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Development of the Caribbean Handbook on Disaster Risk Information Management

Jetten, V.1 , Alkema, D[1]. van Westen, C.J.[1], and Brussel, M.[1].

[1]Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, The Netherlands.

Corresponding author details:
Faculty of Geo-Information Science and Earth Observation, University of Twente, Hengelosestraat 99, 7514 AE Enschede, the Netherlands email: c.j.vanwesten@utwente.nl

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INTRODUCTION

The Caribbean region is highly impacted by natural hazards. In the last two decades the region suffered over 5 billion US$ losses from natural disasters. Its location within the path of the Atlantic hurricanes exposes the small island states and countries in the Caribbean to extreme wind conditions and torrential rains. This, in combination with steep terrain makes them extremely susceptible for landslides, floods and storm surges. Their location along the edges of tectonic plates adds tectonic hazards to their threats as well, including earthquakes and tsunamis for the whole region as well as active volcanism on some islands. On a longer time scale, sea level rise is expected to make the hazard situation worse for the coastal areas.

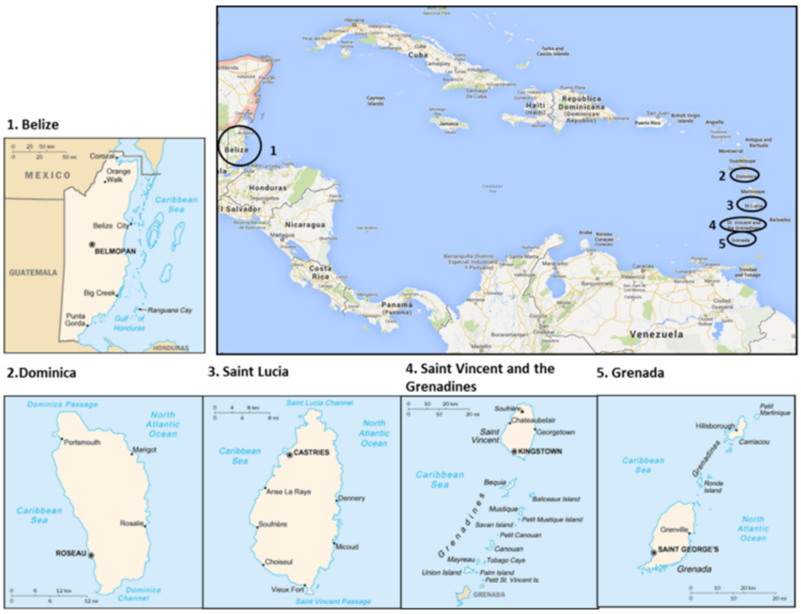

Figure 1: Location of the 5 countries involved in this project.

The small island states and countries in the Caribbean – especially those of volcanic origin with rugged and steep terrain – have limited suitable surface area for development and agricultural production. Most of the population live along the coast and most economic activities are concentrated. These areas are affected by floods (flash floods, drainage floods and coastal floods) and disrupt the socio-economic systems. Vital infrastructure that

traverses the mountainous areas can be severely damaged by landslides, thereby isolating parts of the islands and disrupting the distribution of goods (and relief). Because of their size there is very little robustness in the system to deal with these impacts. As a consequence these events have a severe impact on the relatively small economy of these countries.
The national governments have limited human and financial resources to cope with these hazards and generally lack the expertise for hazard and risk assessment in their territory. This is aggravated by the lack of geospatial data that is needed to carry out these analyses. As a consequence new development activities are often carried out with limited considerations to these hazards. It also hampers the authorities in developing pro-active hazard mitigation plans, such as early warning systems, preparedness planning and risk-reduction strategies.

