Main components and characteristics of territorial landslide early warning systems operational worldwide

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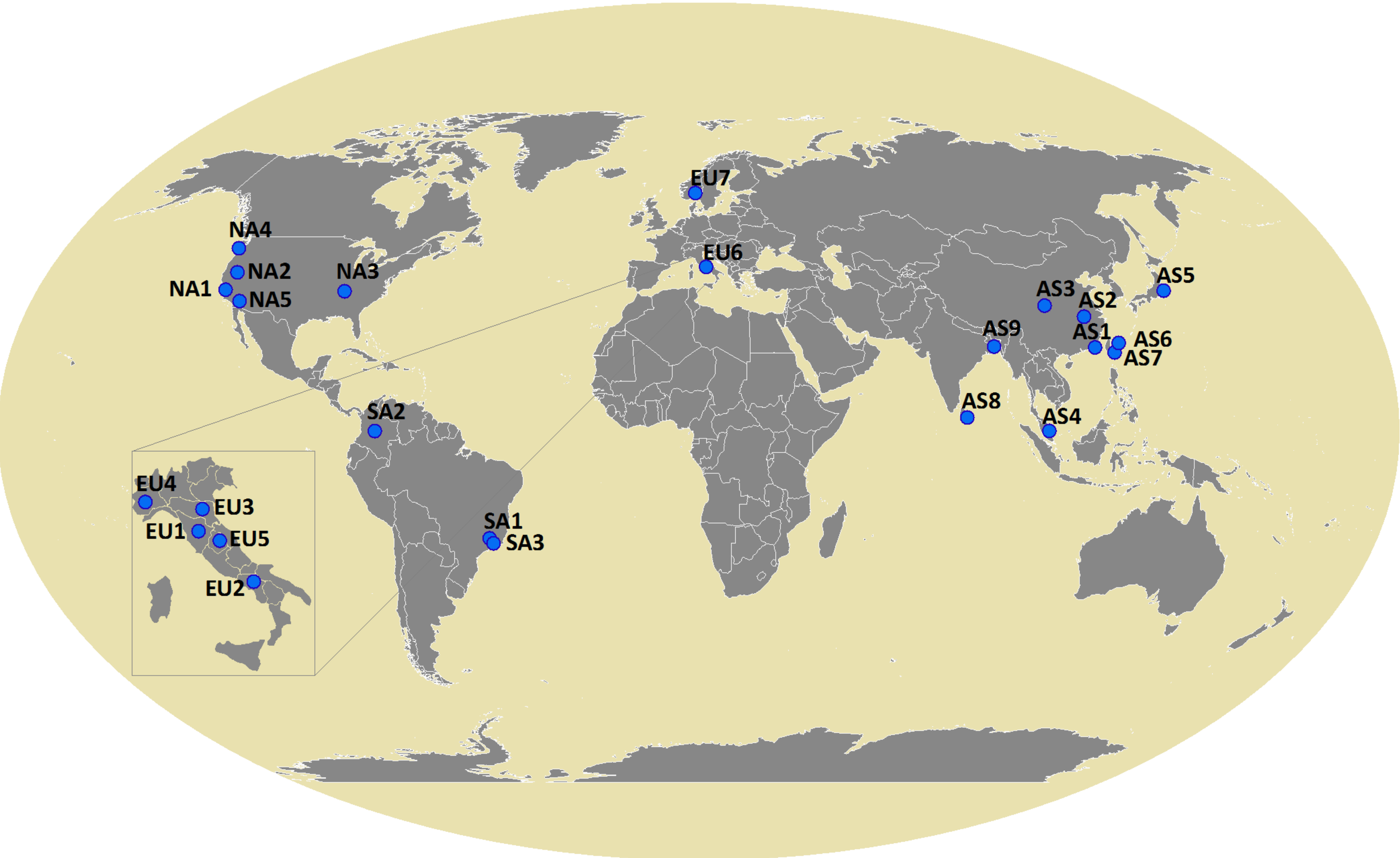
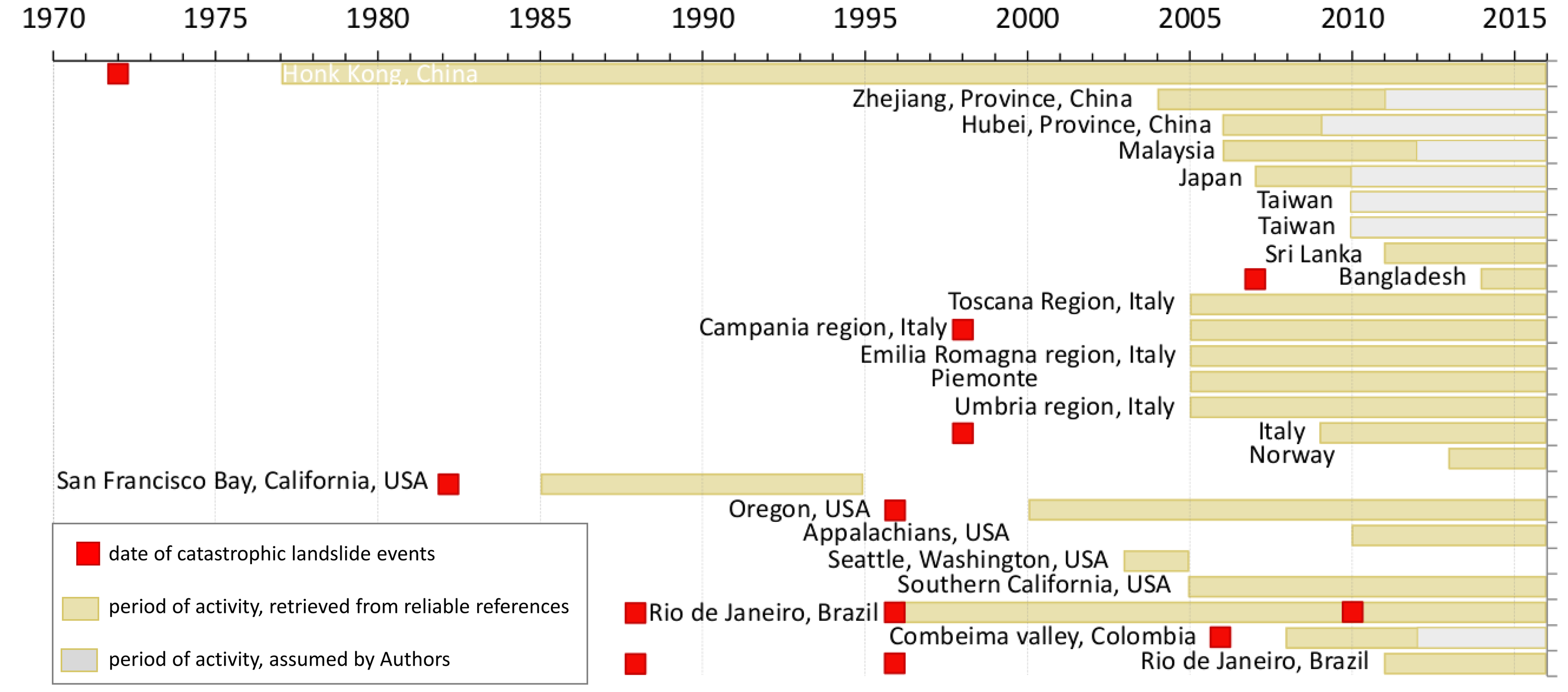
Territorial landslide early warning systems (TE-LEWSs) operational worlwide



