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A SWIFT APPROACH FOR IDENTIFYING VULNERABLE LINEAR TRANSPORT INFRASTRUCTURES IN AREAS PRONE TO FLOODS AND EROSION

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EXTENDED ABSTRACT

Le infrastrutture di trasporto lineari, come strade e ponti, sono una componente essenziale per lo sviluppo economico e sociale dei Paesi industrializzati in quanto permettono il trasporto di persone e merci. Questo tipo di infrastrutture si sviluppano longitudinalmente su vaste porzioni di territorio e pertanto sono continuamente esposte a eventi meteorologici e idrogeologici avversi come precipitazioni intense, inondazioni, erosioni, frane. ecc. Questi eventi sono in grado di generare interruzioni e malfunzionamenti alle infrastrutture determinando perdite economiche significative (Samela *et alii*, 2023).

Le alluvioni rappresentano la tipologia di disastro naturale che a livello globale ha avuto il maggior impatto negli ultimi 20 anni, sia in termini di persone colpite che di danni economici (EM-DAT; http://www.emdat.be/). Le stime previsionali basate sugli scenari climatici legati al *climate change* prospettano, inoltre, un incremento nella frequenza e nell'intensità degli eventi alluvionali e, di conseguenza, un aumento dei danni attesi. Oltre ai cambiamenti climatici, altri fattori possono contribuire all'aumento del rischio alluvionale su infrastrutture e persone. Tra questi, lo sviluppo socioeconomico di territori potenzialmente allagabili, che si riflette in un incremento delle superfici urbanizzate e nell'estensione delle reti di trasporto, rappresenta uno dei maggiori fattori di rischio. Pertanto, nell'identificazione delle strategie efficaci di adattamento ai cambiamenti climatici che gli Stati membri sono chiamati a valutare per effetto della normativa europea sul clima (EC, 2023), gli studi finalizzati alla valutazione e all'implementazione di sistemi di mitigazione adeguati ed efficaci, che siano in grado di integrare gli aspetti legati alla pericolosità intrinseca dei territori e l'esposizione e vulnerabilità degli elementi a rischio, sono di fondamentale importanza (Jaroszweski *et alii*, 2010).

Obiettivo di questo studio è la sperimentazione di un approccio semi-empirico speditivo per l'individuazione di porzioni di reticolo idrografico potenzialmente critiche dal punto di vista del pericolo alluvionale ed erosivo su cui insistono opere di attraversamento delle infrastrutture viarie, come ponti e/o viadotti. L'areale della Città Metropolitana di Cagliari è stato scelto come sito pilota a causa dell'elevata urbanizzazione e densità abitativa dell'area e del particolare contesto fisiografico, caratterizzato dalla presenza di numerosi bacini costieri con elevate pendenze e brevi tempi di corrivazione. L'approccio metodologico qui presentato si basa sull'utilizzo di dataset immediatamente disponibili sui database pubblici e analisi GIS, articolate attraverso le seguenti fasi: *i*) la caratterizzazione del contesto fisiografico dell'area e la definizione delle condizioni geomorfologiche del reticolo idrografico e dei bacini attraverso l'utilizzo di indici quali il grado di gerarchizzazione del reticolo secondo Strahler, le condizioni di confinamento, l'indice di sinuosità, la pendenza media di tratti omogenei del reticolo, e la pendenza media dei bacini; *ii*) il censimento dei tratti di reticolo idrografico dove insistono opere di attraversamento che hanno subito danni in occasione di eventi alluvionali passati; *iii*) l'individuazione, all'interno dell'area di studio, dei tratti del reticolo idrografico potenzialmente critici caratterizzati da indici geomorfologici simili; *iv*) l'analisi multi-temporale delle immagini satellitari dei tratti potenzialmente critici per il riconoscimento degli eventi alluvionali e, di conseguenza, l'identificazione degli attraversamenti vulnerabili.