OBJECTIVES

In 2014 the World Bank initiated the Caribbean Risk Information Program with a grant from the ACP-EU Natural Disaster Risk Reduction Program. A consortium led by the Faculty ITC of the University of Twente was selected to implement the project. The consortium consists of ITC, the University of the West Indies (Trinidad and Tobago), the Asian Institute of Technology (Bangkok), and the University of Bristol. The project is carried within 5 Caribbean target countries: Belize, Dominica, Saint Lucia, Saint Vincent and the Grenadines and Grenada (See figure 1).
The CHARIM project (Caribbean Handbook for Disaster Information Management) has the following objectives:

1. To make an inventory of the needs of each target country in terms of their capacity for spatial data collection, analysis and management, (landslide and flood) hazard and risk assessment, and integrate this information in spatial development planning and risk reduction planning;
2. To make an inventory of the tools available worldwide in terms of technical training manuals linked with practical applications and in terms of methodologies applied for flood and landslide hazard and risk assessment at different scales, as well as open source modelling tools for these hazard types;
3. To develop a theoretical framework for landslide and flood hazards and risks assessments, based on the review of existing quantitative and qualitative assessment methods and their appropriate use;
4. To develop nine national hazard mapping studies in the five target countries. One in Belize related to floods and two on each island for landslides and floods;
5. To develop a handbook to support the generation and application of landslide and flood hazard and risk information;
6. To develop a number of use cases of the application of hazard and risk information to inform projects and program of planning and infrastructure sectors. The methodology provides the overall framework for the use cases. To make the handbook, data and methodology available through a pdf document and through a web-based platform, consisting of web-based databases, and a Decision Support system set-up for risk reduction planning;
7. To provide training courses based on the materials and the handbook, that is made available to the entire region through a web-based platform and distance education course in collaboration with the University of the West Indies;
8. To contribute to knowledge exchange between the target countries as well as to the regional and international expert community.

DEVELOPING THE HANDBOOK

The development of a handbook for the assessment of landslide and flood hazards and risks is one of the main deliverables in this project. This book will comprise three components:

Figure 2: Proposed landing page of the CHARIM handbook (www.CHARIM.net)

- **a methodology book**, which focuses on the methods for generating landslide and flood hazard and risk information for different scales (nationwide, local and for detailed areas) and taking into account different situations of data availability. The methodology book is aimed to be used by technical staff from government organizations and private consultants
- **a use case book**, which illustrates the steps required to use the hazard and risk information in so-called use cases for spatial planning and land management, planning of critical infrastructure, planning of risk reduction measures, emergency preparedness and emergency response. The use case book is aimed to be used by representatives from government sectors, specifically from the Ministries of Physical Planning and Public Works;
- **a data management book**, which indicates the aspects related to the collection, management and sharing of spatial data related to landslide and flood hazard and risk and planning. This book will detail the types and quality of data needed for activities at different scales and methods for data creation and sharing. The data management book

is targeted to technical staff from government organizations and consultants that work on geo-spatial data management & GIS;

In practice these will be three individual parts which can also be joined together as the overall handbook through an on-line platform (www.charim.net). The platform will allow users to generate their own handbook through customized pdf printing options. The platform will also contain a series of GIS exercises that show the various procedures of the use cases in a step-by-step tutorial , using an Open source GIS and datasets from the five Caribbean countries. Although the platform will be developed targeting the specific needs of the five beneficiary countries, the scope will be sufficient generic to extent its use to the wider region. In general, the platform should be easy to use and support government institutions to easier identify which information required for their work. The platform is also intended to be used as the vehicle for distance education courses.

A detailed table of contents for the handbook has been developed, which was presented to the stakeholders from the 5 target countries in a workshop in Grenada in September 2014, where also examples of the use cases were presented. The development of the handbook will take place in the second half of 2014 and the final handbook will be presented in the first quarter of 2015.

One of the main components of the CHARIM project is the development of national scale landslide and flood hazard assessments for the 5 countries. The next part of this paper will illustrate the approaches that are proposed for the four island countries, which are mountainous. The flood hazard approach for Belize, which is mostly flat, is quite different and is not treated here.