CODE	Institution	Sources of information
AS1	HK-GEO	Brand et al. 1984, Chan et al., 2003, Cheng et al., 2006, Cheung et al., 2006, Information note 02/2009, Lump 1975, Massey et al., 2001, Pang et al., 2000, Pun et al. 2003, Wong 2006, Wong et al., 2006, Yu et al. 2004, Yu et al., 2004; personal contacts
AS2		Yin et al., 2007, Zhang et al., 2011
AS3		Yin et al., 2007, Zhong et al., 2009
AS4	PLUS	Huat et al., 2012, Lloyd et al. 2001,
AS5	MLIT and JMA	Kuramoto et al. 2001, Kuramoto et al. 2005, Okada 2005, Osanai et al., 2010
AS6	DGH	Chen et al., 2007, Wu et al., 2011
AS7	NCDR	Huang and Hong, 2010, Su et al., 2010
AS8	NBRO	http://www.nbro.gov.lk/
AS9	BUET-JIDPUS	Ahmed and Murillo 2015, http://www.landslidebd.com/, http://www.landslidebd.com/reports/, http://www.icimod.org/?q=19755
EU1	Civil defence	Segoni et al., 2015; personal contacts
EU2	Civil defence	DPRC 299-30/06/2005; personal contacts
EU3	Civil defence	Lagomarsino et al., 2013, Martelloni et al., 2012; personal contacts
EU4	Civil defence	Tiranti et al., 2014, Tiranti and Rabuffetti 2010, http://www.arpa.piemonte.gov.it/rischinaturali/rischi/rischio-idrogeologico/frane-superficiali/scenario-attuale.html, personal contacts
EU5	Civil defence	Brocca et al., 2008, DGR 2312/2007, Ponziani et al., 2013, http://www.cfumbria.it/FraneMonitoraggio/LandWarn/FraneMonDescrizione.php; personal contacts
EU6	CNR-IRPI	Brunetti et al. 2010, Rossi et al., 2012; personal contacts
EU7	NVE	Beldring et al., 2003, Boje et al. 2014, Colleuille et al., 2010, Devoli et al., 2014, Piciullo et al., 2017; personal contacts
NA1	USGS and NWS	Cannon 1988, Cannon and Ellen 1985, Ellen and Wieczorek, 1988, Wieczorek 1987, Wilson et al., 2004; personal contacts
NA2	ODOT and DOGAM	Baum and Godt, 2010, DOGAMI 2005, Jibson 1989, Larsen and Simon 1993, Mills 2002, Montgomery et al. 2000, Wieczorek and Morgan, 2008, Wiley 2000, Wilson and Wieczorek 1995, http://www.oregongeology.org/sub/Landslide/debrisflow.htm http://www.oregongeology.org/sub/Landslide/debrisflow.htm personal contacts
NA3	USGS	Baum 2007, Wieczorek et al. 2000; personal contacts
NA4	USGS, NWS, City of Seattle	Baum and Godt, 2010, Baum et al. 1998, 2005, Chleborad 2000, 2003, Chleborad et al. 2006, 2008, Gerstel et al. 1997, Godt et al. 2006, Laprade et al. 2000, Tubbs 1974; personal contacts
NA5	NOAA and USGS	Campbell, 1975, Cannon and Gartner, 2005, Cannon et al., 2008, 2011, NOAA-USGS Debris-Flow Task Force 2005, Restrepo et al., 2008, 2009, Staley et al., 2013, USGS 2005; personal contacts
SA1	GEO-Rio	Calvello and Piciullo 2016, Calvello et al., 2015, d'Orsi et al. 1997, 2000, 2004, 2013, d'Orsi, 2012, Tatizana et al. 1987; personal contacts
SA2	SDC	Huggel et al., 2008, 2010, 2012, Terlien, 1998
SA3	GEO-Rio	Calvello et al., 2014, d'Orsi, 2012; personal contacts

