Geomorphologically based early warning system for flood-landslide events in minor hilly catchments and local urban areas: example form the Abruzzo region (Central Italy)

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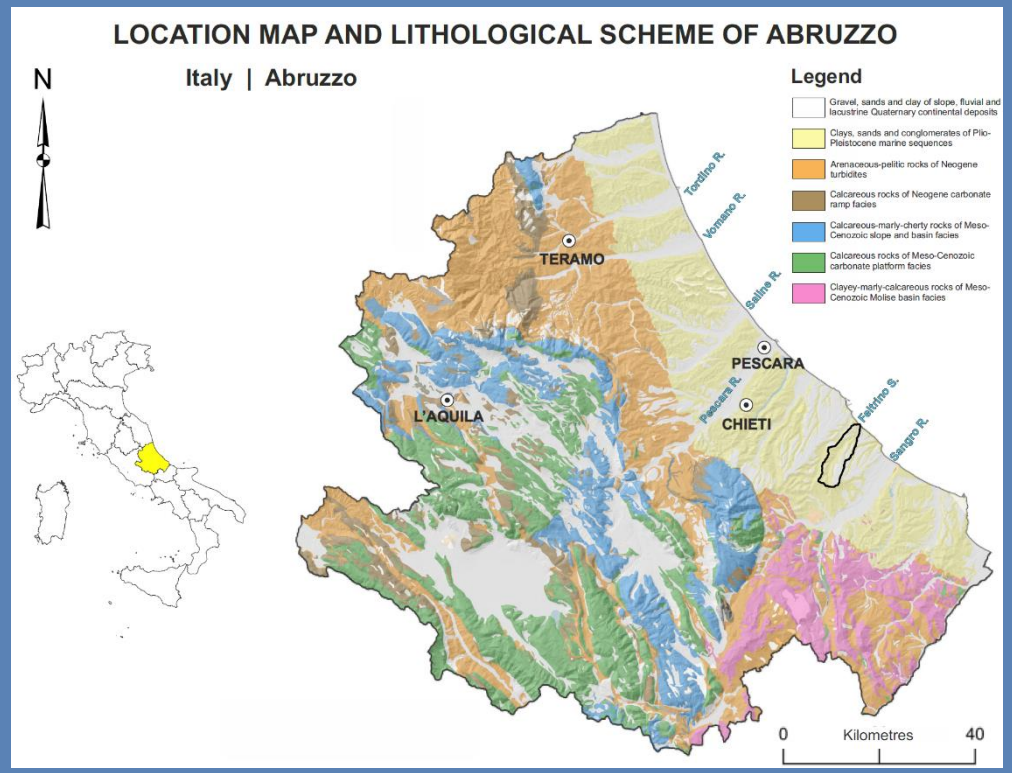
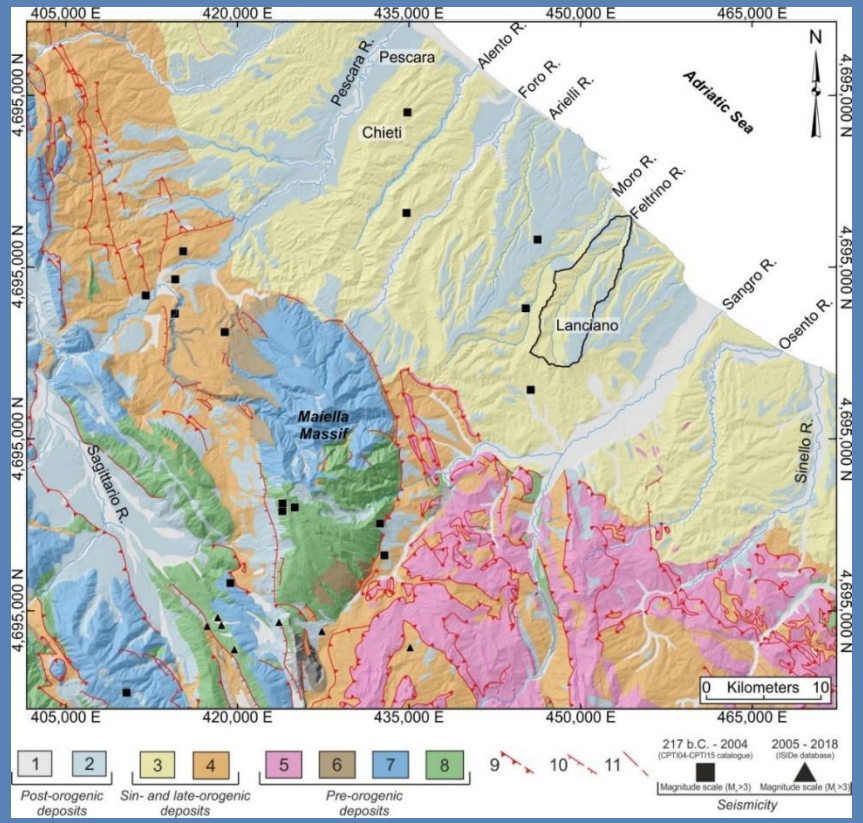
INTRODUCTION

Apennines piedmont – hilly area

NE Apennines piedmont Hilly area of Abruzzo



Clay-dominated bedrock (impermeable-erodible)



Legend: post-orogenic deposits
(1) fluvial deposits (Holocene),
(2) fluvial and alluvial fan terraced deposits (Middle–Late Pleistocene);
Sin- and late-orogenic deposits
(3) clay, sand, and sandstone of hemipelagic sequences with conglomerate levels (Early Pleistocene),
(4) pelitic–arenaceous turbiditic foredeep sequences (Late Miocene–Early Pliocene);
pre-orogenic deposits
(5) marl–clay–limestone of the Molise pelagic sequences (Oligocene–Miocene),
(6) limestone of carbonate ramp facies (Early Miocene–Early Pliocene),
(7) limestone and marl of slope and pelagic basin sequences (Cretaceous–Miocene),
(8) limestone of carbonate platform sequences (Jurassic–Miocene);
(9) major thrust (dashed if buried);
(10) major normal fault (dashed if buried);
(11) major fault with strike–slip or reverse component (dashed if buried);
Seismicity
CPTI04 -CPTI15 catalog (black square), ISIDe database (black triangle).

Carabella et alii, 2019

BACKGROUND

Flooding events

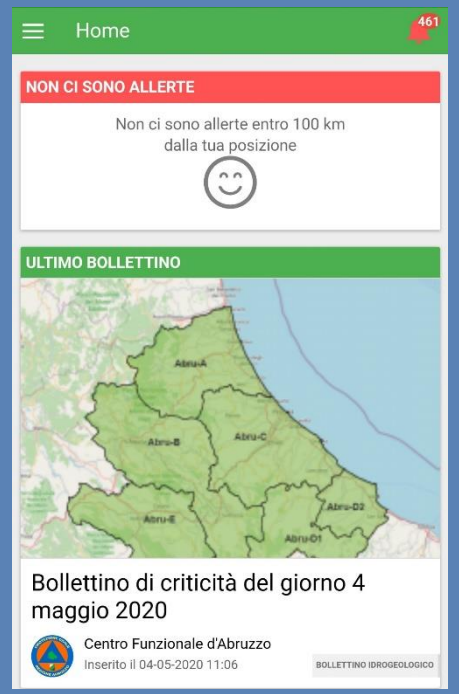
1 major event every 2-4 years

Regional alerting system
Forecast based

allarMETEO

REGIONE ABRUZZO

PROTEZIONE CIVILE REGIONE ABRUZZO
CENTRO FUNZIONALE



MOTIVATION

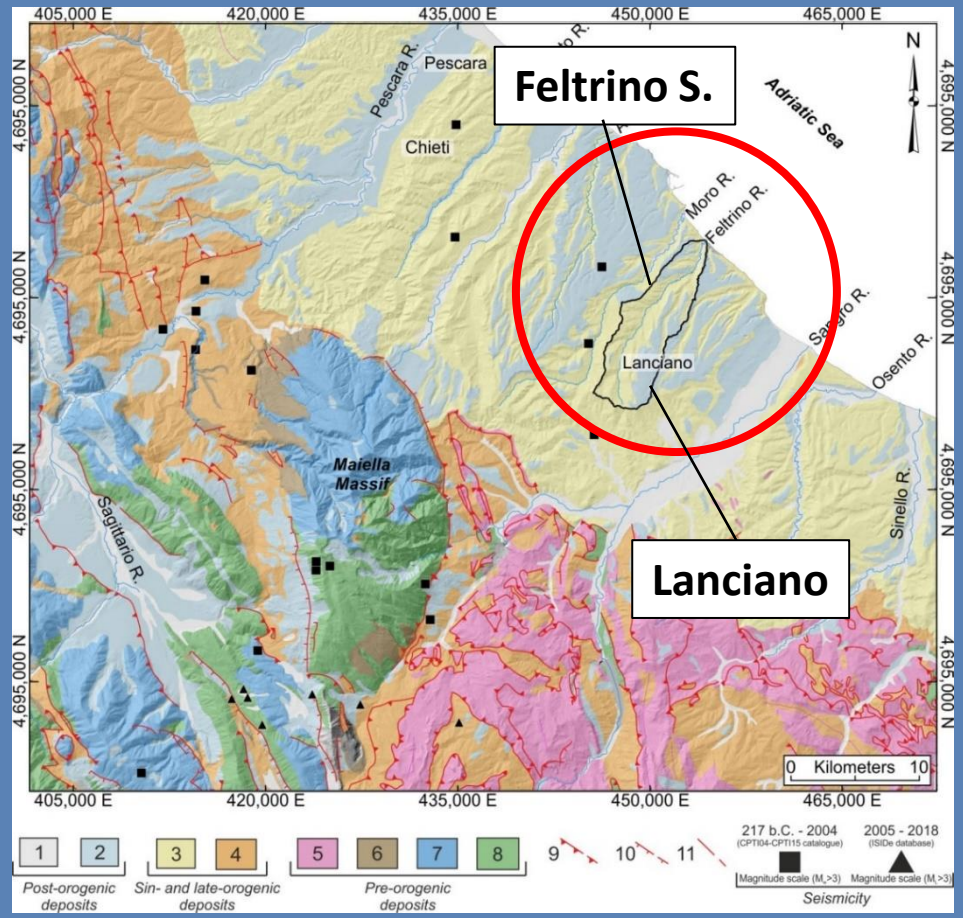
Need for URBAN communication and Early Warning Systems