NATIONAL SCALE LANDSLIDE HAZARD ASSESSMENT

The landslides in the islands are predominantly shallow soil slides and flow slides, which may turn into debris flows, or hyper concentrated flows that affect buildings and bridges located in the river channels. Landslides occur mostly in the soil cover, which is volcanic origin and of varying thickness, and doesn't seem to be related to one particular type of soil. Landslides may occur in different land cover types, and also landslides occurring in tropical forests or plantation areas are quite common in the area. Most of the landslides seem to be first time failures, and relatively few are reactivations of older landslides. Due to the tropical climate the vegetation recovery within the areas affected by landslides is extremely fast. This forms one of the major obstacles in the landslide inventory mapping from images.

Collection of data on triggering events

One of the key factors for the generation of landslide susceptibility and hazard maps is information on when landslides occurred in the past, and by which triggering events. For the four islands intense rainfall events are considered the most important triggering events. Therefore a study was carried out using various literature sources to reconstruct the major disaster events in the history of the islands. First of all we visited the Offices of Disaster Management in the target countries. One of the best sources for older information was O'Keefe and Conway (1977) for the older disaster occurrences. They based their own data on extensive analysis of newspaper searches for the various countries. Rainfall data were also collected for the four islands. These are mostly available for sites along the coast, and it is difficult to model rainfall distributions for the higher parts of the islands. Rainfall data is problematic, as there are large gaps in the time series, and data is mostly available as daily rainfall only. There are only a few rain gauges with hourly data. We are currently analysing the relation between the reported event days and the daily and antecedent rainfall, in order to determine rainfall thresholds and their return periods, that will be used in the hazard assessment.

Collection of landslide inventories

For each of the 4 islands all available landslide inventories were collected. Whereas Saint Lucia has more than 5 individual inventories, other islands like Grenada or Satin Lucia have only one. To complement these also new inventories were generated based on a series of very-high resolution satellite images (Pleiades) which were obtained in early 2014. Figure 3 gives an example for Dominica.