State of activity



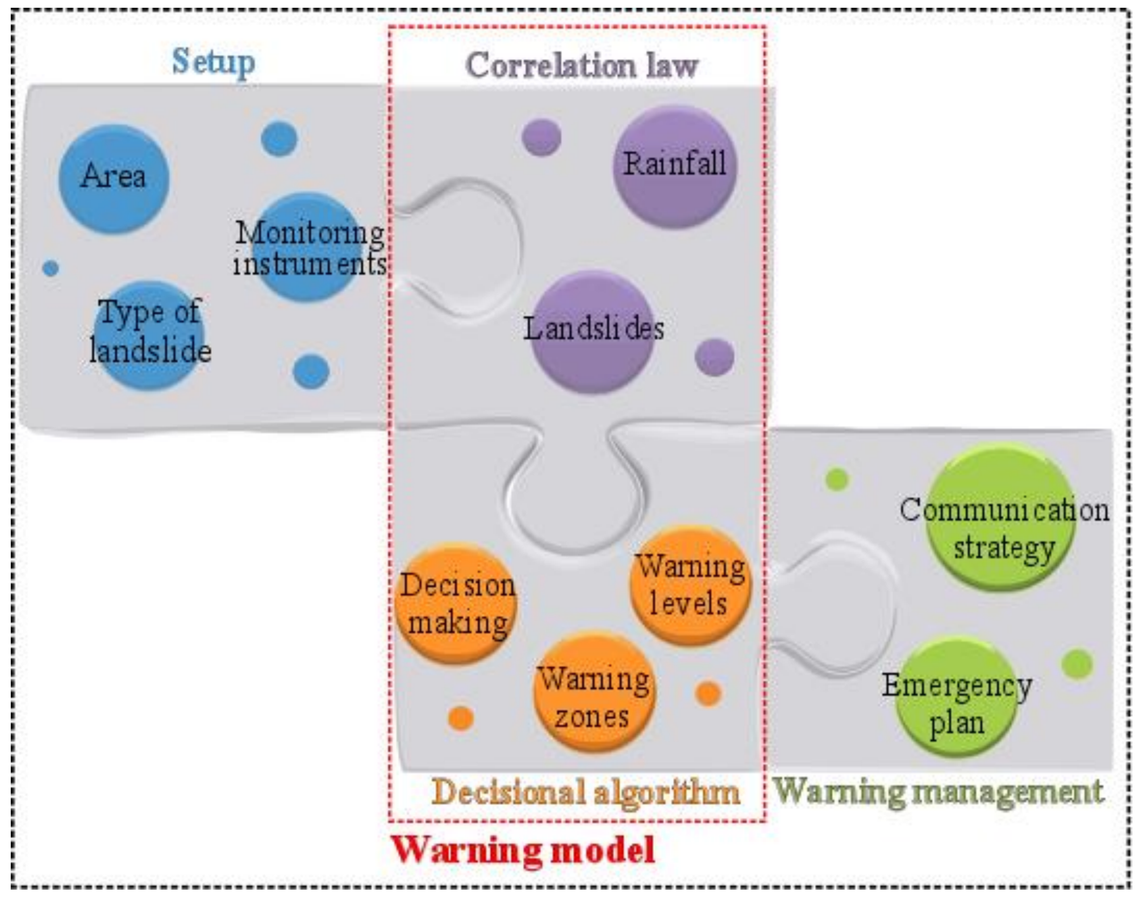
In the last two decades many EWSs at a regional scale have been designed as landslide risk mitigation measures at regional scale all over the world. Many reasons may be identified for that: cost-effectiveness; easy applicability in large and high density populated areas; increased knowledge on rainfall-landslide correlations; upgraded technologies and increasing reliability in weather forecasts.

Structure and general components of a LEWS

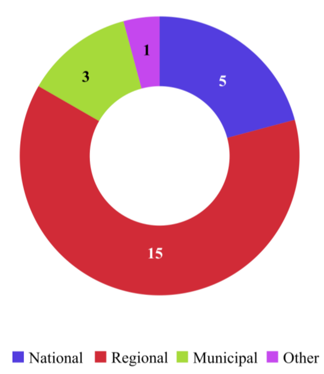
Te-LEWSs are important non-structural risk mitigation measures to reduce the risk to life connected to weather-induced landslides.