Communicate to Protect Project
(funded by Abruzzo Region)

REGIONE ABRUZZO
PROTEZIONE CIVILE REGIONE ABRUZZO
CENTRO FUNZIONALE

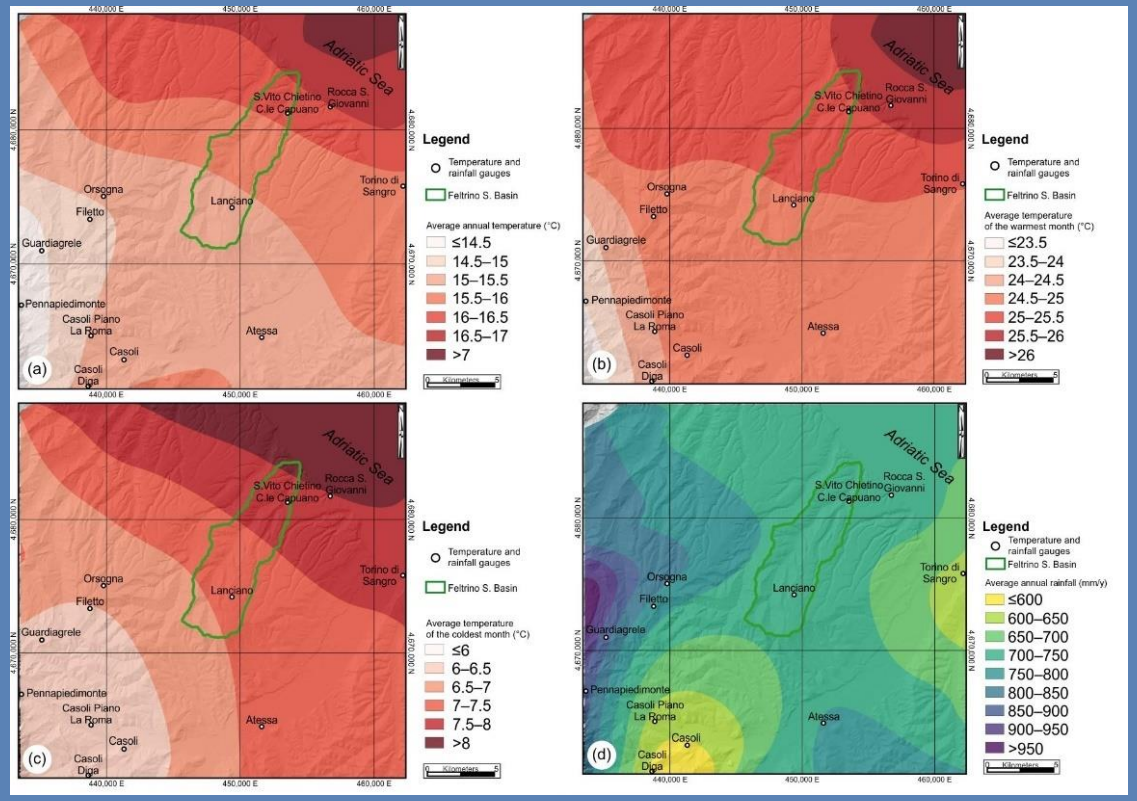
Case study

The Feltrino stream and Lanciano town



CLIMATIC SETTING

Avg. Annual Temp 14-17°C

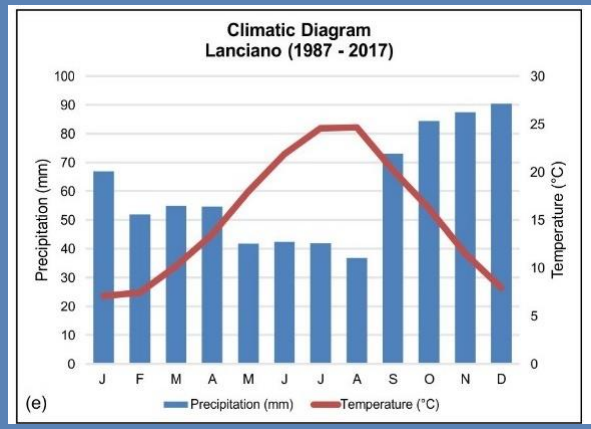


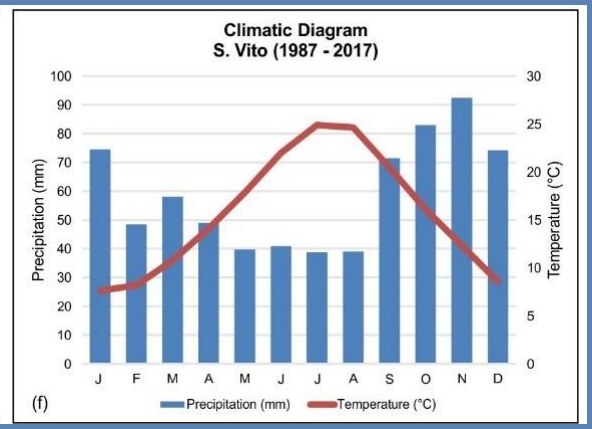
Avg. January Temp 6-8°C

Avg. July Temp 23-26°C

Avg. Annual Rainfall 600-950 mm/yr

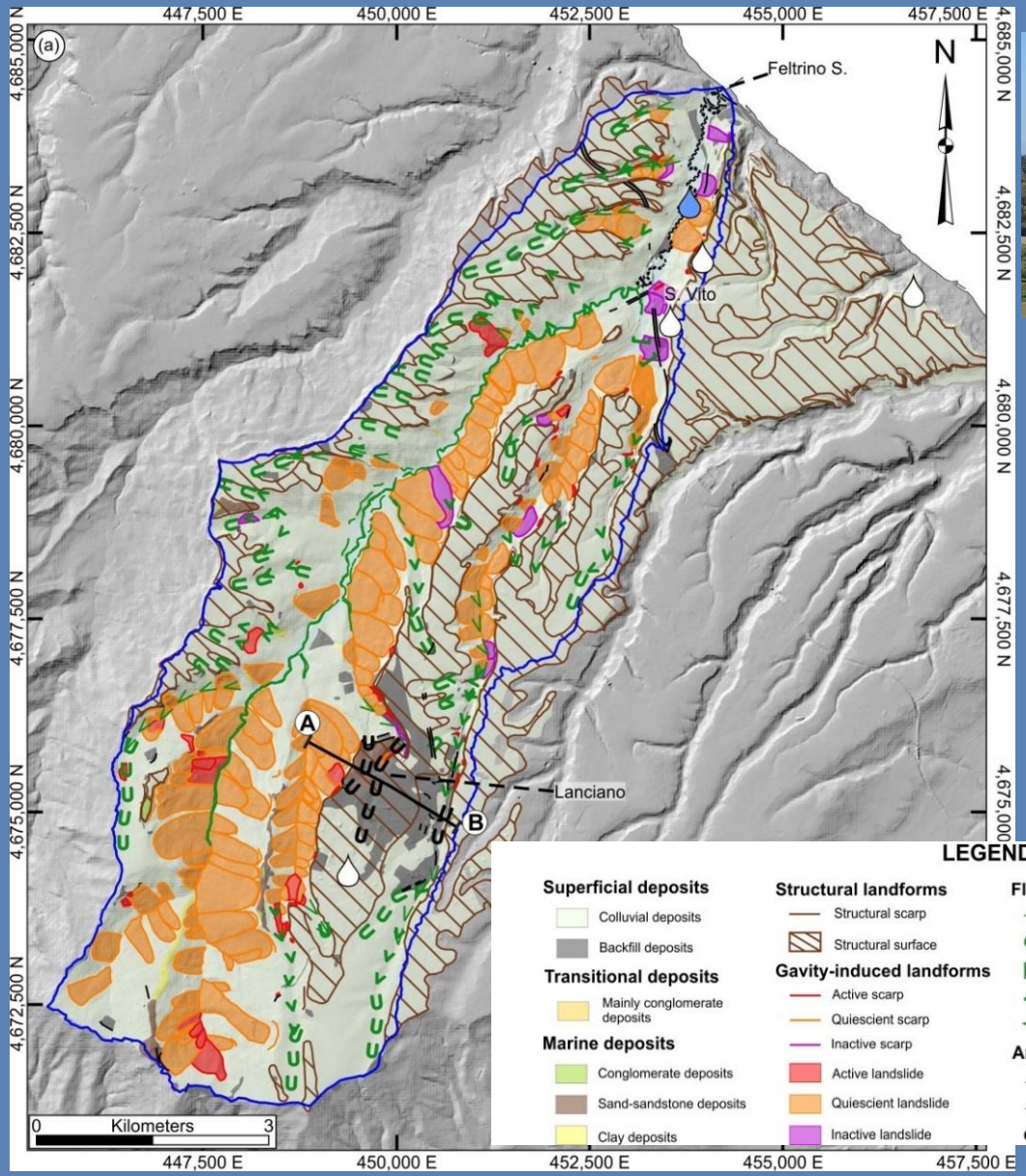
TEMPERATE CLIMATE IN THE INLAND AREA



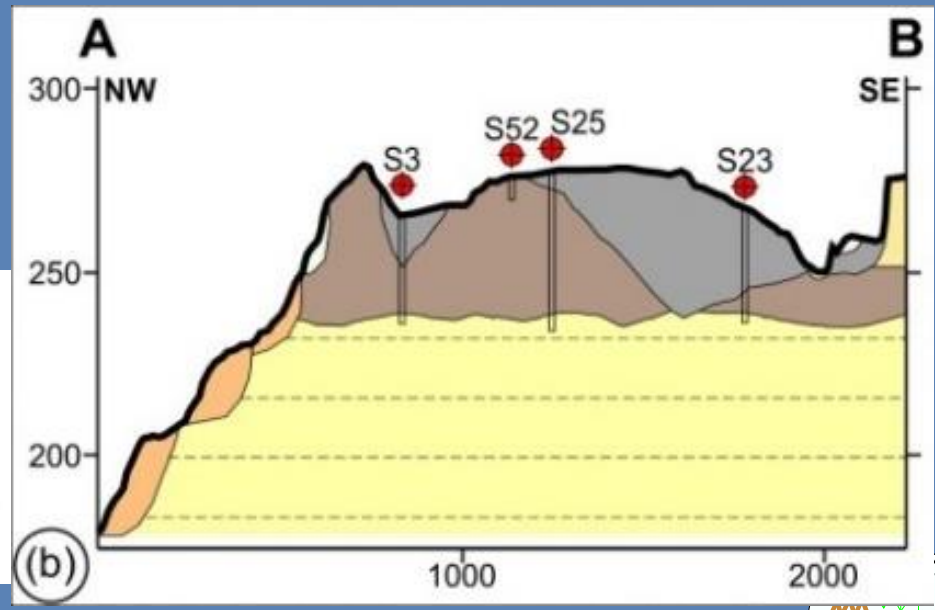


MEDITERRANEAN CLIMATE ALONG THE COAST (WITH MARITIME INFLUENCES)

GEOMORPHOLOGY



GRAVITY-DRIVEN PROCESSES
FLUVIAL PROCESSES
ANTHROPIC CHANGES (in urban areas)



FLOOD-LANDSLIDE EVENTS TIME-SERIES

Summary of the main historical and recent landslide and flood events (1928-2018), which affected and induced damages in the Lanciano area and the Feltrino Stream.

DATE	EVENT	TRIGGERING
February 1928	Landslide	Rainfalls
July 1937	Urban flood	Rainfalls
February 1938	Landslide	Rainfalls
January 1940	Landslide	Snow–Rainfalls
April 1940	Floods	Rainfalls
