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DOCUMENTING IMPACTS OF HYDRO-METEOROLOGICAL EVENTS USING EARTH OBSERVATION

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ABSTRACT

The ambition of H2020 OPERANDUM project is to develop and document Nature Based Solutions (NBS) to mitigate risks associated with hydro-meteorological (HM) hazards. NBS mitigate risks by reducing the vulnerability of a particular system. The aim of this work is to demonstrate the use of multisource remote sensing data in documenting the impact of extreme HM events to advance knowledge on vulnerability and exposure. In particular the focus is to document past impacts due to extreme events selected from a characterization of recent (30 years) HM events in 11 Open Air Laboratories (OALs) where co-design, co-development and deployment of NBS are taking place. The impacts were documented by applying a wide spectrum of satellite image data and other, close – range, remote sensing techniques. A better understanding of the consequences due to extreme HM events in a particular area (OALs) is essential to identify elements at risk and expected to provide a reference to evaluate the reduction of vulnerability and mitigation of risks past the completion of NBS.

Index Terms— Hazards, Risks, Impacts, Optical and SAR remote sensing, Sentinel.

1. INTRODUCTION

Risk is intended as “the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values' [1]. A metric applicable to risks is the probability of occurrence of hazardous events multiplied by the product of vulnerability and exposure to estimate the probability of the magnitude of impacts. Risk results then from the interaction of vulnerability, exposure, and hazard.

From the definition above it is clear that risk is expressed as a functional relationship between hazard, exposure and vulnerability. Vulnerability represents the ability of the system to cope with, resist and recover from a particular hazard.

The risk concept implies that hazards have to be quantified in probabilistic terms. Vulnerability and exposure are properties of an ecosystem (landscape) at a given moment in time and are assumed to be modifiable by human interventions. In quantitative terms, risk can then be estimated as the product of the probability of occurrence of the hazard intensity with both vulnerability and exposure. Since vulnerability and exposure determine also the impact of actual HM events, analysis of a limited number of events provides useful insight to estimate risks, given the probability of hazard intensity.

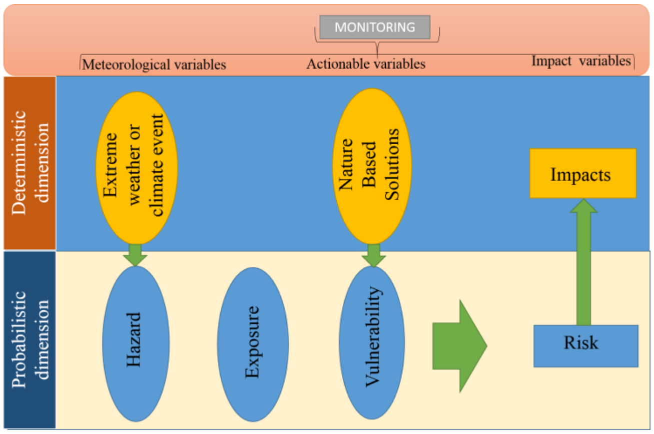

Figure 1. Main components of the deterministic dimension of the risk concept explored in this work against the probabilistic one.

The approach used in this work explores, therefore, a deterministic dimension specular to the risks vs. hazards concept where three aspects of the specific system are analyzed (Figure 1):

- The forcing is an observed occurrence of an extreme event, i.e. a weather or climate event.
- The properties of the system acting on the vulnerability and modified by the NBS to be implemented in the OALs, which are co-designed to

reduce the vulnerability to HM hazards, i.e. to mitigate risks.
- The effect of a HM event, i.e. its physical impact

On the basis of the schematization of Figure 1 we identified, for each OAL, hazard and planned NBS, two different categories of biophysical variables to be monitored using multisource remote sensing data: the impact and actionable variables. Actionable variables are geophysical variables most directly related to the impact of the extreme events. Actionable variables are observable landscape properties that can be modified (by NBS) to reduce vulnerability and mitigate impacts.

Appropriate satellite observations have been identified to assess impacts of extreme events (impact variables) and to characterize actionable variables due to the capability to capture the conditions of a landscape at sufficient spatial and temporal resolutions.

The aim of this work is to present a first step of the analysis where the main goal was to document the impact of extreme meteorological events identified within the last 30 years on the basis of their severity. The analysis from remote sensing data was performed by the retrieval of one or more impact variables during the identified extreme events.