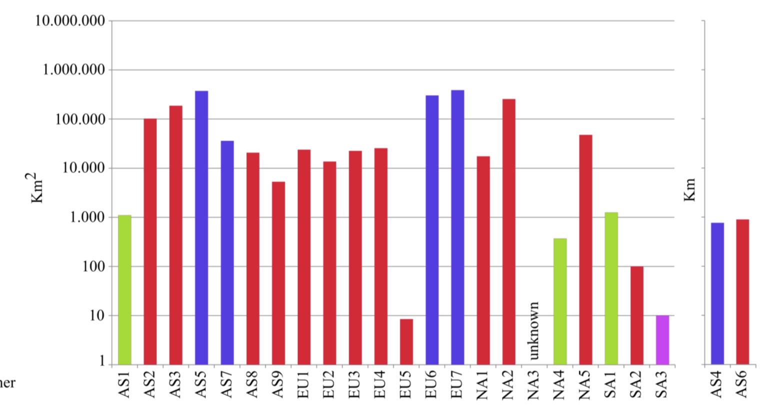
Main components necessary to operate a territorial EWS for weather-induced landslides. The scheme, structures as a jigsaw puzzle, is based on four main tiles, i.e. main modules of the warning system.

The correlation law and the decisional algorithm, if considered together, constitute the warning model of the system.



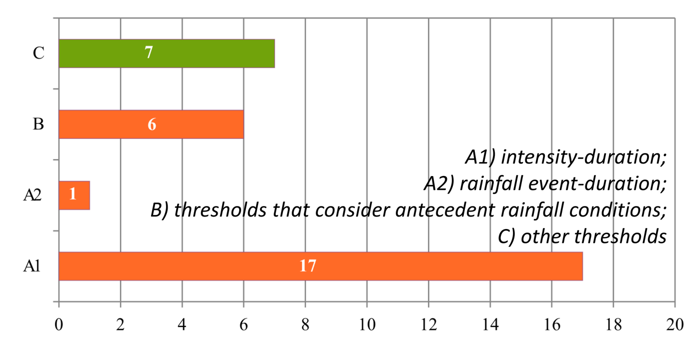
Main characteristics in a nutshell

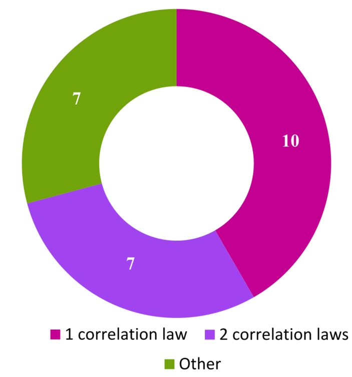




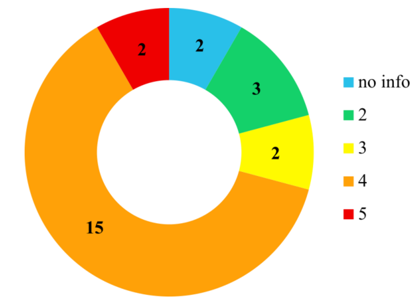
The reviewed systems are mostly designed to operate at three different territorial levels: national, regional, and municipal. The warning area varies, even among systems designed to operate at the same territorial level, by orders of magnitude.

Most of the rainfall thresholds employed in these systems are intensity-duration (ID) thresholds, followed by other thresholds, sometimes considering antecedent rainfall conditions.





The use of more warning levels means the system differentiates states with an increased probability of landslides, which in turn activate different emergency procedures.



Setup

The setup module includes all the preliminary actions and choices needed to start the design of a Te-LEWS.