August 1940	Landslide	Rainfalls
January 1941	Floods	Rainfalls
December 1941	Landslide	Rainfalls
February 1942	Landslide	Snow–Rainfalls
August 1955	Floods	Rainfalls
October 1955	Landslide	Rainfalls
February 1956	Flood/Landslide	Flooding
August 1957	Flood/Landslide	Flooding
November 1957	Flood/Landslide	Flooding
December 1957	Landslide	Snow
July 1959	Landslide	Rainfalls
August 1959	Flood/Landslide	Flooding
January 1961	Flood/Landslide	Flooding
March 1961	Landslide	Rainfalls
1980	Landslide	Rainfalls
April 1992	Landslide	Rainfalls
January 1999	Landslide	Rainfalls
October 2000	Landslide	Rainfalls
April 2001	Flood/Landslide	Rainfalls
January 2003	Landslide	Snow–Rainfalls
February 2005	Landslide	Rainfalls
November–December 2013	Landslide	Rainfalls
March 2015	Landslide	Rainfalls
January 2017	Landslide	Snow
June 2018	Flood	Rainfalls/Flooding

Rainfall triggered events

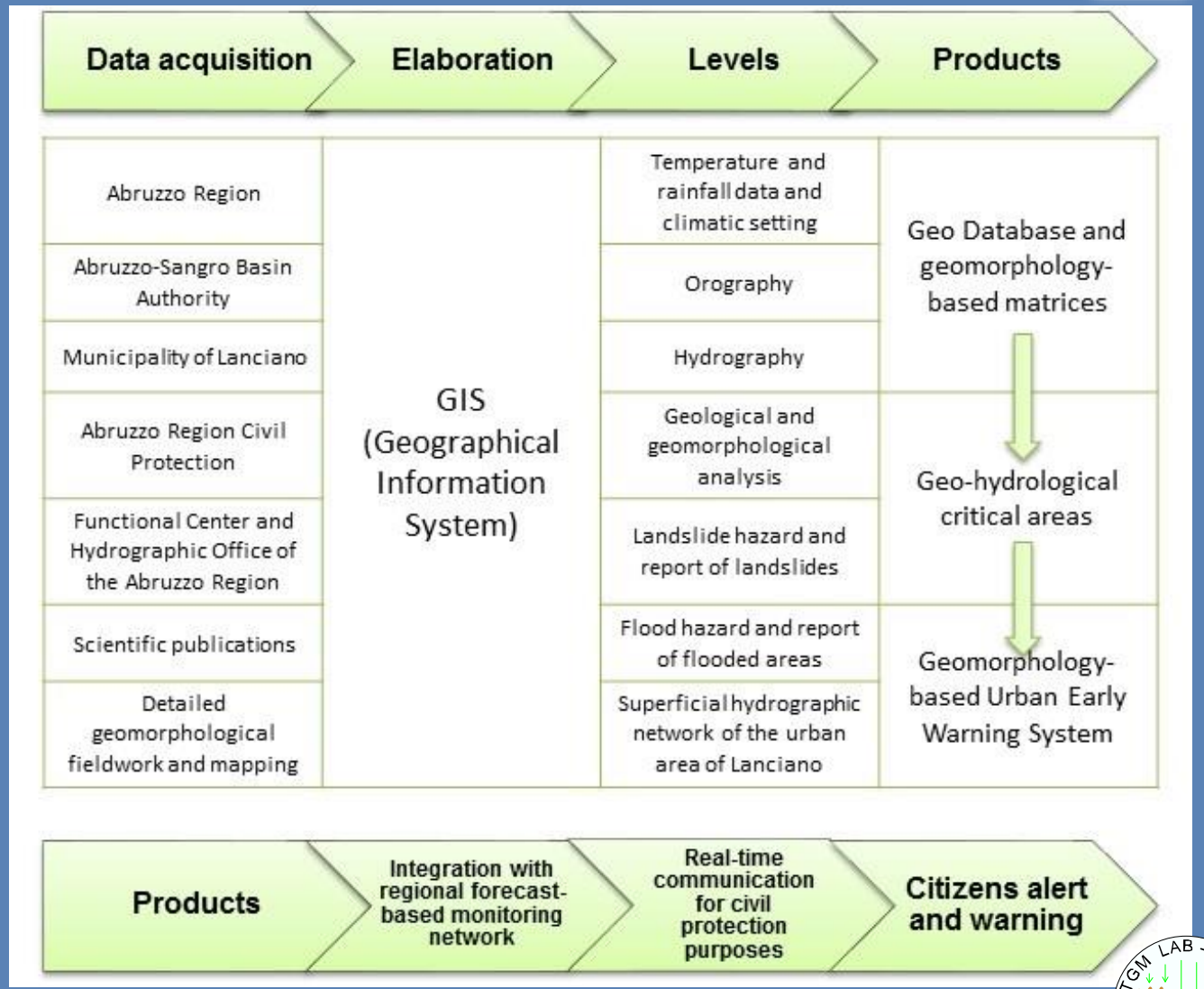
>30 events in 92 years

>1 event/3 year

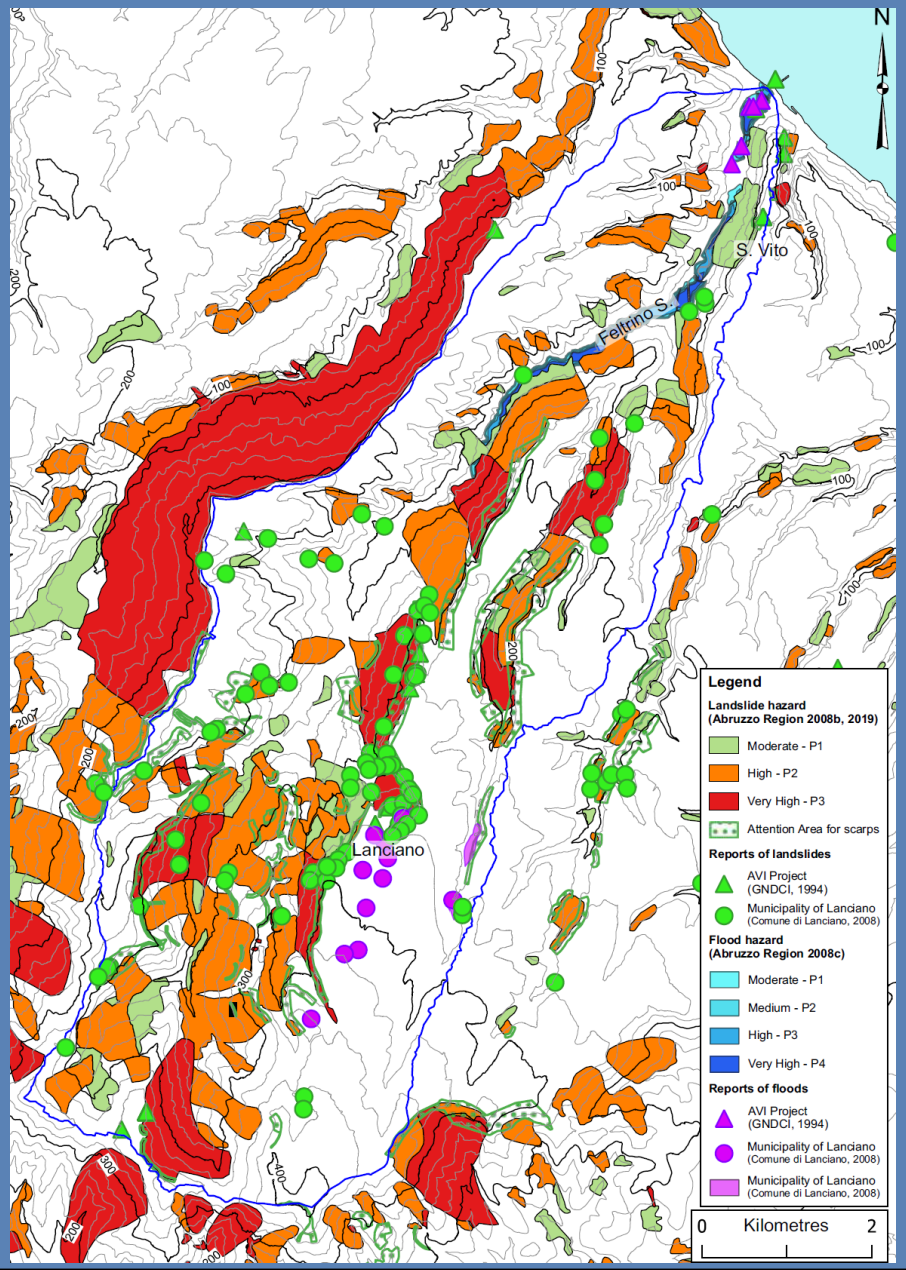
MATERIAL AND METHODS

The Feltrino Stream and the Lanciano urban area were investigated through a drainage basin-scale geomorphological analysis

