User requirements for an Earth Observation (EO)-based landslide information web service

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ABSTRACT: Detailed, accurate and complete digital landslide maps are still rarely available. Nevertheless, such maps are essential for recovery and documentation after landslide-triggering events, for landslide monitoring and for hazard and risk mapping. These tasks concern national and federal authorities, owners, maintainers and insurers of infrastructure, and ultimately the public. The increased availability and quality of Earth Observation (EO) data, in combination with efficient image analysis techniques, foster semi-automated mapping approaches. Apart from the challenge of generating valid landslide information (e.g. landslides mapped as polygons including metadata, landslide-affected infrastructure) based on various optical satellite imagery, ways have to be found to make landslide information products accessible to the stakeholders. Here, we present the user requirements analysis for an innovative EO-based landslide information web service which will allow for fast and efficient provision of landslide information products. The need for such a service was confirmed by practitioners. The identified requirements were considered suitable for the planned development of a pre-operational web service for selected study areas in the Alps (Austria, Italy), which are highly susceptible to weather-induced landslides.

1 INSTRUCTION

1.1 *Background*

Landslides claim people's lives and destroy man-made infrastructure. Heavy rainfall is often the main factor for triggering landslides. In June 2013, continuous and intense rainfalls in the northern region of the Austrian Alps reached up to 150% of the usual monthly rainfall (ZAMG 2013). They caused numerous, mostly shallow landslides and related hazards like mudflows and flooding. The damage that resulted from landslides concerned mostly buildings and road infrastructure. Several landslides carried material into torrents and triggered mudflows with high severity that caused damage to many more buildings and to the rail and road infrastructure (Lebensministerium 2013). Figure 1 shows a landslide in the region of Salzburg that has been triggered by the heavy rains in June 2013 and transported debris into the stream below. The June 2013 events in Austria demonstrate that landslides constitute a major natural hazard in the Alps. Climate change will most likely further increase the frequency of heavy rainfall events causing an increase in landslide events (Stoffel et al. 2014).

Figure 1. Landslide in Niedernfritz, Salzburg, Austria. Photo: D. Hölbling.

In Austria, the legislation has introduced laws for the management of hazards like landslides. Among other stakeholders, one organ for its implementation is the Austrian Service for Torrent and Avalanche Control (WLV, Wildbach- und Lawinenverbauung). The WLV is concerned with installing protective measures in areas where landslides may endanger people or assets. They also care for the monitoring and the maintenance of the protective measures. Where areas at risk cannot be protected or where protection measures would be too expensive, laws prohibit any construction projects (Lebensministerium 2015). In case of landslides, WLV and other stakeholders such as civil protection agencies take actions of emergency response and for recovery. The success of their actions depends on their available knowledge and information about landslides. This applies not only to Austria but also to stakeholders in other mountainous regions. The most useful basis of information about landslides is a landslide inventory. "*History is the best guide to the future. Geologists say that any effort to reduce the risks from landslides must start with an inventory, a detailed map showing where landslides have happened*" (Dedman 2014). National and federal authorities are responsible for the documentation of recent and historic landslides.

It has been recognised that optical Earth Observation (EO) data is highly efficient for mapping the location and spatial extent of landslides at different spatial scales, ranging from local to regional (van Westen et al. 2008). Other available airborne and terrestrial remote sensing technologies can be suitable alternatives depending on the displacement velocities and the type of the to-be-measured landslides, the employed risk management strategies and other user requirements (SafeLand 2011). A survey conducted by Tofani et al. (2013) confirmed the usability and reliability of EO data for the mapping of landslides. About 50 % of the practitioners participating in the survey use optical satellite images. Today, numerous satellites equipped with diverse types of sensors (e.g. optical, SAR - Synthetic Aperture Radar) are repeatedly sensing the whole globe with increasingly higher detail. The number of satellites will further increase, as new missions are on the way (e.g. the Sentinel satellites). The global availability of EO data promotes the development of automated and reliable methods for detecting, analysing and monitoring landslides in a consistent manner to assist hazard and risk analysis (Guzzetti et al. 2012, Harp et al. 2011), and to support local, regional and national authorities, civil protection agencies, as well as spatial planners.