CODE	Monitoring system	Covered area	Landslide typologies
AS1	110 Pluviometers, radars	Municipality of Hong Kong	Cut slopes, rock slopes, fill Slopes, retaining walls
AS2	Pluviometers	Zhejiang Province	Rainfall-induced landslides
AS3	no info	Hubei Province	Rainfall-induced landslides
AS4	70 Pluviometers, piezometers	Malaysia	Debris flow
AS5	Radar	Japan	Debris flows, shallow landslides
AS6	Pluviometers, radar	Areas at risk along highway in Taiwan	Shallow landslides and debris flows
AS7	Pluviometers, radar	Taiwan	Shallow landslides and debris flows
AS8	Pluviometers, radar	ten districts	Rainfall-induced landslides
AS9	34 pluviometers	Chittagong Metropolitan area	Rainfall-induced landslides
EU1	332 Pluviometers, radar	Toscana region	shallow landslides, debris slides/flows
EU2	147 Pluviometers, radar	Campania region	shallow landslides, debris slides/flows
EU3	Pluviometers, radar	Emilia Romagna region	shallow landslides, debris slides/flows
EU4	Pluviometers, radar	Piemonte Region	shallow landslides
EU5	Pluviometers, radar	Umbria region	shallow landslides, debris slides/flows
EU6	1950 pluviometers	Italy	Rainfall-induced landslides
EU7	pluviometers, piezometers, tensiometers, radar	Norway	Debris flows, shallow landslides, slush flows, debris avalanches
NA1	Pluviometers, transportable weather radar and NWS network radars	San Francisco Bay region	Debris flows and flash-floods
NA2	pluviometers	West Oregon	Landslide/Debris flow
NA3	pluviometers	Appalachians	
NA4	Pluviometer, piezometer, radar	Municipality of Seattle	Shallow landslides and debris flows
NA5	Pluviometer, radar	Southern California	Debris flows and flash-floods
SA1	33 Pluviometers, two radars	Municipality of Rio de Janeiro	13
SA2	Pluviometers	Combeima valley	
SA3	86 Pluviometers	113 Communities (i.e. Favelas) of Rio de Janeiro	13

Correlation law

The rainfall thresholds established through correlation laws can be either based on a conceptual schematization of the causal relationship between rainfall and landslides or on empirical criteria derived from a statistical analysis of historical data.

CODE	Correlation law	Other variable considered
AS1	Failure frequency and rolling 24 hour rainfall in semi-log plot	none
AS2	Landslide density and effective rainfall	rainfall intensity
AS3	intensity-duration; antecedent condition	none
AS4	Intensity-duration	Pore pressure
AS5	Cumulative rainfall and soil-water index for a 5 km grid mesh	soil water index
AS6	Intensity-duration; event duration	none
AS7	Intensity-duration	none
AS8	Intensity-duration	none
AS9	Intensity-duration	none
EU1	Intensity-duration	none
EU2	Probabilistic approach considering different return periods 2,5,10 years	hydrometric
EU3	Multiples of the standard deviation of cumulative rainfall distributions	none
EU4	Intensity-duration	territorial parameters
EU5	Probabilistic approach (return periods 2,5,10 years); Soil water balance model	soil moisture
EU6	Intensity-duration	none
EU7	Water supply rain and snowmelt and soil water content	none
NA1	intensity-duration; antecedent condition	MAP
NA2	Intensity-duration	occasionally snowmelt
NA3	Intensity-duration	none
NA4	Intensity duration; antecedent condition	AWI, Soil moisture, pore pressure
NA5	Peak intensity- duration	none
SA1	Intensity duration; antecedent condition	none
SA2	rainfall intensity-duration frequency IDF) curves	antecedent rainfall
SA3	Intensity duration; antecedent condition	none

In all cases the monitored variables to be compared with thresholds are cumulative rainfalls computed considering different time intervals.