La metodologia proposta rappresenta uno strumento rapido ed efficace per l'individuazione preliminare, su vaste aree di territorio, dei tratti critici del reticolo idrografico su cui insistono attraversamenti stradali e/o ferroviari vulnerabili ai fenomeni di alluvione ed erosione. I risultati ottenuti forniscono le informazioni di base per l'indirizzamento di ulteriori analisi e rilievi in situ, finalizzati alla caratterizzazione di dettaglio dell'intensità del fenomeno alluvionale e dell'integrità dell'infrastruttura. Queste informazioni sono fondamentali per lo sviluppo di strategie di adattamento ai cambiamenti climatici efficaci e di sviluppo del territorio, in quanto sono in grado di indirizzare puntualmente le risorse necessarie per il monitoraggio e la messa in sicurezza degli attraversamenti più critici.

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ABSTRACT

Linear transport infrastructures are essential for the socio-economic development of industrialized countries. However, adverse meteorological and hydrogeological events can result in significant economic losses.

Globally, floods have the most substantial socio-economic impact. Climate Change, due to the extent of transport infrastructures over flood-prone territories, is a very important factor in worsening flood risk.

The main objective of this study is to identify the sections of the hydrographic network that are susceptible to flood and erosion hazards where road infrastructures are located. The Metropolitan City of Cagliari (Sardinia, Italy) is selected as test site, due to the presence of several coastal watersheds and of a high population density.

A swift methodological approach, based on already available datasets from public repositories and GIS analyses, is presented. This approach includes: i) geomorphological characterization of the hydrographic network; ii) census of stream tracts where bridges were damaged in past flood events; iii) identification of potentially critical tracts (PCT), based on similar geomorphological conditions; iv) multi-temporal satellite imagery analysis of PCT for the identification of flood-prone areas and, therefore, vulnerable road crossings.

The adopted methodology has proved to be effective for the identification of vulnerable road crossings over wide portion of territories, identifying critical sites that need further investigation.

***Keywords**: transport infrastructures, flood hazard, flood risk, climate change.*

INTRODUCTION

Among the 17 Sustainable Development Goals (SDGs) adopted by all United Nations Member States for 2030, SDG9 and SDG11 are closely related to the resilience of critical infrastructures and to disaster risk reduction strategies. They promote investments for the creation of safe, resilient, and sustainable communities, hence addressing a reduction in the number of natural disaster-related fatalities and infrastructure damage (Donkor *et alii*, 2022).

Transport infrastructures are one of the most important lifelines: in the event of natural disasters, their damage prevents access to housing and other resources and facilities. Moreover, linear transport infrastructures, such as roads and bridges, are essential for the socio-economic development of industrialized countries, facilitating the mobilization of people and goods. However, these infrastructures, extending over wide portions of territories, are continuously exposed to adverse meteorological and hydrogeological events, including intense rainfall, floods, erosion, and landslides. Such events can cause disruptions or malfunctions that not only limit civil protection response, but also strongly affects both private mobility and public transportation, leading to significant socio-economic effects. Some studies have attempted to quantify these effects (Garau *et alii*, 2022; Campisi *et alii*, 2021; Coni *et alii*, 2020). Therefore, the analysis of the vulnerability of transport networks is crucial for planning, design, construction, and management.

Four different approaches to assessing the vulnerability of road infrastructure can be identified in the literature. Chen *et alii* (2007), Jenelius *et alii* (2006), Qiang & Nagurney (2008), Sullivan (2011), Maltinti *et alii* (2012a and 2012b), and Taylor & Susilawati (2012) propose different methodologies to assess the vulnerability of road networks. Other authors (Erath *et alii*, 2009; Knoop *et alii*, 2008; Luathep e*t alii*, 2011) engage with modelling, proposing quantitative and qualitative vulnerability evaluations. The utilization of scenario planning, in order to create hypothetical events and to assess realistic vulnerabilities, represents the third line of research (Bell *et alii*, 2017; Matisziw & Murray, 2009). Finally, in the fourth approach, emphasis is placed on the vulnerability assessment itself, where various indices are developed and verified (Bono & Gutiérrez, 2011; Dalziell & Nicholson, 2001; Tatano & Tsuchiya, 2008). More recently, Minhans & Chatterjee (2023), starting from the idea that the assessment of the vulnerability of transport networks should encompass several factors (Social, Technological, Environmental, Economic and Political), have applied catastrophe theory to assess the macro-level vulnerability; according to the study, social factors have the greatest impact on transport vulnerability.