(1) acquisition of available geological, geomorphological, and hazard data;
(2) geomorphological fieldwork and mapping;
(3) historical heavy rainfall data analysis;
(4) Geodatabase and GIS for data management
(5) critical areas assessment
(6) Early Warning System.



MATERIAL AND METHODS



Legend

Landslide hazard
(Abruzzo Region 2008b, 2019)

Moderate - P1

High - P2

Very High - P3

Attention Area for scarps

Reports of landslides

AVI Project
(GNDCI, 1994)

Municipality of Lanciano
(Comune di Lanciano, 2008)

Flood hazard
(Abruzzo Region 2008c)

Moderate - P1

Medium - P2

High - P3

Very High - P4

Reports of floods

AVI Project
(GNDCI, 1994)

Municipality of Lanciano
(Comune di Lanciano, 2008)

Municipality of Lanciano
(Comune di Lanciano, 2008)

EXISTING DATA

Landslide Hazard data
(PAI Abruzzo Region Basin Authority)

Landslide Reports
AVIproject (CNR-GNDCI)
Lanciano Municipality

Flood Hazard data
(PSDA Abruzzo Region Basin Authority)

Flood Reports
AVIproject (CNR-GNDCI)
Lanciano Municipality

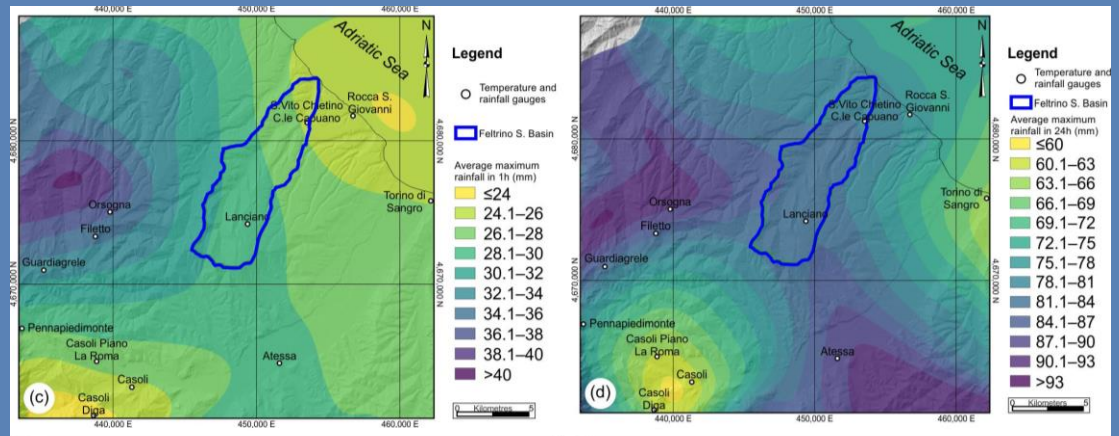
MATERIAL AND METHODS

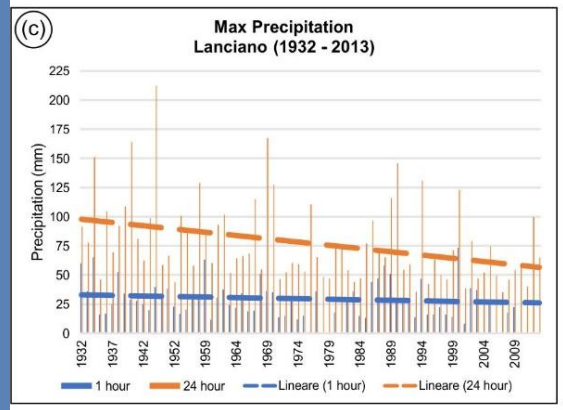
Geomorphological field survey of fluvial and anthropic drainage features

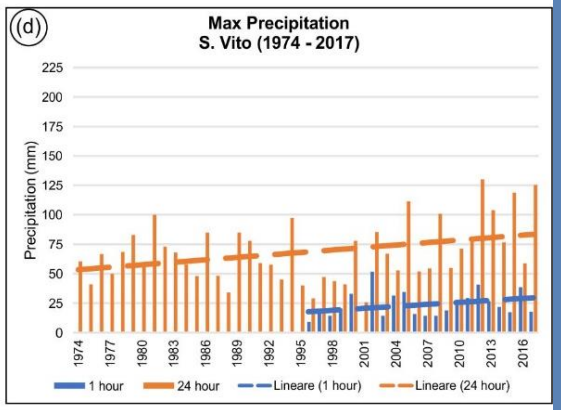
Rainfall and Hydrometric analysis - 13 gauges

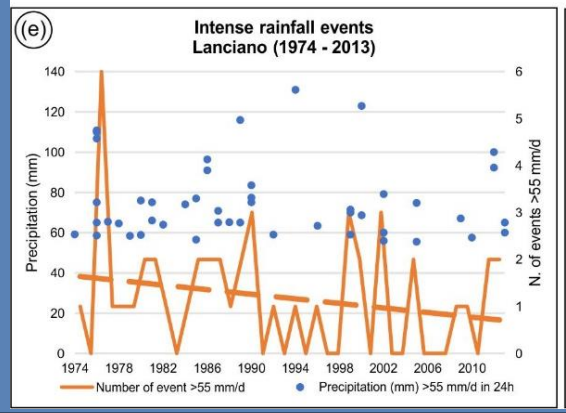
Station code	Type	Name	Lat.	Long.	Elevation (m a.s.l.)	Temporal coverage
1240	TRg	Guardiagrele	42.188	14.215	537	1921–2013
1245	TRg	Filetto	42.209	14.258	858	2006–2013
1310	TRg	Orsogna	42.225	14.270	410	1921–2013
1330	TRg	Lanciano	42.218	14.388	315	1904–2019
1335	TRg	S. Vito–C.le Capuano	42.282	14.437	149	2007–2019
1340	TRg	S. Vito Chietino	42.297	14.444	128	1921–2006
1345	TRg	Rocca San Giovanni	42.287	14.475	79	2013–2019
1610	TRg	Casoli Diga	42.096	14.258	250	1990–2019
1620	TRg	Pennapiedimonte	42.152	14.195	679	1920–2013
1625	TRg	Casoli–Piano la Roma	42.132	14.260	348	2006–2013
1630	TRg	Casoli	42.115	14.290	337	1920–2013
1645	TRg	Atessa – Piazzano	42.131	14.415	78	2015–2019
1660	TRg	Torino di Sangro	42.233	14.544	5	1937–2013
6560	Hg	Feltrino–S. Vito	42.296	14.439	15	1986–2019

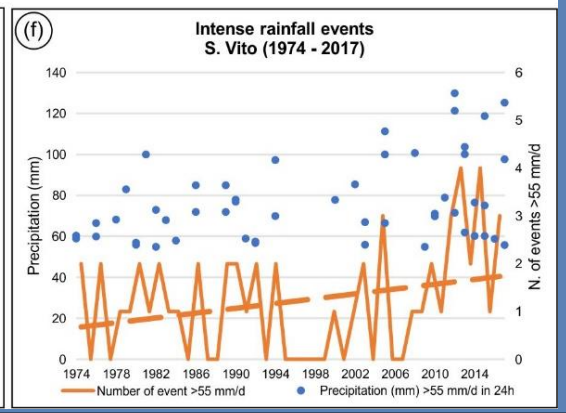
RESULTS – Heavy rainfall events analysis