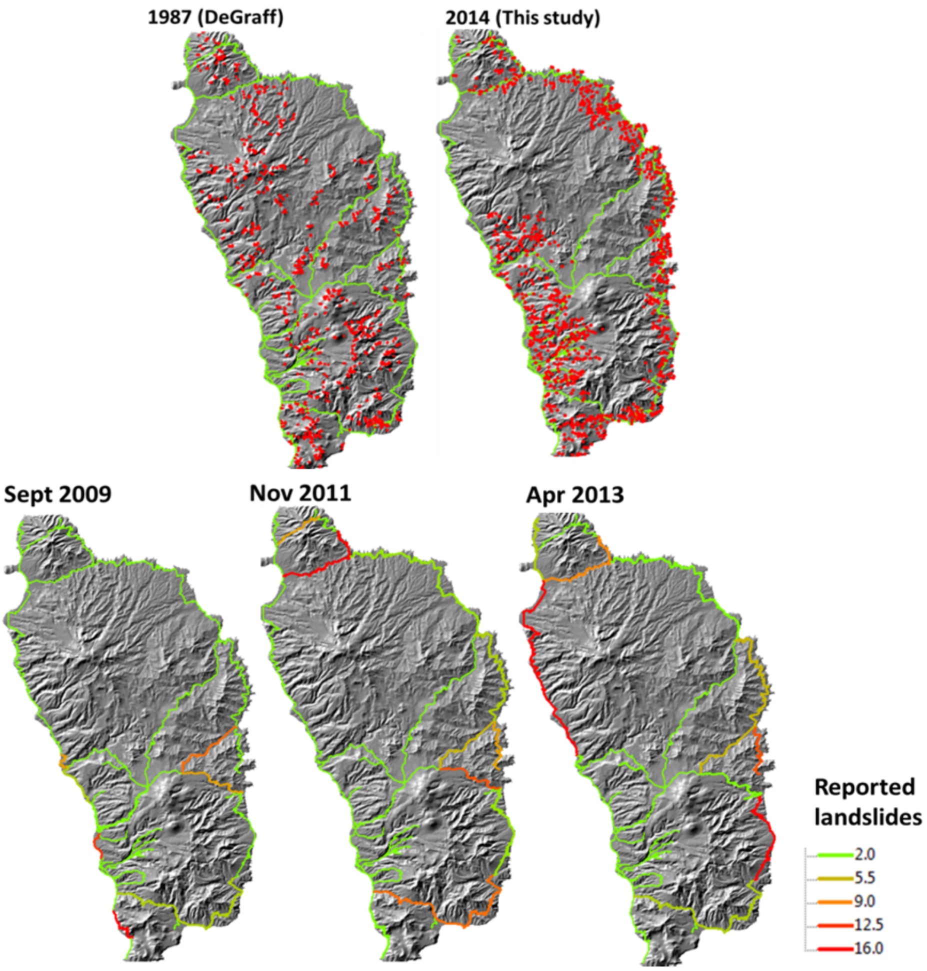

Figure 3: Landslide inventories that were produced for Dominica. Above: Landslide inventory made by De Graff in 1987 and the landslide inventory made through this project in 2014. Below: reporte4d number of landslides for three recent triggering events based on data from the Ministry of works. No location information was available

Landslide susceptibility assessment

For the national scale the use of physically-based modelling is not possible, as the parameterization of such models is not feasible for such large areas, and due to the absence of reliable soil maps. Although there are so-called soil maps available for most of the study areas, these are pedologic soil maps, and not engineering soil maps, which don't contain information on soil thickness distribution or on the geotechnical and hydrological parameters required to carry out physically-based modelling. If we would still apply physically-based modelling using software such as SINMAP, SHALSTAB, TRIGGRS or STARWARS/PROBSTAT, this would be rather meaningless, as the slope angle distribution would completely dominate the analysis in the absence of the relevant factor maps.

For a statistical approach we require a sufficiently large landslide dataset that is related to different failure mechanisms, and contains different landslide types. Although the overall number of landslides per country is reasonable, there is a very large difference between the 4 countries, and the landslide inventories cover a large number of years, during which the causal factors might have changed (e.g. land use/land cover).

One of the main difficulties is that the triggering rainfall distribution that caused the landslides in the various landslide inventories is not known, as we do not have a sufficient amount of rainfall data to model the rainfall distribution for the specific event. It may be that certain triggering events produced much more rainfall in one part of the country, and if there are more landslides in the same area, this will overrule the importance of the topographic, lithological and other factors. Also the rainfall stations are mostly along the coast, and the variation of rainfall with elevation and orientation is difficult to assess. For that we intend to further study the DOMEX (2014) results from Dominica where a network of 10 rain gauges was used in a transect over the island. However, it is questionable whether the same relation could be applied to the other islands directly.

Another difficulty is that many of the earlier landslide inventories are not covering the entire country. For many of the inventory it is difficult to find out what the exact method of mapping was, and which criteria were used for the mapping. A number of inventories focus on landslide mapping along the roads, due to the lack of suitable imagery or skill for image interpretation. Since the majority of the existing landslides that have been mapped in the field are located along the roads, the use of a statistical method would have resulted in a very large susceptibility along roads and a low susceptibility elsewhere, as the factor "close to roads" would have dominated very much over the other factors.

One major difficulty is when we would also include the scarps of the photo-interpreted landslides into account in the statistical analysis; we do not know the relative age of these and therefore would not use the current land use to correlate with the landslide occurrence. Land cover change as a factor would probably be much better.

For several countries we do not have sufficient event-based landslide inventories that relate to a particular triggering event. For many areas the date information is still rather incomplete and needs to be further improvement before it can be used in a temporal frequency analysis.