Over the last two decades, floods have represented globally the natural disaster with the greatest socio-economic impact (EM-DAT; http://www.emdat.be/), and it is expected that their frequency, intensity, and impact will increase in the near future due to the Climate Change. In addition, the expansion of urban areas and the extent of large transport infrastructure networks over potentially flood-prone territories are contributing factors in increasing the flood risk.

Studies assessing the impact of climate change effect on the transport sector are still preliminary; however, there is a clear need for a multidisciplinary, holistic approach (Jaroszweski *et alii* i, 2010).

GIS-based approaches applied to geomorphology have significantly increased in the last decades, addressing a variety of applications including natural hazard reduction, assessment, and perception (Keller *et alii*, 2020). In the frame of flood risk assessment and vulnerability, GIS-based approaches allow the integration of multiple type of data and the extraction and analysis of geomorphic indices to produce flood maps illustrating the extent and depth of possible flood inundation (Kumar *et alii*, 2023).

In recent years, the attention of researchers has focused on the state of bridges, as they represent the road-hydrographic network intersections most susceptible to damage and for which fast and low-cost monitoring techniques are being developed

(Zucca *et alii*, 2023). To date, studies on this topic include large-scale assessment of flood hazard on transport infrastructure, based on the Geomorphic Flood Index (GFI) (Samela *et alii*, 2023) and the application of multivariate statistical modelling (Kalantari *et alii*, 2019). A comprehensive review of such methods is proposed by Rebally *et alii* (2021).

In this study, we propose a swift methodology for the identification of portions of the hydrographic network prone to flood and erosion hazards where road infrastructures, including bridges and/or viaducts, are located. The Metropolitan City of Cagliari, in southern Sardinia (Italy), has been selected as test site, due to the occurrence of several coastal watersheds with high slope gradients and short corrivation times, as well as high population density.

SITE CHARACTERIZATION

The Metropolitan City of Cagliari, in Southern Sardinia (Italy), extends over a surface of 1,247 square kilometers and includes the municipality of Cagliari and other 16 towns of the hinterland. The total population is over 430,000 inhabitants, half of them living in the city of Cagliari and Quartu S. Elena.

The physiographic context and the hydrographic network of the area are strongly influenced by the geological and geodynamic evolution of southern Sardinia (Barca *et alii*, 2005). A wide extensional structure, the Campidano plain, developed through multiple phases from Early Miocene to Pliocene-Pleistocene, and is filled with marine, transitional, and continental deposits. Along the south-western and eastern boundaries of the plain, metamorphic and intrusive rocks of the Paleozoic basement of Sardinia outcrop, constituting reliefs reaching maximum elevations of about 1,000 m asl. Several coastal watersheds, with high slopes and short corrivation times, characterize the eastern and south-western sectors of the metropolitan area, while in the central sector insists a wide alluvial plain-lagoon system related to the fluvial dynamics of the Flumini Mannu river, whose basin extends beyond the limits of the metropolitan area (Fig. 1).

MATERIAL AND METHODS

The methodological approach presented in this study is based on input dataset coming from public repositories, easily downloadable as shapefile and raster files, or consultable through Web Map Services (WMS), online map services, and WebGIS platforms. These repositories include the Sardinia Geoportal, Google Earth Pro/Google Maps, the National Repository of Soil Defense interventions (ReNDiS) inventory, and the Province road system registry. The ReNDiS dataset was integrated with information from the Flood Risk Management Plan (PGRA) of Sardinia. The PGRA contains a summary of funded remediation projects updated to October 2021, which were not included in the ReNDiS repository. This integration allowed for a more comprehensive understanding of funded remediation projects aimed at addressing flood risks in Sardinia, incorporating both historical data from ReNDiS and more recent updates from the PGRA. In Table 1, detailed information on the used dataset is provided.

