystem degradation, and assess impacts of climate change on water resources,

2. Sea Level Anomaly produced as a part of ESA Climate Change Initiative. Credits: CNES, CLS for ESA/World Bank.

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- supporting risk assessment and crisis mapping including post disaster recovery, rehabilitation, and reconstruction,
- monitoring of urban development to understand how cities are evolving over timeat the local, regional and, global level, and
- supporting dialogue by putting development issues in a spatial context, in a reliable and unbiased manner.

The e-learning module was tailored to end-users who are involved in climate services project design focusing on a several key topics to explain the value that EO data can provide to weather and climate services, describe links to the Weather and Climate Services Value Chain, provide examples how satellite EO can be integrated into climate resilient practices and climate smart planning, and raise awareness about EO products and data sources (Figure 3).

Results

As a result of the project the selected Earth Observation datasets were visualized within the World Bank country's risk and adaptation profiles to enhance information available for country resilience strategies. A custom open source processing tool that combines relevant information has been created to enable CCI products and CCKP integration. Finally the e-learning module has been integrated into the World Bank-led online e-course "Water, Weather and Climate Services: A Value Chain Approach to Project Design".

3. The WBG Climate Screening Tools will now include training (EO module) on Satellite Earth Observation (EO) and its Application in Climate Service Investments' to enhance the utilization of these technologies.

Snow Monitoring and Climate Modeling in Lesotho

Users:

- World Bank Global Practice on Environment and Natural Resources
- IFAD Environment and Climate Division
- Ministry of Energy, Meteorology and Water Affairs (Lesotho Meteorological Services)
- Disaster Management Authority
- Ministry of Agriculture and Food Security
- Ministry of Tourism, Environment and Culture

EO services provided

- Snow Cover Monitoring

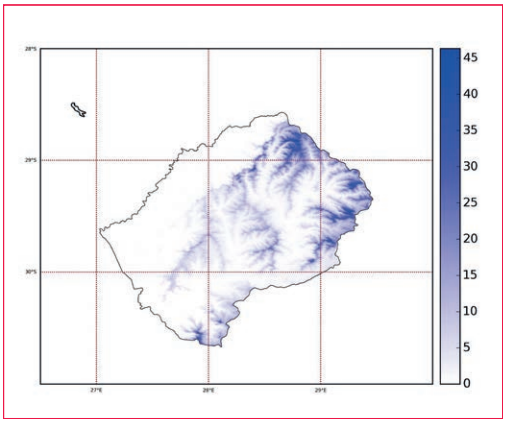
Service Providers

- Federal Office of Meteorology and Climatology MeteoSwiss (Switzerland)
- University of Bern (Switzerland)

Background

Lesotho – known as a 'Mountain Kingdom' – is ranging from 1400 m to 3500 m, with over 80% of the country above 1800 meters. Due to its altitude, it is one of the few locations in sub-Saharan Africa that receives snow, which the country is able to harness as a secure source of water for the fast-growing, lowland urban areas. However, only 6% of the water resources is consumed domestically. The Government's strategy is therefore to maximise the benefit from its resources through the sale of the excess water to South Africa's water-stressed and economically important Gauteng region (where the city of Johannesburg is located). As a result, the Lesotho Highlands Water Project (LHWP) is Africa's largest water transfer scheme consisting of a system of dams and tunnels to store and transfer water from the catchment of the Orange river in the Highlands of Lesotho to the industrial heartland of South Africa. At the same time, the evidence shows that precipitation in Lesotho is becoming increasingly erratic. Therefore, the long-term planning and management of water resources requires improved monitoring of weather, hydrology and climatology to inform decision-making. The World Bank as well as IFAD are currently supporting various analyses in order to facilitate integration of such meteorological and climate change risks into the country's economic, water and land management planning, in particular to assess changes in precipitation, snow cover and snow melt. However, due to gaps in Lesotho's snow cover monitoring network, the characterization of snow cover variability in Lesotho has been difficult to estimate. To fill in that gap a novel snow cover product based on satellite data has been provided through an ESA project, generating new type of information on the spatio-temporal dynamics of snow cover over the entire area of Lesotho.