24-40 mm/h Avg of max 1h rainfall in each year

60-93 mm/d Avg of max 1d rainfall in each year

210 mm/d max daily precipitation in the time series

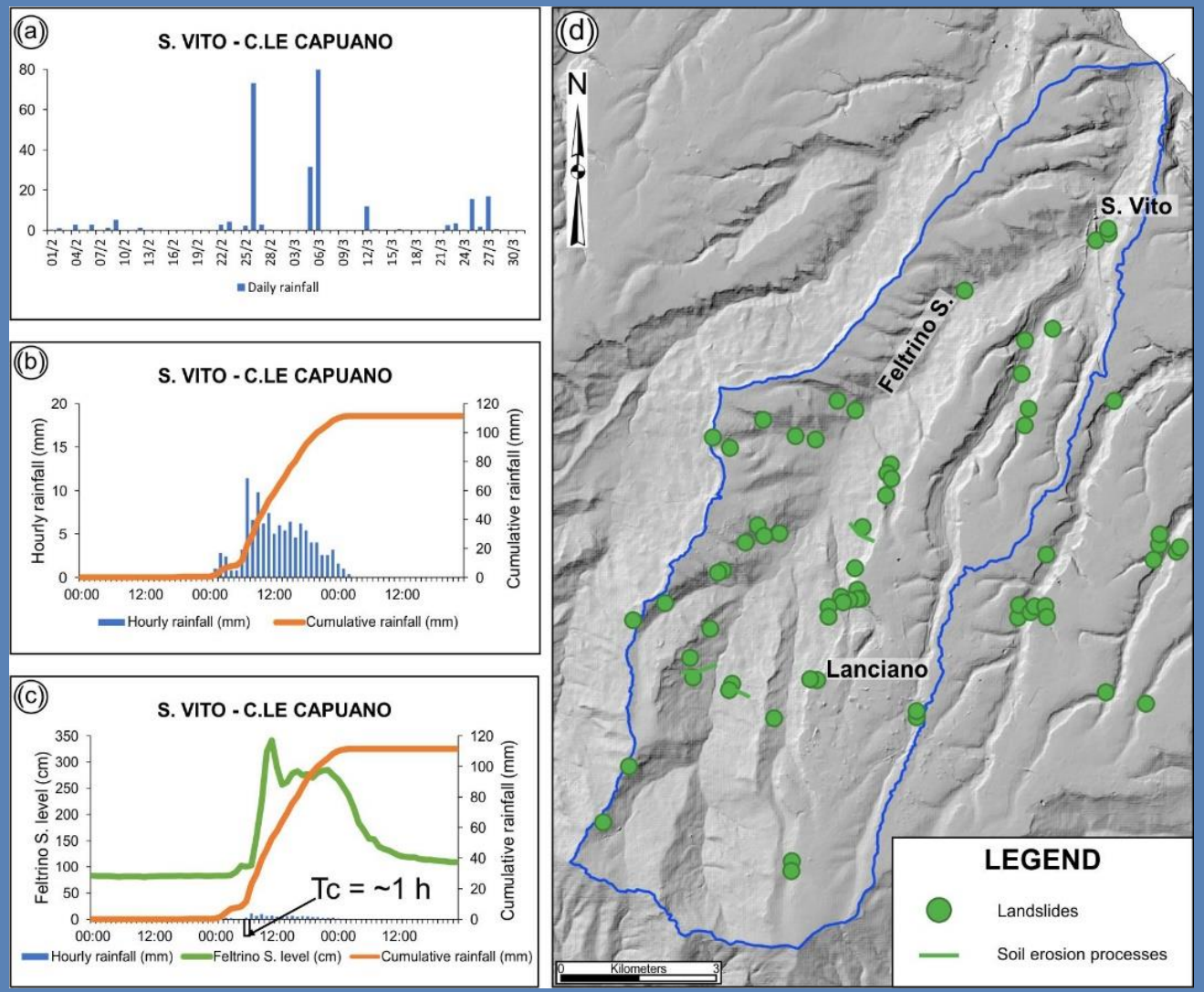
Heavy rainfall events >55 mm/d (99th percentile)

0-6 events per year
range 55-130 mm/d

Maximum precipitation distribution in the study area.
(a) Distribution of average maximum rainfall in 1 h;
(b) distribution of average maximum rainfall in 24 h;
(c) diagram of the yearly maximum precipitation in 1h and 24h for the Lanciano gauge (1932–2009);
(d) diagram of the yearly maximum precipitation in 1h and 24h for the S. Vito gauges (1974-–1995 S. Vito Chietino; 1996–2017 S. Vito–C.le Capuano);
(e) diagram of the intense precipitation and number of intense events (>55 mm/24 h) of the Lanciano gauge (1974–2013);
(f) diagram of the intense precipitation and number of intense events (>55 mm/24 h) of the S. Vito gauges (1974–1995 S. Vito Chietino; 1996–2017 S. Vito–C.le Capuano).

RESULTS – Example 1 – Heavy rainfall event Feb-Mar 2015

110 mm in 24 h – cumulate rainfall
10 mm/h max rainfall intensity



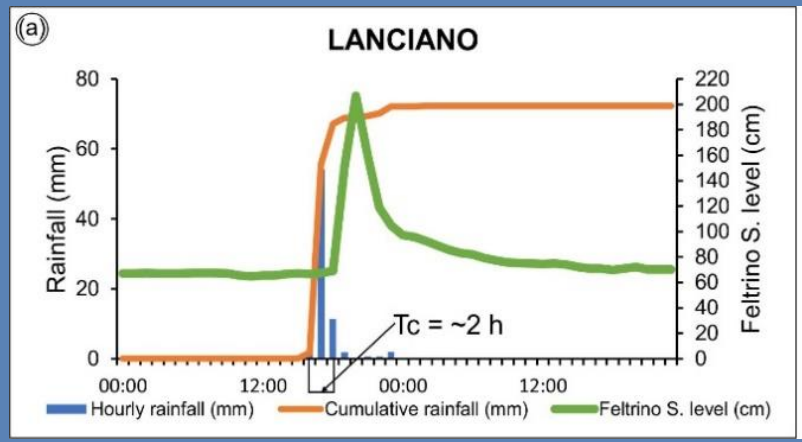
71 landslides occurred

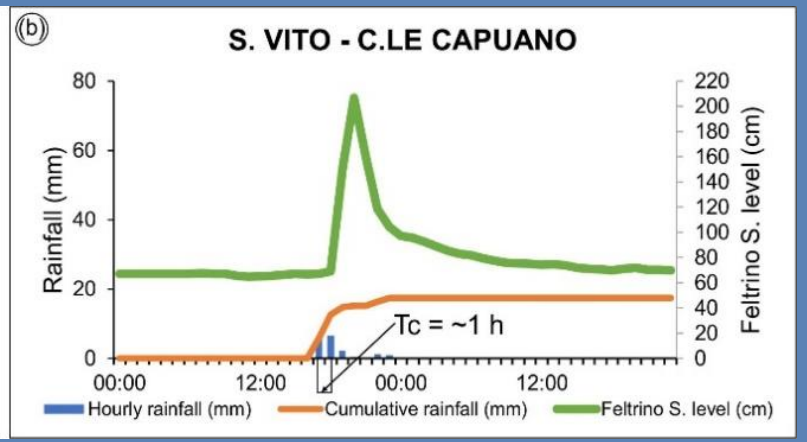
(a) Daily rainfall of February–March 2015;
(b) hourly and cumulative rainfall of 4–6 March 2015 in the S. Vito–C.le Capuano gauge;
(c) hourly and cumulative rainfall of March 2015 event in the S. Vito–C.le Capuano gauge and the hydrographic level of the Feltrino S. (Feltrino–S. Vito gauge; for the gauges' locations, see Figure 4);
(d) distribution of the landslides induced by the intense rainfall events in March 2015. Blue line: The Feltrino Stream basin.