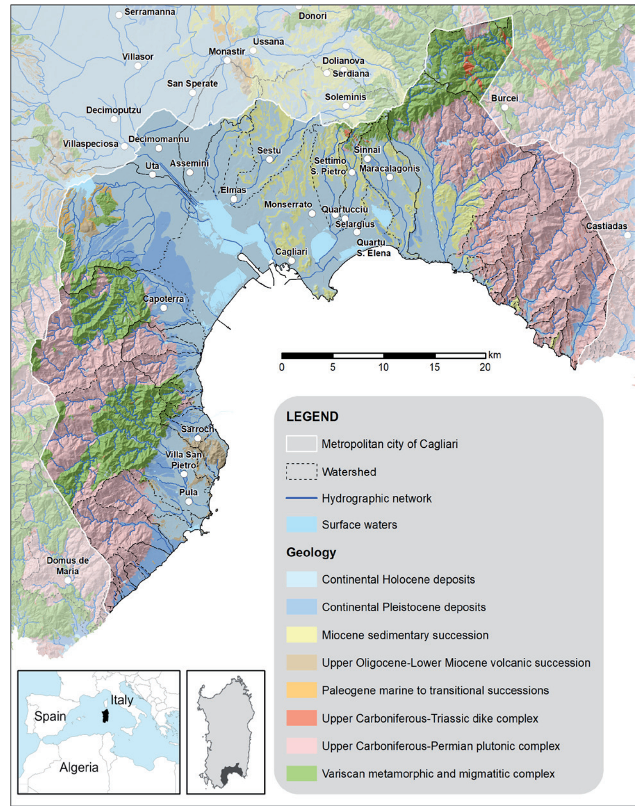

Fig. 1 - Geological framework and physiographic context of the Metropolitan City of Cagliari (S. Sardinia, Italy)

These datasets were integrated and analyzed within the ESRI ArcMap 10.8 GIS environment. The methodological approach can be summarized into the following main steps:

1. Characterization of the study area physiographic context and segmentation of the hydrographic network, based on geomorphological indicators.
2. Identification of reference stream tracts where past floods events have damaged road crossings.
3. Selection of potentially prone to flood/erosion stream tracts across the study area, based on physiographic and geomorphological characteristics similar to known, previously damaged tracts.
4. Multi-temporal analysis of ortho-photo/satellite imagery of tracts to identify road crossings at risk of flood/erosion.

Step 1

Physiographic and geomorphological characteristics of the study area and the hydrographic network, respectively, were evaluated to define homogeneous stream tracts.

Source repository	Description	Origin / last update / data type
Sardinia Geoportal (https://www.sardegnageoportale.it/)	Digital Terrain Model (DTM) of Sardinia with a 10 m pixel	/ 2008 / raster
	Hydrographic drainage network of Sardinia, classified through the Horton-Strahler ordering system	Geo Topographic Database (DBGT) 1:10000 scale / 2022 / shapefile
	Road network of Sardinia, classified into main and secondary extra-urban roads, urban neighbourhood and traffic roads, and local roads	
	Geological map of Sardinia 1:25000 scale	Regional Landscape Plan (PPR) / 2008 / shapefile
	Multi-temporal ortho-photo imageries of Sardinia	/ from 1954 to 2019 / WMS
	*Funded remediation projects in Sardinia. *Used to integrate the ReNDiS Database	Flood Risk Management Plan (PGRA) of Sardinia / October 2021 / table in document
Google Earth Pro / Google Maps	Multi-temporal satellite imagery of the studied area	/ from 2003 to 2023 / online map service
National Repository of Soil Defense interventions (ReNDiS) inventory (http://www.rendis.isprambiente.it/)	Database of mitigation measures funded by the Italian government, planned to restore the damage caused by natural events like floods and landslides	/ 2020 / WebGIS
Province road system registry	Inventory of infrastructure crossings insisting over the Metropolitan City of Cagliari	/ 2014 / shapefile

Tab. 1 - Information on used dataset, grouped according to their source repository

Physiographic Units

To describe the physical context of territories where river and streams flow across the study area, three different Physiographic Units (PU), namely Inner Reliefs, High Plains, and Plains, were defined, based on information derived from the outcropping geology and topographic slope (Fig. 2).