Given these considerations we propose the following approach:

- **Landslide initiation assessment.**
    - For landslides a combination of statistical analysis using Weights-of-Evidence modelling and expert-based analysis using Spatial Multi-Criteria Evaluation is considered the best method.
    - For landslide along the roads, we propose to subdivide the road network into segments with different characteristics in terms of landslide density, cutslopes dimensions, road drainage, geology and topography. For some of the countries a database of these road segments is already available
- **Landslide run-out assessment**: After generating the initiation susceptibility map, and classifying it into a number of classes, we will extract the high susceptible areas, and used these in a regional scale run-out model (Flow-R developed by the University of Lausanne). The national scale run-out modelling will be carried out using Flow-R (Horton et al., 2013), a modelling software that uses a GIS empirical distribution model to probabilistically estimate the flow path and run-out extent of gravitational mass movements at regional scales.
- **Landslide susceptibility assessment**: The landslide initiation susceptibility assessment will result in two maps (one for the entire area, and one for the road network) which are classified into 5 classes, that are then characterized by the density of landslides. The initiation susceptibility will be combined with the runout susceptibility using a matrix approach.
- **Landslide hazard assessment**: characterize the susceptibility classes with landslide density for specific return periods.

An example of the approach for a test area is shown in Figure 4.

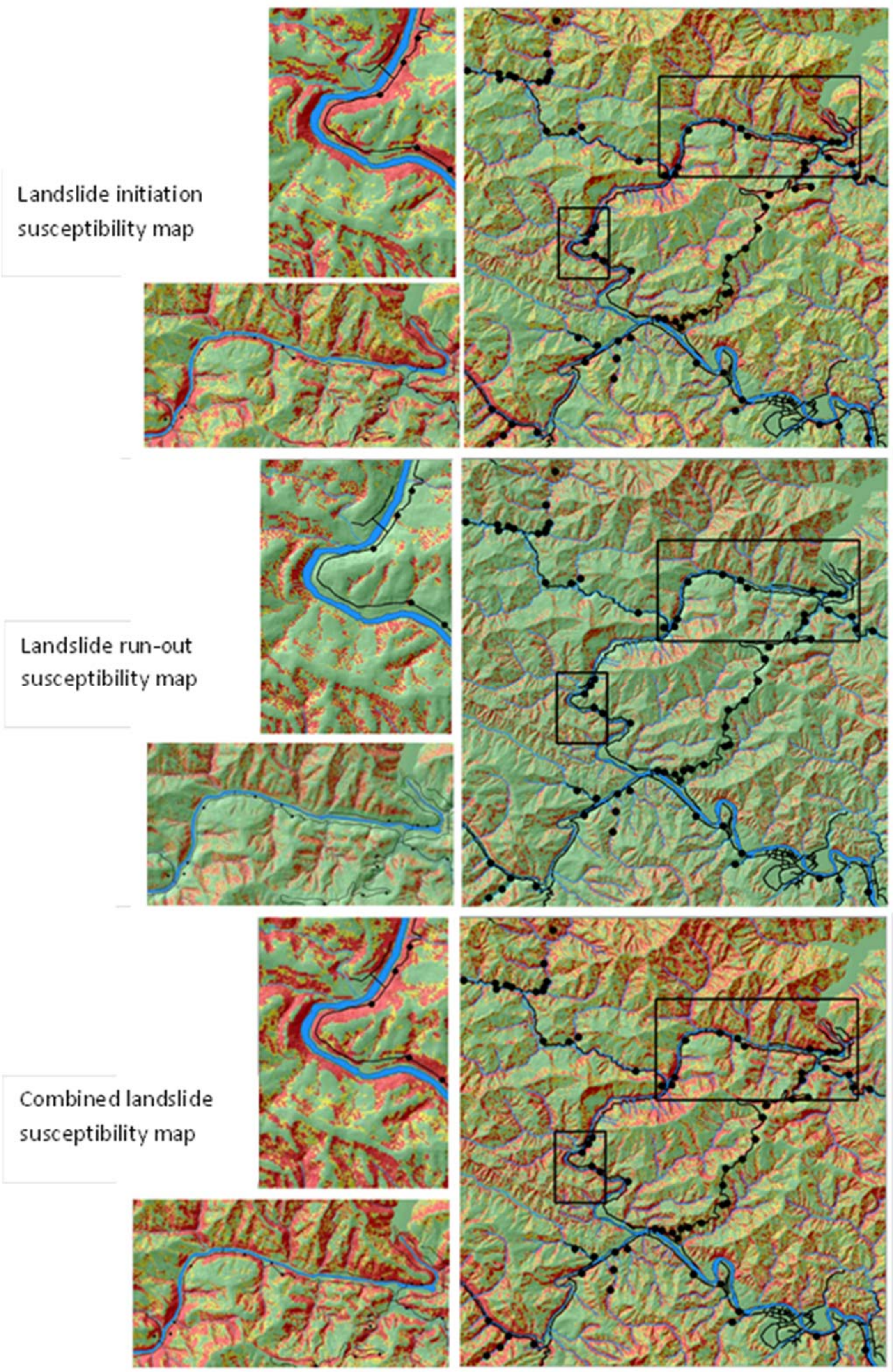

Figure 4: Example of an initiation susceptibility map (Above), landslide run-out map (Middle) and combined susceptibility map (Below) for a test site

NATIONAL-SCALE FLOOD HAZARD ASSESSMENT

The flood hazard assessment will be based on flash flood modelling of all watersheds on the island. Figure 5 gives the methodology to create flood hazard maps. The hazard is expressed as the flood extend and depth for rainfall events of different return periods, with and without blockage of important bridges and culverts. Normally only recurrence periods are included, but partial blockage of bridges by debris (trees, rocks) play an important role in the Caribbean, and are taken into account as scenarios ("with" and "without" blockage).

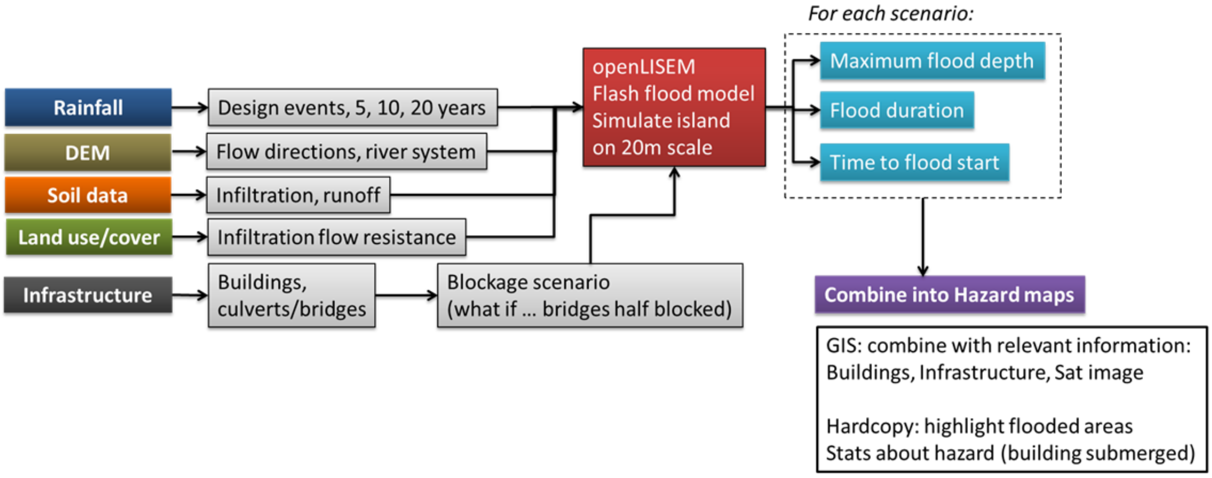

Figure 5. Flood hazard assessment methodology: basic information layers to the left are used for hydrological information that is given to the model. Rainfall for different return periods and partial blockage of culverts are different scenarios. The model gives flood information as separate maps that are combined in a GIS to hazard maps.