RESULTS – Example 2 – Heavy rainfall event June 2018

70 mm in 4 h – cumulate rainfall
50 mm/h max rainfall intensity

Flooding in 6 sites in the Lanciano city center

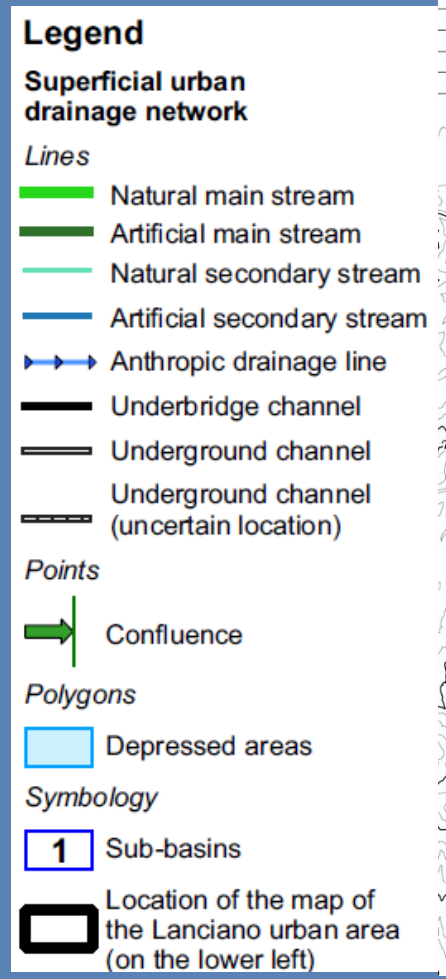


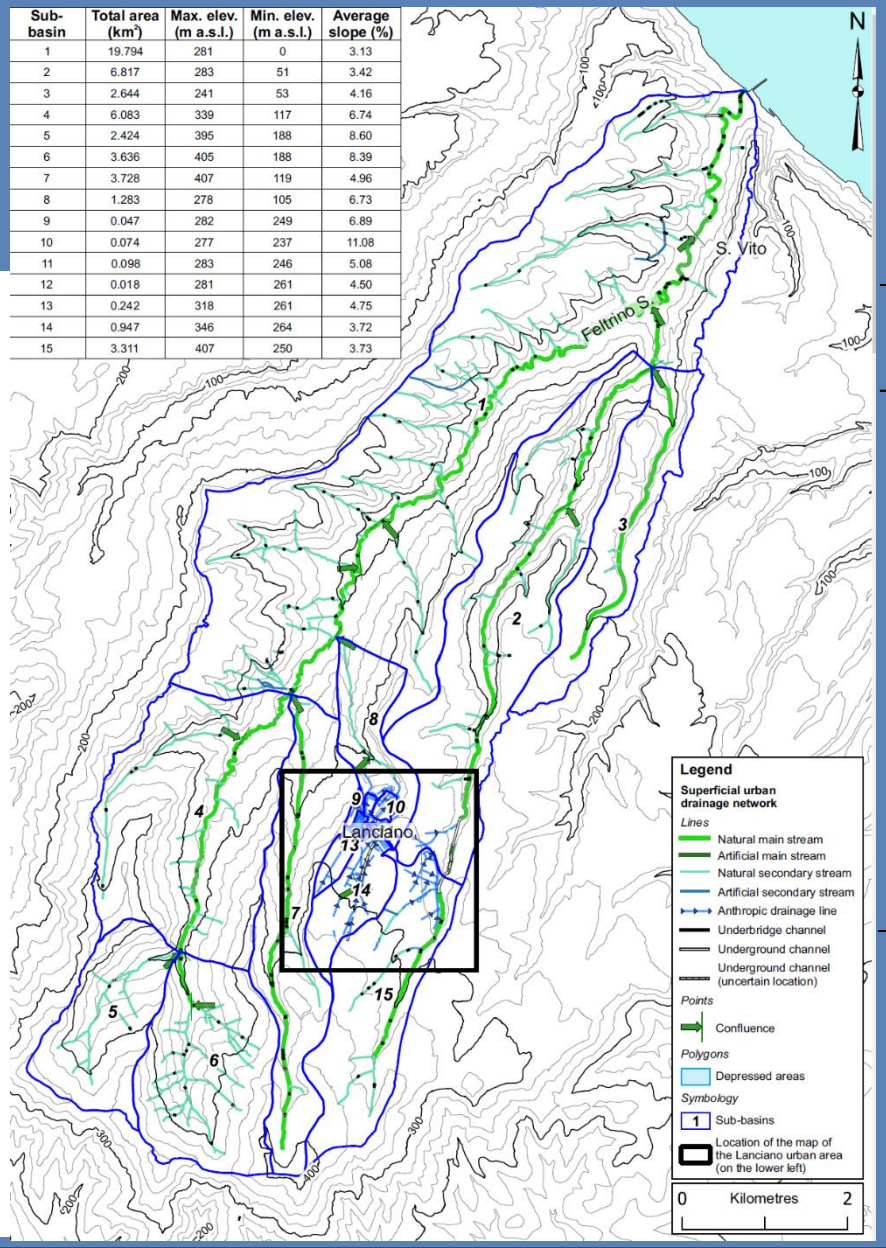


Hourly and cumulative rainfall and hydrographic level of the Feltrino Stream (Feltrino–S. Vito gauge) during the event of June 2018;
(a) Lanciano gauge;
(b) S. Vito–C.le Capuano gauge

RESULTS – Hydrography field investigation

Sub-basin	Total area (km²)	Max. elev. (m a.s.l.)	Min. elev. (m a.s.l.)	Average slope (%)
1	19.794	281	0	3.13
2	6.817	283	51	3.42
3	2.644	241	53	4.16
4	6.083	339	117	6.74
5	2.424	395	188	8.60
6	3.636	405	188	8.39
7	3.728	407	119	4.96
8	1.283	278	105	6.73
9	0.047	282	249	6.89
10	0.074	277	237	11.08
11	0.098	283	246	5.08
12	0.018	281	261	4.50
13	0.242	318	261	4.75
14	0.947	346	264	3.72
15	3.311	407	250	3.73





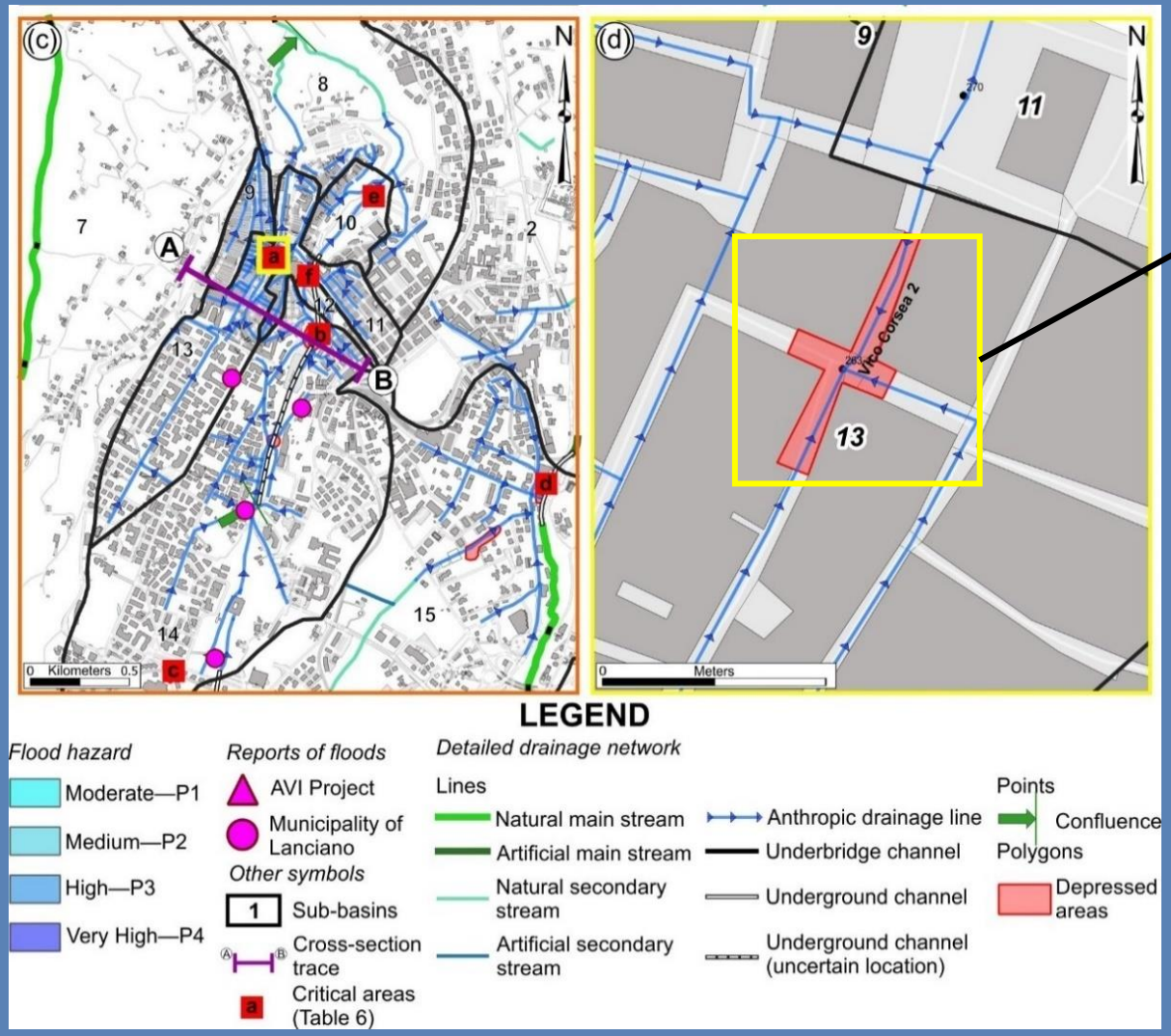
15 sub-basin (0.018-19.8 km²)

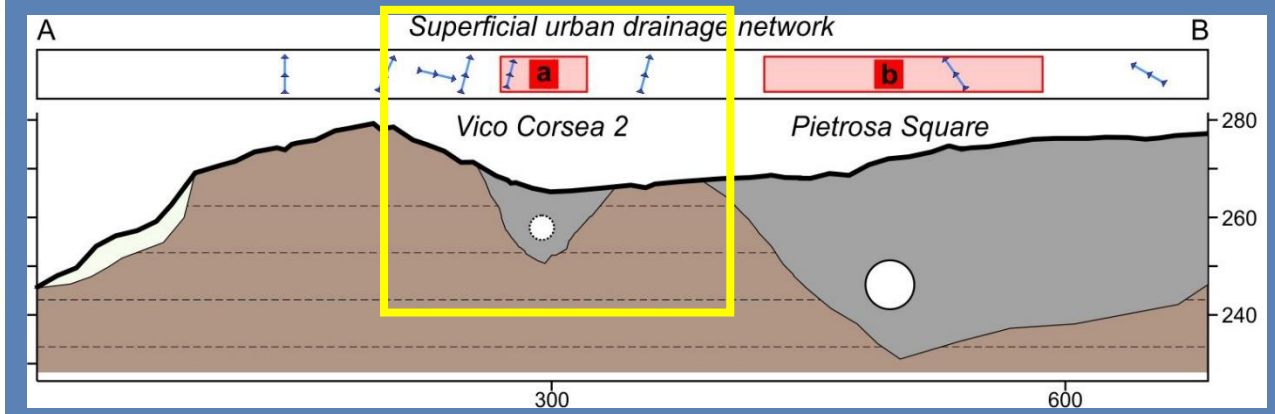
Sub-basin	Tot. area (km²)	Urban area (km²)	Semi-urban area (km²)	Natural area (km²)	Perimeter (km)	Max. elevaton (m a.s.l.)	Min. elevation (m a.s.l.)	Relief (m)	Average slope (%)
1	19.794	2.108	5.577	12.108	28.081	281	0	281	3.13
2	6.817	1.724	1.873	3.221	16.403	283	51	232	3.42
3	2.644	1.444	0.062	1.139	11.042	241	53	188	4.16
4	6.083	0.292	2.173	3.618	11.027	339	117	222	6.74
5	2.424	0.455	0.113	1.856	7.145	395	188	206	8.60
6	3.636	0.382	0.709	2.545	7.810	405	188	217	8.39
7	3.728	0.348	3.163	0.217	13.401	407	119	288	4.96
8	1.283	0.239	0.210	0.833	6.799	278	105	172	6.73
9	0.047	0.047	0	0	1.213	282	249	33	6.89
10	0.074	0.042	0	0.033	1.133	277	237	40	11.08
11	0.098	0.098	0	0	2.496	283	246	36	5.08
12	0.018	0.018	0	0	0.918	281	261	19	4.50
13	0.242	0.242	0	0	2.726	318	261	57	4.75
14	0.947	0.827	0.017	0.102	5.490	346	264	81	3.72
15	3.311	1.433	0.681	1.062	10.379	407	250	157	3.73

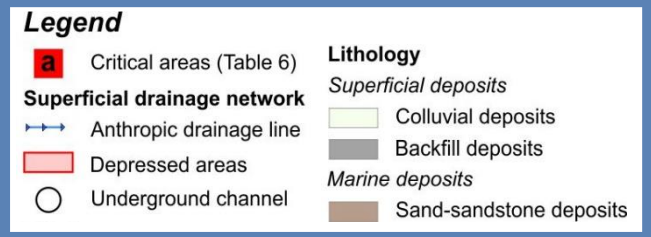
RESULTS – Field investigation of critical flooding areas

Drainage network and flooding critical areas

Example of Vico Corsea 2 area historic center of Lanciano.