- Inner Reliefs (R): such PUs characterize the eastern and south-western sectors of the study area; outcrops are mainly represented by intrusive rocks from the Paleozoic bedrock and, secondarily, by Oligo-Miocene volcanoclastic and calcareous rocks; slopes are generally higher than 20 %.
- High Plains (HP): such PUs include outcrops of continental Pleistocene deposits, at the piedmont of the inner reliefs, and Oligo-Miocene deposits; these surfaces, with slopes generally lower than 10%, were terraced by the Holocene alluvial activity of the main streams.
- Plains (P): such PUs represent areas with slopes lower than 10%, mainly constituted by Holocene alluvial to coastal deposits, related to dynamics of main rivers and streams.
- The PUs are then used to perform a preliminary segmentation of the hydrographic network.

Confining Conditions

Confinement conditions were used to further segmentate the hydrographic network. Due to the lack of a detailed input dataset, that would have been required for the definition of quantitative indicators, such as the degree of confinement and the confinement index, segmentation was performed through a qualitative approach, based on the occurrence of alluvial deposits along the hydrographic network, as well as its proximity relationships with lateral boundaries of alluvial plains; for this purpose, alluvial deposits only include Holocene, current and recent, alluvial sediments, as defined in the Geological Map of Sardinia. The following segment types are then identified (Fig. 2):

- Confined: (c) the thalweg is in direct contact with confining deposits or rocks; no plain occurs.
- Unconfined (u): the thalweg is located within the alluvial plain, in central position.
- Semiconfined (s): the thalweg is located within the alluvial plain, proximal to a plain side.

Further segment types are identified, based on combinations of the previous ones, as an alternation of unconfined and semiconfined (u-s); unconfined and confined (u-c); confined and semiconfined (c-s). Highly anthropized (HA) segments are also identified and considered in the analysis phase.

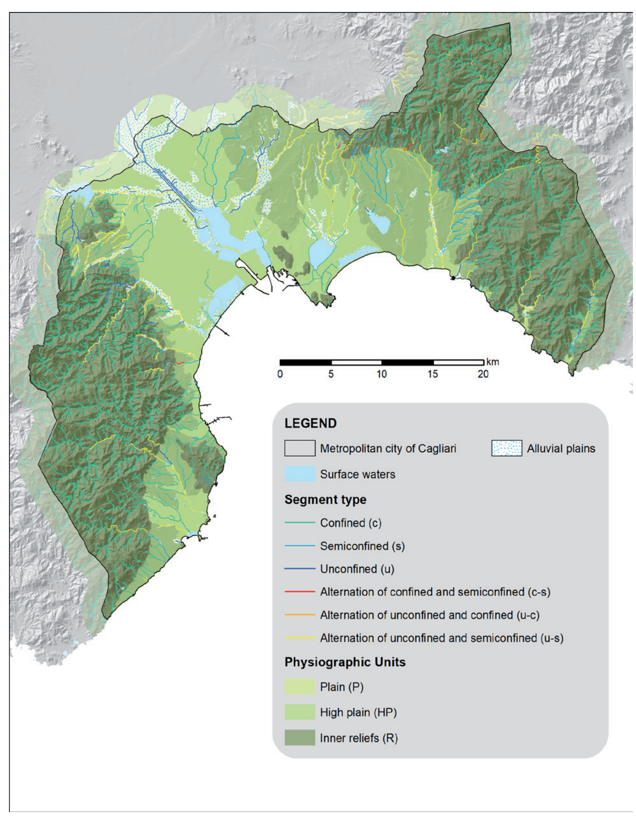

Fig. 2 - Physiographic Units and segmentation of the hydrographic network based on confinement characteristics; Strahler order 1 and 2 are not shown for a better visualization

Geomorphological Indexes

Geomorphological indexes, as the Sinuosity Index (SI) and the Average Slope (AS), were then evaluated for each segment, representing a homogeneous tract of the hydrographic network. The SI was defined as the segment length along the thalweg divided by its planimetric extent. The AS of the segment was defined as the difference between upstream and downstream elevation divided by the segment length. The Arc Hydro tools for Arc map 10.8 (Ewrt, 2011) were used to evaluate both indexes.