The method is based on the open source integrated watershed model **openLISEM**. This model is based on the well-known LISEM erosion/runoff model, combined with the FullSWOF2D opensource 2D flood package from the University of Orleans (Deleste et al., 2014). OpenLISEM is a hydrological model based on the surface water balance. It uses spatial data of the DEM, soils, land use and man-made elements (buildings, roads, channels) to simulate the effect of a rainfall event on a landscape. The resulting runoff is derived form a Green and Ampt infiltration calculation for each gridcell, and routed to the river channels with a kinematic wave. The water in the channels is also routed with a kinematic wave (1D) but when the channels overflow the water is spread out using the full St Venant equations for shallow water flow. Runoff can then directly add to the flooded zone. Since it is an event based model, LISEM does not calculate evapo-transpiration or groundwater flow.
Figure 6 shows a typical screen of openLISEM during a run, with flood depth (in m) and time to inundation (in min) after the start of the rainfall. Figure 6 also shows a typical flood depth map directly imported in QGIS (reads model output directly) and combined with roads and housing footprint.
The individual catchments can be easily retrieved, as the analysis is for the entire island in a single simulation. If the user wants to do a simulation for a single catchment, this can be selected automatically from the database and the simulation can be rerun (for instance when changes in building footprint have occurred).

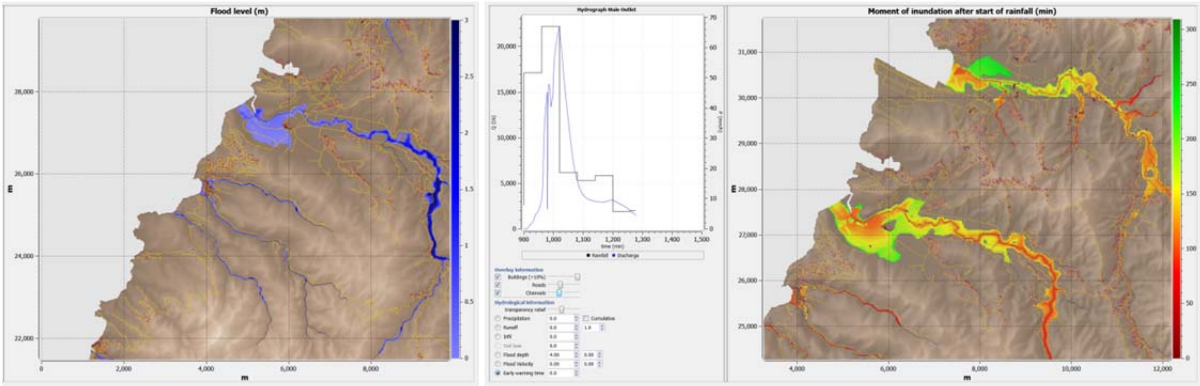

Figure 6: OpenLISEM result screens: Flood Depth at the height of the rainfall (left), and Time to first inundation (min) at a location relative to the start of the rainfall (bottom). This and other information can be directly imported in a GIS.

CONCLUSIONS

The CHARIM project aims to contribute to the development of capacity in landslide and flood hazard assessment in small Caribbean island countries. It will also contribute to the homogenization of data required to carry out such studies, and will support the mechanisms for recoding of hazard and risk information over time. The resulting datasets will be shared with trhe governments through OpenSource softwares, such as GeoNode platforms (e.g. http://sling.gosl.gov.lc/ for Saint Lucia). Staff from the Ministries of Planning and Works are also directly involved in the generation of the final hazard maps and in the development of the use cases, as they will be attending a one-month training in ITC in February 2015.

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