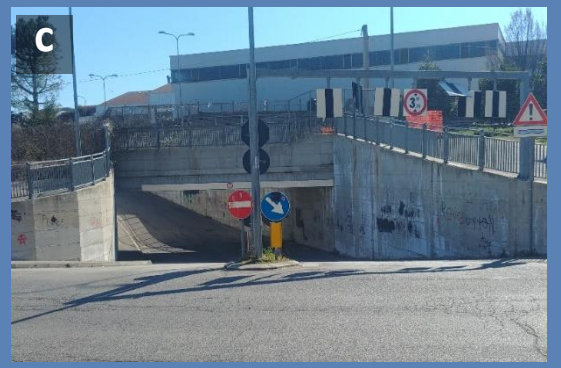




RESULTS – Field investigation of critical flooding areas

Underground hydrography and critical flooding areas

Id	Locality	Basin	Area (m^2)	Lat.	Long.	Elevation (m a.s.l.)	Category
a	Vico Corsea 2	13	1912	42.231	14.389	263	Anthropic drainage line; underground channel
b	Pietrosa Square	14	6523	42.228	14.391	260	Depressed area; underground channel
c	Industrial area	14	809	42.218	14.385	315	Depressed area; underbridge channel
d	Commercial area	15	14,482	42.224	14.400	251	Depressed area; underground channel
e	Public garden	10	18,418	42.232	14.393	240	Underground channel
f	St. Errico D'Amico Square	12	719	42.230	14.390	266	Depressed area



RESULTS – Flood-landslide critical areas

Geomorphology-based matrix for critical areas assessment

Flood critical areas

1) Flood hazard	2) Reports of flood	3) Detailed hydrographic network	Categories of critical area
Moderate	No	–	C1—Moderate
Medium	No	–	C2—High
High	No	–	C2—High
Very High	No	–	C3—Very High
Medium	Yes	–	C3—Very High
High	Yes	–	C3—Very High
–	Yes	–	C3—Very High
–	No	Natural main stream	C2—High
–	No	Artificial main stream	C2—High
–	No	Natural secondary stream	C1—Moderate
–	No	Artificial secondary stream	C1—Moderate
–	No	Anthropic drainage line	C2—High
–	No	Underbridge channel	C3—Very High
–	No	Underground channel	C3—Very High
–	–	Confluence	C2—High
–	–	Depressed areas	C3—Very High

Landslide critical areas

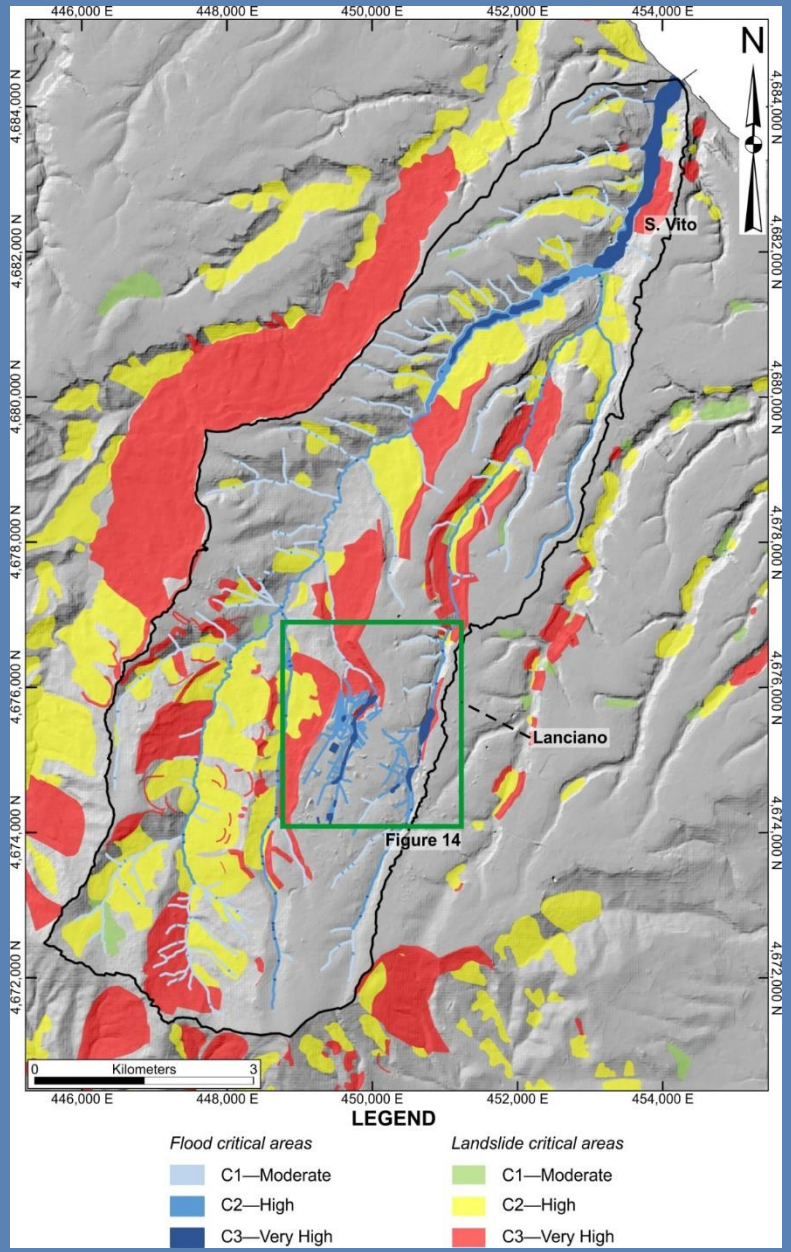
1) Landslide hazard	2) Reports of landslide	Degree of critical area
Moderate	No	C1—Moderate
High	No	C2—High
Very High	No	C3—Very High
	Yes	C3—Very High
High	Yes	C3—Very High
Moderate	Yes	C3—Very High
Attention Areas for scarps	No	C2—High
Attention Areas for scarps	Yes	C3—Very High

Based on

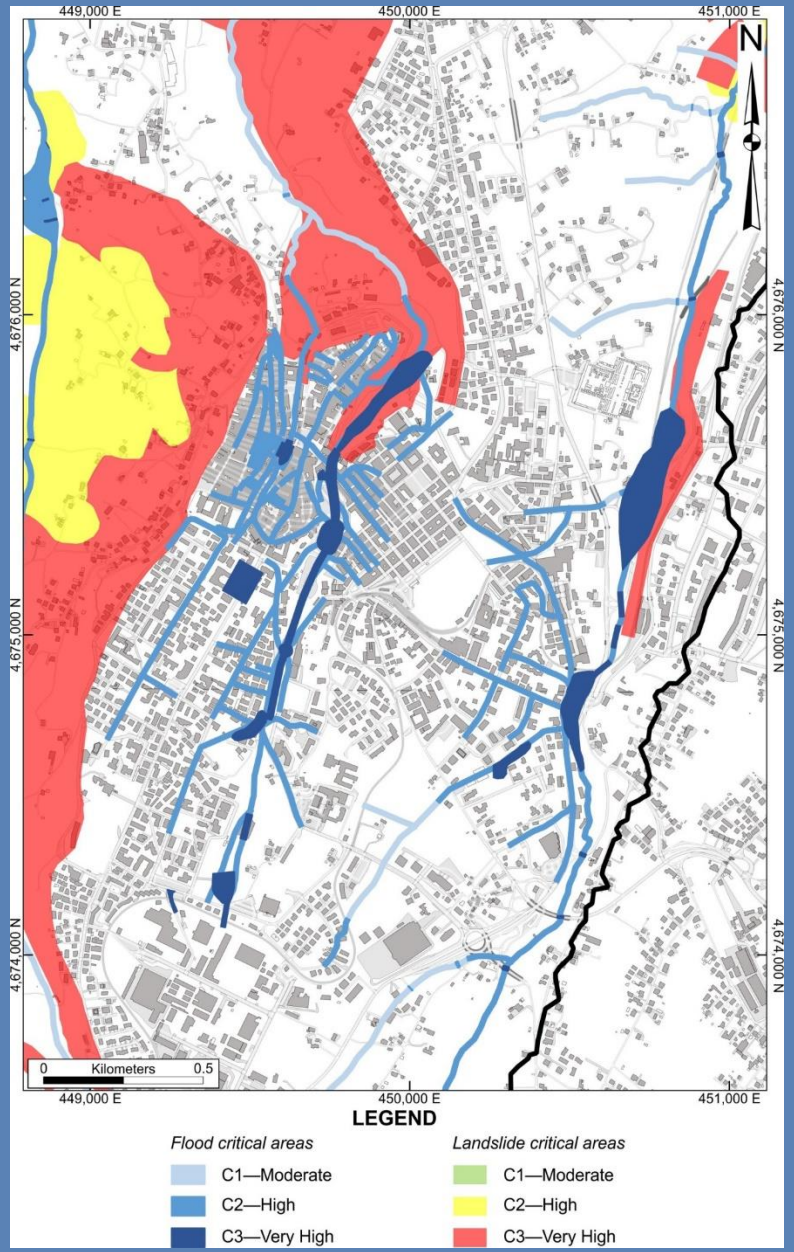
- existing official hazard data
- Flood reporting in national and local inventories
- Detailed geomorphological field mapping of the natural and artificial drainage network