Step 2

The identification of reference stream tracts where past flood events had damaged road crossings was performed through the interrogation of the ReNDiS inventory, updated with information from the PGRA as described above. For the purpose of this research, only remediation projects related to damages produced by floods to the infrastructure networks were selected. As every project is georeferenced, it was straightforward to relate project information from the ReNDiS/PGRA to the stream segments defined in the previous step. This selection represents the reference stream segments.

Step 3

For each reference stream segment associated to a flood remediation project, physiographic and geomorphological characteristics (Strahler, Confinement Type, Sinuosity Index and Average Slope) are extracted. These characteristics were then used to identify, throughout the whole study area, potentially critical stream segments. The assumption was that stream segments with similar geomorphological characteristics can be prone to similar flood events.

Step 4

Potentially critical stream segments were overlaid with the infrastructure crossings inventory to identify segments where elements at risk are present. Then, on this selection, a multi-temporal analysis of ortho-photo and satellite imagery was performed, aiming at the identification of stream segments where flood/erosion events have occurred in the last decades. For the purposes of this work, infrastructure crossings were firstly selected based on their intersection with the road network of Sardinia.

RESULTS

In the metropolitan area, 15 remediation projects related to flood damages at crossing infrastructures were identified, insisting over a total of 11 different stream segments. As shown in Table 1, most of these are associated with Strahler order 5, followed by Strahler order 4, 6, 7 and 3. Additionally, segments mainly insist over the Plain PU, while the confinement types vary, with unconfined to semiconfined segments prevailing. SI and AS range from 1.05 to 1.4, and from 0.0 to 0.05, respectively. However, SI and AS were not used to further constrain the selection.

The application of Step 3 resulted in a total of 220 potential critical stream segments, with 67 infrastructure crossings (Table 2). Multi-temporal analysis revealed that past flood events have affected 12 crossing infrastructures distributed over 8 segments.

			Potential Critical Tracts	
	Stream name	***Characteristics***	***Segments***	***Crossings (damaged)***
Reference Stream Segments	Sa Is Coddus	3 P u-s	2	2 (0)
	Sant'Antoni	4 R c	150	7 (2)
	Canale Bacu Liconosu	4 HP u-s	24	25 (2)
	Masoni Ollastru	4 P s	5	6 (0)
	San Girolamo	5 R u-s	10	4 (2)
	Cuba	5 P u	2	0 (-)
	San Girolamo	5 P u-s	5	7 (4)
	Coccodi	5 P c	13	8 (1)
	Guttureddu	6 R u	1	0 (-)
	Pula	6 P u-s	2	3 (1)
	Santa Lucia	7 P u-s	6	5 (0)
	TOTAL		**220**	**67 (12)**

Tab. 2 - Summarized results of the method application, showing the total number of Potential Critical Tracts (PCT) having geomorphological characteristics similar to the reference stream segments, and also the total number of crossing infrastructure located in it, as the number of the damaged crossings. Legend: in the characteristic's column, abbreviation represents Strahler order (numbers 3 to 7), Physiographic Unit (P: Plain; HP: High Plain; R: Inner Reliefs), and confinement type (u: unconfined; s: semiconfined; c: confined)

Results obtained through the application of the method are shown in Fig. 3, while in Table 3 a synopsis matrix is presented. Each reference segment is reported in the column fields, with the resulting PCT displayed in the rows. We have identified 31 potential stream segments where significant crossing infrastructures insist. The results of the multi-temporal analysis allowed the identification of stream segments where it is evident the occurrence of past flood events (i.e. sediment accumulation or side erosion) at road crossings and nearby location (class YES, 8 segments) or not (class NO, 19 segments); additionally, a distinct class, HA, is defined as a specific case within the NO class and is assigned to Highly Anthropized stream segments (4 segments). No PCT were obtained for the Riu Cuba and Riu Guttureddu type selection (NA). In Fig. 4 is shown an example of a YES class PCT, identified through the application of the methodology.

DISCUSSION AND CONCLUSIONS

The YES class results identify stream segments with comparable geomorphological characteristics to those of the reference segments, both in terms of the segment itself but also in terms of the up-stream portion of the watershed.