1



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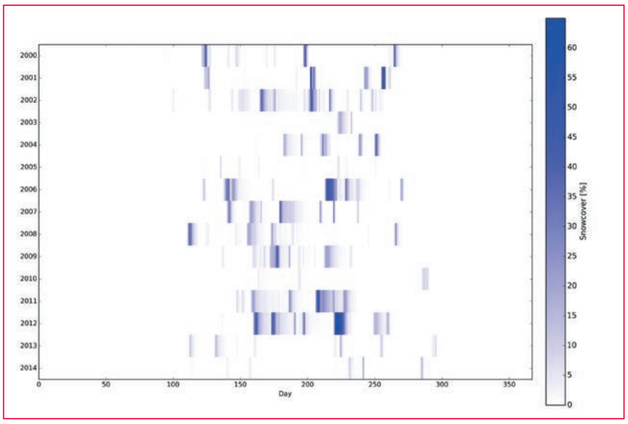

1. Mean snow covered days per pixel in Lesotho for the period 2000- 2014. MODIS data © NASA. Credits: MeteoSwiss & University of Bern for ESA/World Bank.
2. Snow covered area (SCA) in Lesotho over the course of each year for the period 2000-2014.. MODIS data © NASA. Credits: MeteoSwiss & University of Bern for ESA/World Bank.

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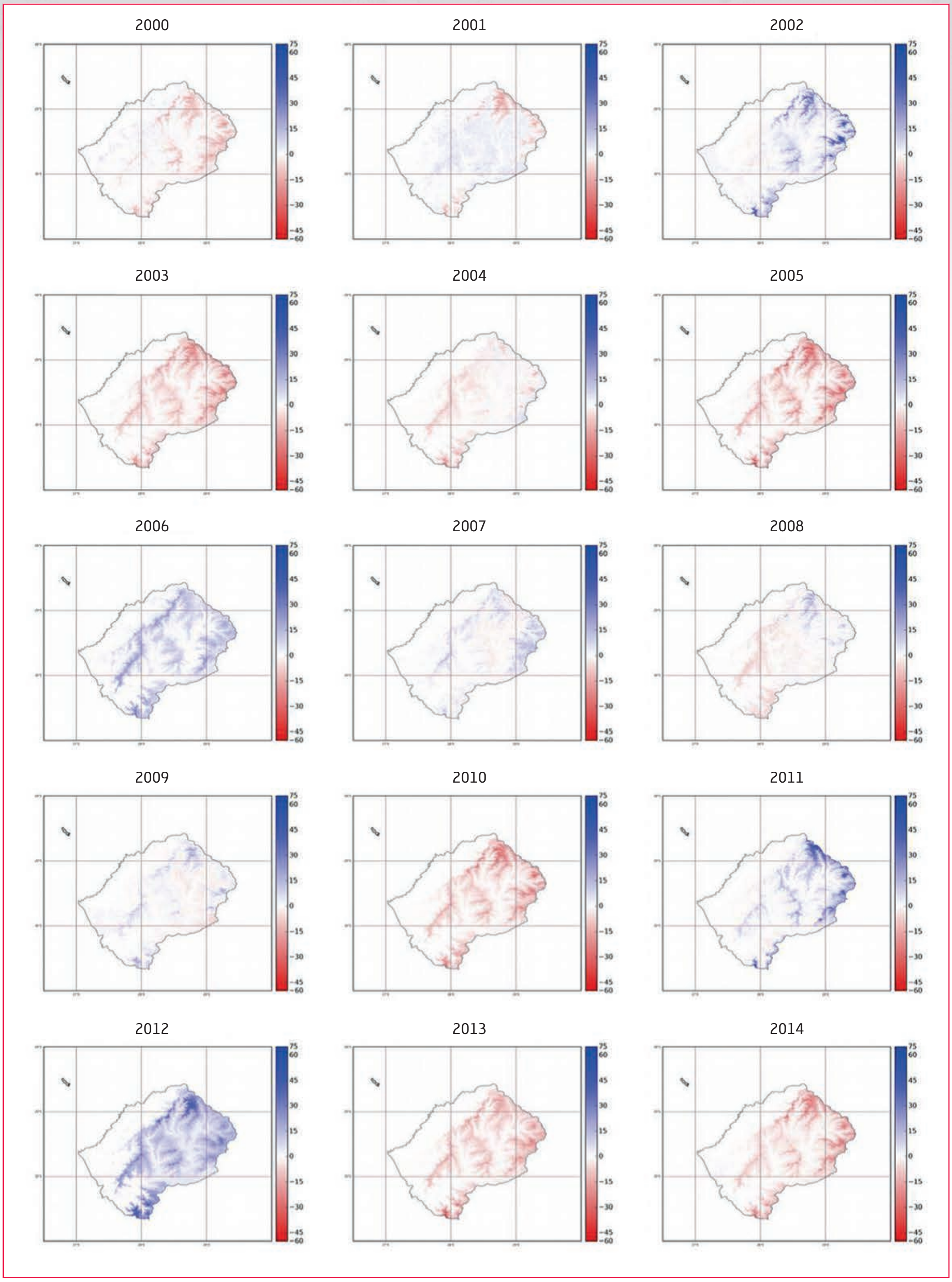