RESULTS – Flood-landslide critical areas

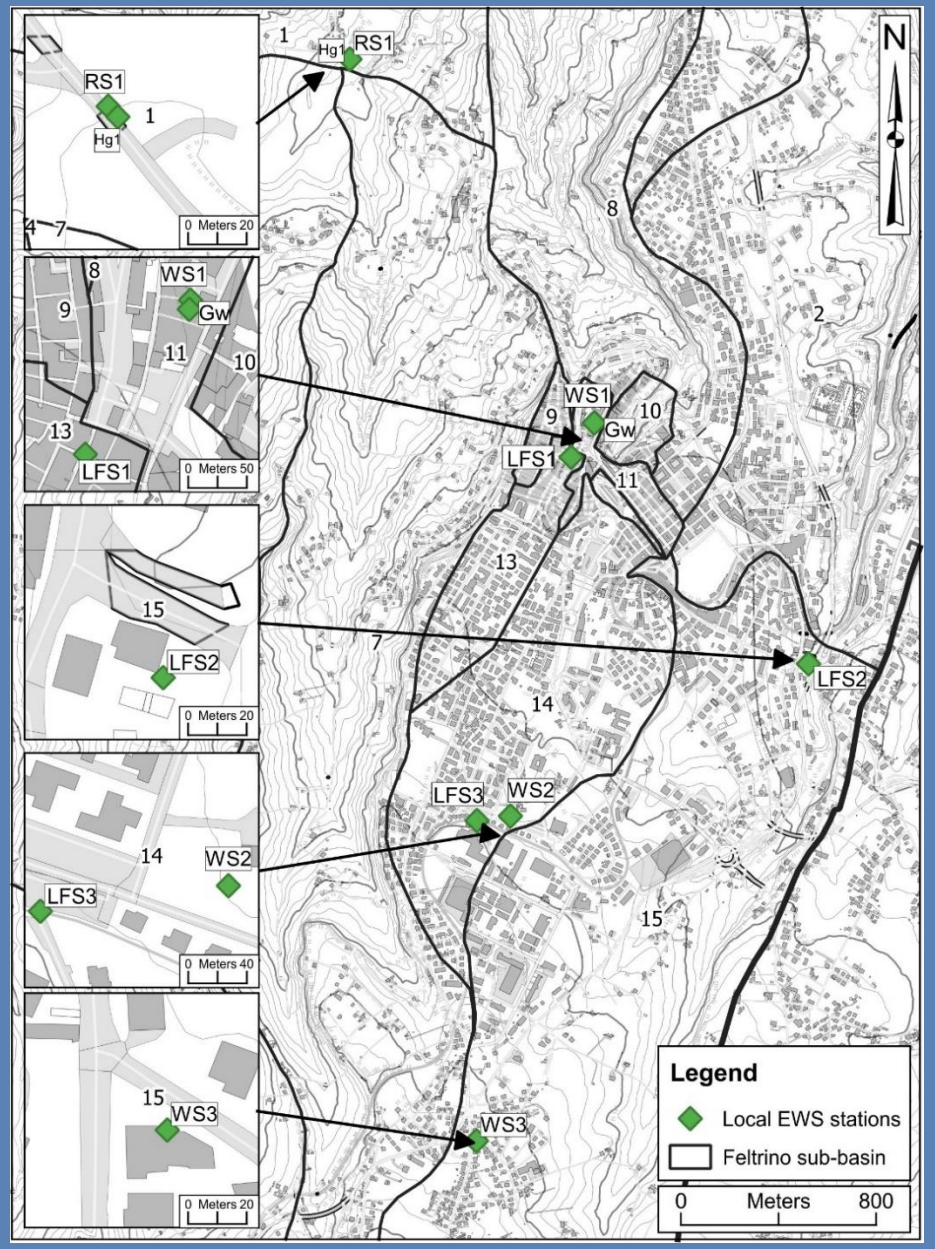
Feltrino basin



Lanciano urban area



CONCLUSION – Emplacement of Early Warning System



URBAN Internet Of Things EWS:

3 weather stations (rain, temperature, wind, humidity)
1 rainfall gouge
2 hydrographic gauges
3 two-level flood sensors
1 gateway
1 webcloud geodatabase
1 Application for smartphones

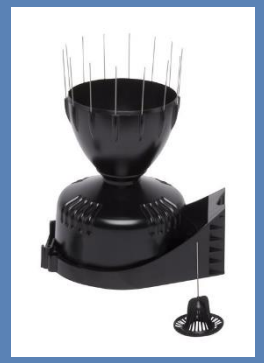
Label—Type	Locality	Lat.	Long.	Elevation (m a.s.l.)
RS1—Rainfall gauge	S. Liberata cleaner, Lanciano	42.244	14.379	121.7
WS1—Complete Weather Station 1	Lanciano City Hall	42.432	14.390	272.5
WS2—Complete Weather Station 2	Southern Lanciano	42.218	14.388	315
WS3—Complete Weather Station 2	Marcianese, Lanciano	42.233	14.391	358
Hg1—Hydrographic gauge 1	S. Liberata cleaner, Lanciano	42.244	14.379	121.7
Hg2—Hydrographic gauge 2	Passo Tucci, Feltrino, S. Vito	42.296	14.439	15
LFS1—2-Level Flood Sensor 1	Vico Corsea 2–Lanciano	42.230	14.389	263.4
LFS2—2-Level Flood Sensor 2	D. Ciriaci Street, Lanciano	42.224	14.400	251.9
LFS3—2-Level Flood Sensor 3	Industrial area, Lanciano	42.218	14.385	315
Gw—Gateway	Lanciano City Hall	42.432	14.390	272.5

CONCLUSION – Emplacement of Early Warning System

Regional alert

Local IOT - Integrated system:

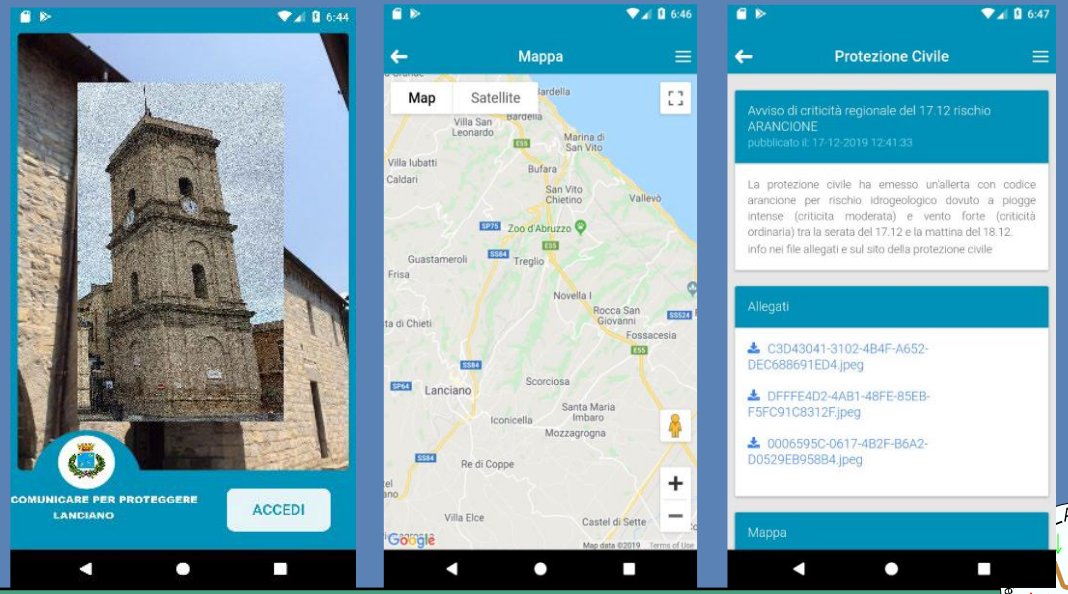
9 sensors, gauges and stations
1 communication tool



From regional alert
To local sensors
To the mobile application
SUPPORT TO THE COMMUNICATION
of flood-landslide events
and Civil Protection management

WEB Server Cloud for data management

Mobile Application for smartphones



CONCLUSION – Hazard communication Sensibilization, Early Warning, Risk mitigation

The integrated study is part of a regional Project in the Abruzzo area that support the integration of the regional alarm system with local Early Warning Systems.

The Feltrino Stream – Lanciano urban areas lead to

- Geomorphological and field investigation of the Feltrino Basin and Lanciano urban area
- Flood critical areas assessment
- Geodatabase web cloud – Internet of Things sensors and communication system

EWS - FROM REGIONAL ALERT, TO LOCAL SENSORS, TO MOBILE APPLICATION SUPPORT to the COMMUNICATION OF FLOOD EVENTS and CIVIL PROTECTION ACTIVITIES

Future activities and implementations:

- Testing and calibration, Flood hydrologic and hydraulic modeling,
- Dissemination to citizens, school students etc.,
- Integration of alerting for Landslides, Wind, Snow, Seismic events etc.

References

Tommaso Piacentini, Cristiano Carabella, Fausto Boccabella, Silvia Ferrante, Carlo Gregori, Vania Mancinelli, Alessandro Pacione, Tommaso Pagliani and Enrico Miccadei (under submission) - Flood–*landslide critical areas in small catchments for civil protection purposes and early warning systems: The case of the Feltrino Stream and the Lanciano urban area (Abruzzo, Central Italy).* Water, MDPI

Cristiano Carabella, Fausto Boccabella, Marcello Buccolini, Silvia Ferrante, Alessandro Pacione, Carlo Gregori, Tommaso Pagliani, Tommaso Piacentini, Enrico Miccadei (submitted) - *Geomorphological mapping of landslide and flood critical areas in minor hilly catchments and urban areas for early warning systems: the example of the Feltrino Stream and Lanciano town (Abruzzo, Central Italy).* Journal of Maps, Taylor & Francis.

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