The NO class PCT can be explained in different ways, depending on local conditions characterizing the site where they insist: a) most of the PCT with Strahler order 4 over the Plain and High Plain PU, are located within low-slope watersheds with little or no extension of the Inner Relief domain; b) for the

Riu Longu (5,R,s-u), Riu Geremeas (5,P,u-s), and the 4,R,c PCT, factors like particular pluviometric conditions and sediments availability, or a combination of them, may have influenced the result; c) the Riu di Corungiu (6,P,u-s) is located down-stream with respect to its homonym YES class segment (5,P,u-s), so the inference is that the load sediment is completely discharged upstream. For the cases b) and c), high level of attention is anyway required, especially in the frame of the Climate Change scenario.

The HA class mainly includes channels located within the city of Cagliari and its suburbs, proximal to urban swamps and to the coast (Canale Palma, di San Bartolomeo, Mortu – 5,P,c), while the Cixerri segment (7,P,u-s) is the stream tract located down-stream of the homonym dam.

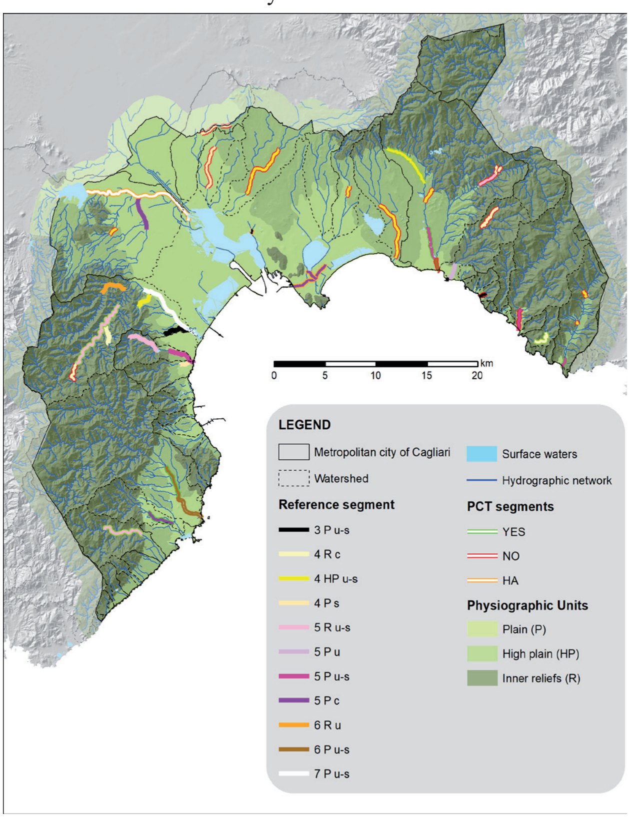

Fig. 3 - Map of the Metropolitan City of Cagliari illustrating the reference stream segments and the obtained Potential Critical Tracts (PCT): the classes YES and NO identify PCT where evidence of past flood events has been recognized through the multi-temporal analysis or not, respectively; the HA class define Highly Anthropized segments. Legend for Reference Segments: Strahler order (3 to 7); physiographic units (P; HP; R); segment confinement characteristics (u: unconfined; s: semiconfined; c: confined)

In spite of the fact that most of the results are associated with stream segments where no past flood events were recognized (NO and HA classes), the methodology has demonstrated a good potential in the preliminary identification of stream segments that can be considered prone to floods (YES class), with particular effectiveness in geomorphological contexts related to coastal watersheds, which are characterized by high slopes and short corrivation times. However, results are strongly influenced by the quality and accuracy of input dataset. ReNDiS database, for instance, is not continuously updated, and therefore there is the need to integrate it with other sources to overcome the lack of information in defining the initial reference segments. Other issues derive from the subjectivity introduced in the stream segmentation, which is mostly related to the quality of cartographic representation of the alluvial deposits and, therefore, to the opportunity of evaluating quantitative index for the confinement conditions.