3. Annual standardized Snow Cover Deviation anomalies per pixel for the country of Lesotho for the period 2000-2014. MODIS data © NASA. Credits: MeteoSwiss & University of Bern for ESA/World Bank.

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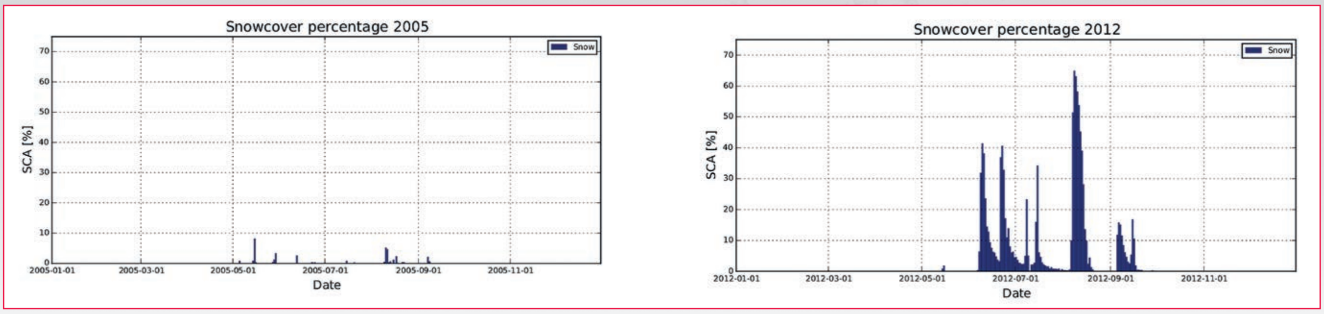

Snow Cover Monitoring

Generally speaking, satellite based snow cover data products can be reliably provided down to a spatial resolution of 500 meters with global coverage and updates on a weekly basis. In addition, historical data sets can be made available for the last 30 years to assess the evolution of snow conditions in the watersheds depending on the available sensor archives.

To customize these capabilities to specific Lesotho characteristics, a 15-year snow cover time series has been compiled based on MODIS reflectance data (MOD09GA) for the years 2000-2014. University of Bern implemented a processing chain considering the concept of the Normalized Difference Snow Index (NDSI) and a temporal-spatial gap filling to retrieve snow information on a daily resolution. This results - for the first time – in a detailed information on the spatio-temporal variability of snow cover in the country (Figure 1). The developed EO snow cover product included the following components:

- daily snow product derived from MODIS data including post-processing to fill gaps caused by cloud coverage
- monthly mean snow cover (in percentage)
- annual mean snow cover (in percentage and days)
- annual deviations of snow cover extent and duration from the long-term mean
- monthly deviations of snow cover extent and duration from the long-term mean
- number of days with snow cover per pixel (at annual and monthly level)
- number and magnitude of major snow fall events per year

Additionally, several key statistics of snow cover were calculated, including annual means, anomalies in snow cover duration, time-series or major snow fall events. The products were validated using Landsat-TM and ENVISAT-MERIS data.