Where huge and detailed landslide catalogues are available more sophisticated and specific correlation analyses were carried out.

Some Te-LEWSs consider information gathered from the monitoring of several parameters.

Decisional algorithm

The decisional algorithm is necessary for defining: the number of warning levels, the decision making procedures, and everything else for issuing warnings in the different warning zones.

CODE	Warning Zones	Territorial units	Alert levels
AS1	Fixed: 1	Municipality	2
AS2	Variable	no info	4
AS3	Fixed: 6	Municipality	4
AS4	Fixed	specific tracks of North-South Highway	3
AS5	Fixed: 1	5 km grid mesh	5 levels depending on lead time
AS6	Fixed	highways in mountainous areas	4
AS7	Fixed	Potential areas at risk of landslides	2
AS8	Fixed: 10 districts	50 communities	3
AS9	Fixed	communities in vulnerable areas	no info
EU1	25	25 Independent warning zones	4
EU2	Fixed: 550	Municipalities	4
EU3	Fixed: 8	25 territorial units	4
EU4	Fixed: 15	Thyssen polygons	4
EU5	Fixed: 6		4
EU6	Fixed: 129	-	5
EU7	Variable	Municipalities	4
NA1	Fixed: 1	San Francisco Bay Region, CA	4
NA2	Fixed: 1	-	4
NA3	Fixed: 1	no info	no info
NA4	Fixed: 1	Municipality	4
NA5	Fixed	burned areas	4
SA1	Fixed: 4	Guanabara, Zona Sul, Sepetiba, Jacarepaguà	4
SA2	Fixed: 1	-	4
SA3	Fixed: 103	Communities	2

The managers of Te-LEWS need to identify the zones where to issue the warnings.

Warning zones can be fixed in time—i.e. the subdivision of the territory to be warned does not depend on the warning event —or variable, if they are composed by grouping together territorial units for which, within a given event, the warning level is the same.

Warnings are not always issued automatically, especially the highest level of warning.

Warning management

The warning management phase usually includes information, communication and emergency strategies, such as education activities and the application of emergency plans.

CODE	Warning methods	Information through..	Public education
AS1	Public statements	Internet, Television and radio	training, school education, seminars
AS2	Public statements	Internet	none
AS3	Public statements	Internet	none
AS4	Public and internal statements	-	none
AS5	Public and internal statements	TV, radio, and the Internet	no info
AS6	Public statements	Local Broadcasting System, highway Changeable Message Signs and text messages	none
AS7	Internal statements	Warning message, Broadcasting	no info
AS8	Public and internal statements	Media, sirens, SMS	training, school education, seminars
AS9	Registered users	Internet, messages	social awareness building program, flyers, website
EU1	Internal statements	FAX, webGIS	none
EU2	Internal statements	FAX	none
EU3	Internal statements	FAX	none
EU4	Internal statements	internet, FAX	none
EU5	Internal statements	internet, FAX	none
EU6	Internal statements	Synoptic-scale maps of critical levels	none
EU7	Public and internal statements	Internet, email, radio and television, app	none
NA1	Public statements	Radio broadcast system, SMS	none
NA2	Public and internal statements	NOAA Weather Radio, Law Enforcement Data System, television	outreach, technical assistance, and disclosure requirements
NA3	Public and internal statements	Internet, CAP, DMIS	no info
NA4	NWS weather statements	Internet, radio, television, CAP, DMIS	none
NA5	Public and internal statements	Internet, NOAA weather, radio, television, AWIPS, CAP, DMIS	no info
SA1	Public and internal statements	Television and radio, internet	none
SA2	Public and internal statements	Emergency protocol	preparedness and social programs
SA3	Public and internal statements	Sirens	training for residents, courses, simulations

For more details: Piciullo L., Cepeda J., Calvello M., 2017. Territorial early warning systems for weather-induced landslides. Earth-Science Reviews (SUBMITTED)