2. METHODS AND MATERIALS

For each hazard one or more geophysical variables most directly related to the impact of the extreme events were identified. The impacts of the extreme events derived from the climatological analysis performed during the project have been documented.

For each observable variable we identified, on the basis of the scientific literature, the most appropriate method to retrieve the variable (Table 1).

Flood extent derived by remote sensing has been selected as the main observation to document the impact of flood and storm surge events. The impact of flood events was also documented in terms of loss of agricultural production. In this case the selected impact variable was the Normalized Difference Vegetation Index (NDVI) [2].

Table 1. Impact variables retrieved from EO data for the extreme events explored in this work

Impact variable	Risk/ number of events	Method
Flood extent	Flood (Greece, Germany, Italy), 18 events) Storm surge (Italy, 3 events)	Thresholding [3] on Normalized difference Water Index [4] or SAR backscatter signal (VV or VH) .
Normalized Drought Anomaly Index (NDAI)	Agricultural drought/ (Italy, China)/ 4	Combination of NDVI and LST normalized anomaly [5]
Surface Urban Heat Island Intensity (SUHII)	Heat Island/Hong Kong/1	Retrieval of Land Surface Temperature from thermal Infrared Remote Sensing. Temperature - Emissivity Separation [6]. SUHII is calculated as $LST_{urban} - LST_{rural}$
Landslides movements	Landslides/Austria/2	Permanent Scatterers High resolution interferometric synthetic aperture radar (PS-InSar)[7]
Chlorophyll content	Deterioration of water quality/Finland/7	Hyperspectral s/multispectral EO data detecting algal pigment spectral signatures [8].

SAR, thermal and optical data available on the dates of the extreme events were searched in the archives of a broad range of satellites. The selection of satellite data to be used was addressed on the basis of different requirements, depending on the specific risk and the spatial characteristics of the targeted area.

3. RESULTS

3.1. Floods

3.1.1. OAL Italy

In the OAL Italy, three severe events occurred in recent years. During the event occurred in 2017 the flood was contained within the riverine areas in both Secchia and Panaro rivers and did not cause impacts. In 2014 and 2020 flood was caused by the break of embankments in Secchia and Panaro rivers, respectively. Flood maps calculated from remote sensing data show that the most frequently inundated area was delimited in the north from Bomporto and in the south from Villavara cities (Figure 2). This area is clearly vulnerable to flood risk.

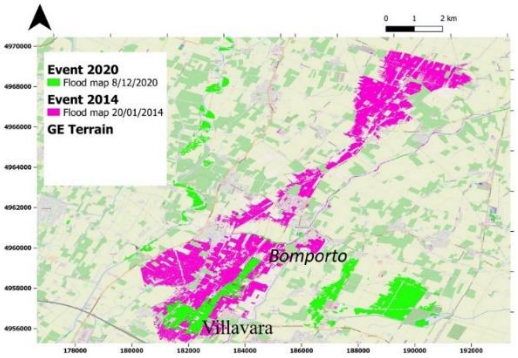

Figure 2. Maps of inundated areas consequent to the extreme events occurred on 19/01/2014 (magenta) and 6/12/2020 (green). The flood maps are retrieved by processing a TerrasarX Stripmap (event 2014) and a Sentinel 1 SAR (event 2020).

In addition, [9] described that the morphology of the river bed increases the vulnerability in the area located to the north of Modena, i.e. the area most frequently inundated and delineated by remote sensing. This indicates that embankments in this area are vulnerable to high water level because the water level is elevated above the surrounding ground.

3.2. Storm Surge

Three severe storm surge events were reported in the last 30 years in the Bellocchio natural park (Emilia Romagna, Italy). Coastal flooding during the events occurred on 26-27/12/1996 and 15-19 January 2017 was documented using Landsat 5-TM and Landsat 8-OLI multispectral images. In both cases the most affected area was the Sacca di Bellocchio (Figure 3).

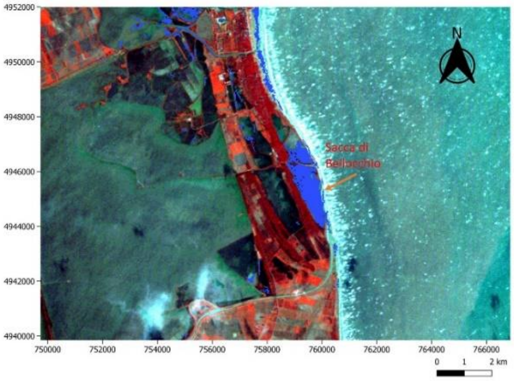

Figure 3. Storm surge flood as observed from Landsat image on the 26-01-2017.