Results

The EO project provided important demonstration of the available state-of-the-art capabilities for the operational snow monitoring system. The Lesotho Meteorological Service (LMS) has been using EO data in the past in the form of near-real-time feed of satellite images from meteorological geostationary satellites for now-casting activities (i.e. the visual analysis of snow fall events), however, a comprehensive and consistent information on snow cover variability was not available to the Lesotho authorities before (data is limited to in-situ snow cover data from five stations mainly situated in the lowlands). The developed products were evaluated with the local stakeholders at a one-week training workshop in November 2015 jointly organized with the Lesotho

4. SCA time-series for 2005 (left) and 2012 (right) as examples for a winter with little snow (2005) and a snowy winter (2012) in Lesotho. MODIS data © NASA. Credits: MeteoSwiss & University of Bern for ESA/World Bank.

Meteorological Service. The meeting revealed a number of application areas which are of high relevance to the local users. The generated data can serve as baseline for local climate models and thus for further analyses of the impact of changing temperature and precipitation patterns in the context of the climate change trends in the region. The time series can also help to develop more reliable interpolation techniques of key snow indicators, such as fractional snow cover or snow depth. Finally, the snow cover climatology can be used for hydrological studies including e.g. run-off modelling of flood forecasting, for agricultural information, as the snowmelt is a source of soil moisture that opens the growing season, as well as for monitoring of recharging of reservoirs (for agriculture and hydropower use). Going forward, establishing a reliable snow cover monitoring services and extracting more complex data on snow depth and snow water equivalent is considered a priority by the local users.

Concerning satellite capabilities, the Sentinel-1, Sentinel-2 and Sentinel-3 satellites will all provide data continuity with respect to monitoring of snow covered areas. With the launch of the first Sentinel-1 operational SAR instrument, a routine broad scale wet snow mapping has become feasible. The high resolution optical multispectral instrument on board Sentinel-2 matches closely the resolution and repeat-cycle of Sentinel-1 for extraction of additional information with 5 day repeat cycle once the units A and B are in orbit. Sentinel-3 launched in early 2016, and will provide enhanced capabilities to continue the optical low resolution snow mapping along with new spectral bands for improved cloud-clearing of optical snow retrievals. Moreover, automation of the generation of snow maps will allow the access to near real-time information. Sentinel-1 with all-weather, day-and-night radar imaging capabilities will be of particular relevance here. SAR can be used to map wet snow conditions characteristic of the springtime snow-melt season. This capability is of high importance because optical-based methods (such as MODIS, Landsat, Sentinel-2 and Sentinel-3) often suffer greatly from cloud contamination. Moreover, enabling monitoring of the hydrology of the snow-melt season with SAR is critical, particularly for forecasting of springtime flood conditions. Finally, in the coming years this area will advance in terms of different algorithmic approaches including the use of InSAR and polarimetry techniques and merging radar, optical and infrared data for even more complex snow cover information (i.e. wet snow depth, fresh snow depth, snow water equivalent, and liquid water content).

5



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5. Malealea Village in snow. © Di Jones (Flickr) under Creative Common License at https://www.flickr.com/photos/lesotho/7352528646
6. Snow landscape in Lesotho. © Di Jones (Flickr) under Creative Common License at https://www.flickr.com/photos/lesotho/with/7165810263/