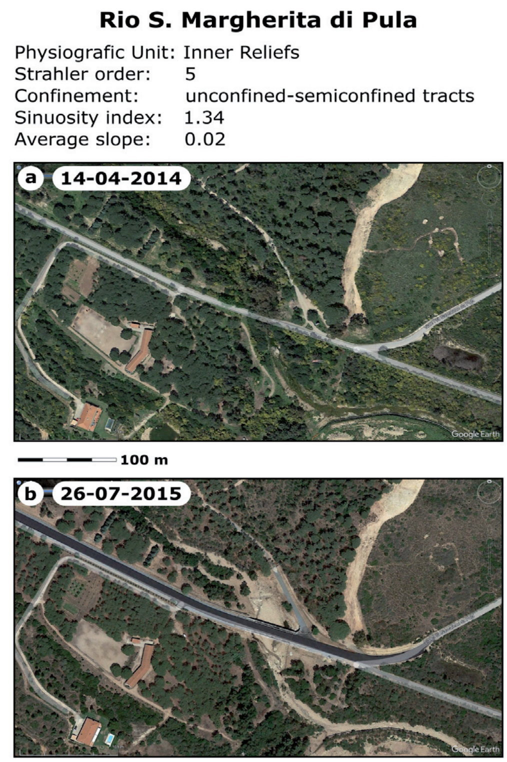

Fig. 4 - Example of a YES class PCT: Rio S. Margherita di Pula; stream segment conditions a) before and b) after the flood event occurred in the winter 2014-2015.

The proposed methodology represents an effective and swift approach for the preliminary identification, over wide portion of territories, of critical tracts of the hydrographic network where crossing infrastructures may be vulnerable to flood and erosion events. The obtained results provide the basic information for addressing further in situ analyses and surveys, aimed at the detailed characterization of the intensity of a potential flooding phenomenon and of the possible degree of damage of the crossing infrastructures. This information is essential for the development of effective climate change adaptation strategies and territorial planning, addressing the resources needed for monitoring and securing of the most critical crossings.

POTENTIAL CRITICAL TRACT STREAM WHERE ROAD CROSSINGS INSIST

		REFERENCE STREAM SEGMENTS										
	Stream name	Sa Is Coddus	Riu Sant'Antoni	Bacu Liconosu	Masoni Ollastru	San Girolamo	Cuba	San Girolamo	Coccodi	Guttureddu	Pula	Santa Lucia
Stream name	*Stream characteristics*	3 P u-s	4 R c	4 HP u-s	4 P s	5 R u-s	5 P u	5 P u-s	5 P c	6 R u	6 P u-s	7 P u-s
Su Tuvu Mannu	3 P u-s	NO										
River_3055	3 P u-s	NO										
Riu Gavoi	4 R c		YES									
Riu Cramoi	4 R c		NO									
Riu Umbra Niedda	4 R c		NO									
Canale Antiogus	4 R c		NO									
Riu Sa Castangia	4 R c		NO									
Riu San Barzolu	4 HP u-s			YES								
Riu Lepris	4 HP u-s			NO								
Riu Loi	4 HP u-s			NO								
Riu Is Cresieddas	4 HP u-s			NO								
Riu Su Castangia	4 HP u-s			NO								
Riu De Is Cungiaus	4 HP u-s			NO								
Riu Foxi	4 HP u-s			NO								
Riu Is Cannas	4 HP u-s			NO								
Riu Di Sestu	4 HP u-s			NO								
Riu San Gimiliano	4 P s				NO							
Riu De Giacu Meloni	4 P s				NO							
Riu S. Margherita	5 R u-s					YES						
Riu Gutturu Mannu	5 R u-s					YES						
Riu Longu	5 R u-s					NO						
-	5 P u						NA					
Riu Solanas	5 P u-s							YES				
Riu Sa Tanca (Riu Di Corongiu)	5 P u-s							YES				
Riu Geremeas	5 P u-s							NO				
Riu Su Tintiori	5 P c								YES			
Canale di San Bartolomeo	5 P c								HA			
Canale Palma	5 P c								HA			
Riu Mortu	5 P c								HA			
-	6 R u									NA		
Riu Mannu	6 P u-s										YES	
Riu di Corongiu	6 P u-s										NO	
Riu Cixerri	7 P u-s											HA

Tab. 3 - Results of the multi-temporal analysis showing, for each reference segment, the corresponding PCTs where evidence of past flood events (i.e. sediment accumulation or side erosion) have been recognized at infrastructure crossings and nearby locations (YES class), or not (NO class), and the Highly Anthropized PCT (HA class)

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