During the event in 1996 also the Lido di Spina beach was inundated. Further analyses are being performed on the latest event occurred in December 2020.

Inflow of sea water due to flooding is likely to cause disturbance of the ecosystem in the Bellocchio lagoon.

3.3. Drought

In Figure 4 the NDAI index histograms are plotted for the years 2003, 2005 and 2006. Heavy agricultural drought characterizes the year 2003, i.e. NDAI values much less than 0 on average. Moderate agricultural drought conditions have been found in 2006, i.e. slightly negative NDAI values. No evident impacts in term of crop stress have been found in the year 2005, i.e. positive NDAI values. The year 2003 was characterized by a long period with positive and persistent LST anomalies, i.e. from beginning of March to the end of September, with negative NDVI anomalies (crop stress) (not shown). Crop stress was due to a prolonged drought period, notwithstanding the anticipated irrigation.

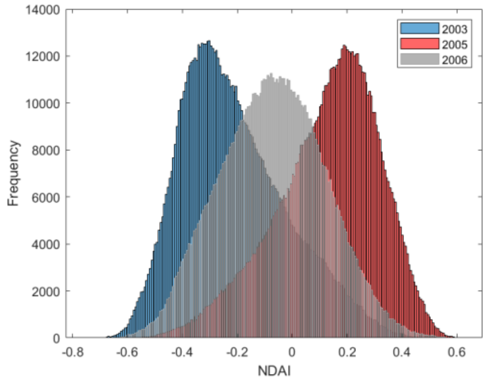

Figure 4. Histograms of NDAI in summer period (1 July to 31 August) for the years 2003, 2005 and 2006.

3.4. Heatwave

SUHII was calculated using Landsat 8 past the retrieval of LST . On one of the identified extreme heat-wave events, i.e. on June 23rd 2016, SUHI values over Hong Kong reached 16 °C with a median equal to 10 °C. On a normal June day, i.e. on June 1st 2011, similar extreme SUHI values were observed, while the median value was much lower, i.e. 7 °C (Figure 5).

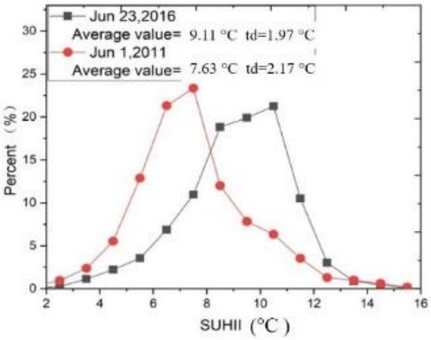

Figure 5. **Hong Kong: Spatial distribution of the Surface Urban Heat Island: extreme heat-wave event on June 23rd 2016 and a normal summer day on June 1st 2011; retrieved from L8 / TIRS data. (J.X.Yang, 2020 pers. Commun.)**

9. CONCLUSIONS

The point of view adopted in this study is that impacts in response to extreme events mirror the relationship of risks with hazards (Figure 1), but on a shorter, observable time scale. In other words, the better understanding of exposure and vulnerability gained by observing impacts of extreme events can be applied to assess risks in response to hazards. The down-side is that extreme events are rare, i.e. a long observation record is necessary to capture a sufficient number of events to gain insights on magnitude and location of impacts. This can then lead to gain a better understanding of exposure to hazards, factors of vulnerability and location of vulnerable areas. The analysis of multiple events leads to assess risks and their spatial dimension.

The observed intensity and extent of the impacts of specific events helped to identify the factors determining the impacts. The latter includes exposure and vulnerability where the exposure is referred to the people, properties and other elements that can be exposed to a HM event and vulnerability is a property of the system determining potential losses due to a HM event. The use of satellite data in this context has the advantages of identifying spatial patterns of impacts, exposure and vulnerability. NBS deployed in the OALs act by modifying the vulnerability towards risk mitigation. Definition of vulnerable areas is a key to select appropriate location where NBS can be deployed and could be useful during co-design phase of NBS.

10. ACKNOWLEDGMENT

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