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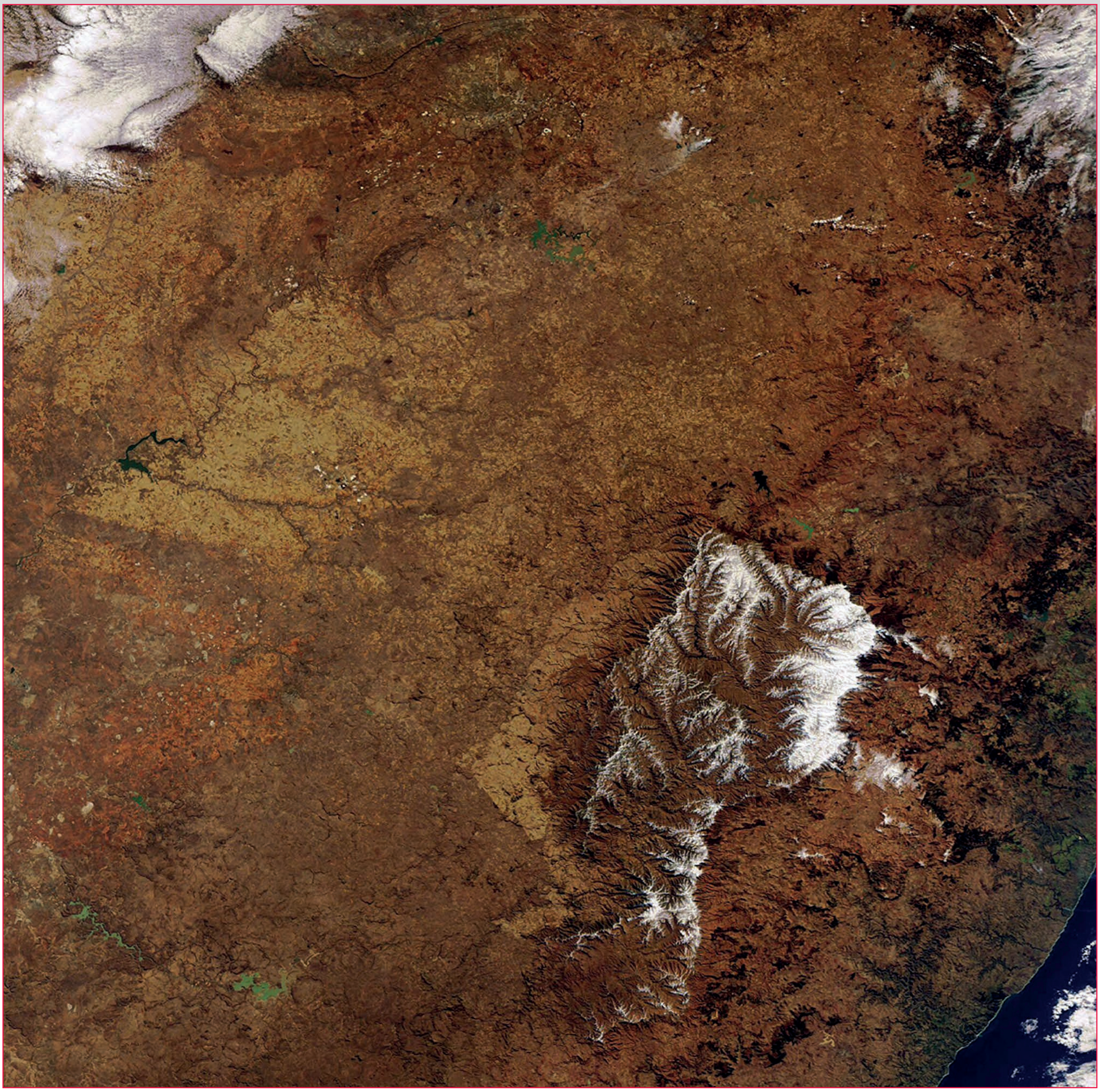

7. Winter snow blankets the heights of the Drakensberg Mountains in Lesotho. Envisat data © ESA. Credits: ESA.

Service Providers

ACRI-ST	Contact Project Manager: Antoine Mangin 260 Route du Pin Montard, BP 234, 06904 Sophia-Antipolis, FRANCE, www.acri-st.fr, information@acri-st.fr
British Geological Survey (BGS)	Contact Project Manager: Colm Jordan & Tom Dijkstra, Natural Environment Research Council (NERC) British Geological Survey Keyworth Nottingham, UNITED KINGDOM, www.bgs.ac.uk
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Total Suspended Matter in the central parts of the Usumacinta Watershed.
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