Traditional approaches for EO-based landslide mapping comprise time- and cost-intensive ground surveys and visual image interpretation (van Westen et al. 2008). Visual interpretation requires very high resolution (VHR) data such as aerial photographs or optical images acquired by satellites (Mantovani et al. 1996), e.g. WorldView, QuickBird. Imagery with lower resolutions has been used for delineating larger landslides (Singhroy 2005). Still, the interpretation of aerial photographs, supported by field surveys, remains the most widespread approach to landslide mapping. This is also valid for Austria (Weidinger, personal communication). Traditional approaches reveal the following drawbacks: due to time and data limitations only small areas can be investigated, and the quality of the resulting landslide maps depends on the experience of the investigator (Galli et al. 2008, Hölbling et al. 2015). Due to advances in computer and satellite technologies there is a clear trend towards semi-automated landslide mapping approaches based on EO data (SafeLand 2010). EO data that have been used for semi-automated landslide mapping comprise multispectral images, digital elevation models (DEMs), and SAR data. Multispectral images from SPOT, FORMOSAT, or QuickBird missions have proven to be useful in cases where landslides are not vegetated (Cheng et al. 2004), and have been combined with satellite-derived DEMs such as obtained from Cartosat-1 for an improved assessment of landslides (Martha et al. 2010). In literature, several examples for EO-based landslide mapping with semi-automated pixel-based or object-based methods have been presented (e.g. Aksoy & Ercanoglu 2012, Barlow et al. 2006, Borghuis et al. 2007, Hölbling et al. 2015, Hölbling et al. 2012, Lu et al. 2011, Martha et al. 2012, Martha et al. 2010, Mondini et al. 2011, Moosavi et al. 2014, Stumpf & Kerle 2011). However, the maturity of the most promising methods for inclusion in an operative service has yet to be evaluated and tested.

For fast and straightforward provision of analysis results web services have become state-of-the-art (e.g. Granica et al. 2007). A service-oriented architecture (SOA) that uses a representational state transfer (REST) technology for the web service implementation (Fu & Sun 2011, Thies & Vossen 2008) is able to present geospatial data compliant to international standards, i.e. from the International Standards Organisation and the Open Geospatial Consortium. A standard-conform implementation enables an easy access to the web service not only for a single user but for a variety of stakeholders. Therefore, an EO-based landslide information web service would be well-suitable for the landslide community.

1.2 *Objective and approach*

New technologies in EO data processing and advanced methods for digital provision of EO-based information can improve current approaches for landslide mapping. Therefore, we intend to develop and test a pre-operational EO-based landslide information web service that supports national and regional authorities and other relevant stakeholders in their activities on mapping and documentation of rapid landslides triggered by heavy rainfall. An initial service concept as basis for discussion with the users has been developed and is shown in Figure 2. The service provides landslide information derived from EO data. In addition, the users can apply implemented classification tools for performing basic analysis and manual adaption of results.

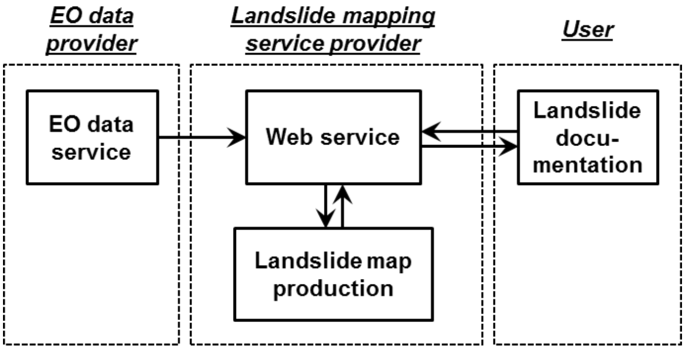

Figure 2. Service concept for a landslide mapping service.

The presented research deals with gathering relevant information about the users' requirements to the design of such a service. We identified potential service users who participated in semi-structured interviews. We recorded their needs for and expectations to a landslide mapping and information service. Finally, we discussed the results from the user requirements analysis in terms of their suitability for the service development.

2 METHODS OF REQUIREMENTS GATHERING

When developing a service, as in our case for the mapping of landslides and the identification of landslide-affected infrastructure, the users with their needs, goals and preferences are the most relevant factor. Therefore, the users have to be involved in the design process so that the service can be fashioned as close to the user demands as possible (Saffer 2007). User-centred design (UCD) approaches for geoinformation services have been applied for example for developing common operative pictures for communication of near-realtime information for disaster management (Atzl 2013) and for EO-based services in aviation (Albrecht et al. 2014). UCD is performed by four main activities: (a) understanding and specifying the user's working context, (b) definition of the user requirements, (c) producing the design solution and (d) design evaluation (Wealands et al. 2007). UCD aligns well with the Agile Manifesto (see e.g. Leffingwell 2010). The Agile Manifesto is an iterative approach for the entire software and service development that also includes requirements gathering and analysis. This research focuses on the user context and the user requirements. Figure 3 presents the iterative workflow.

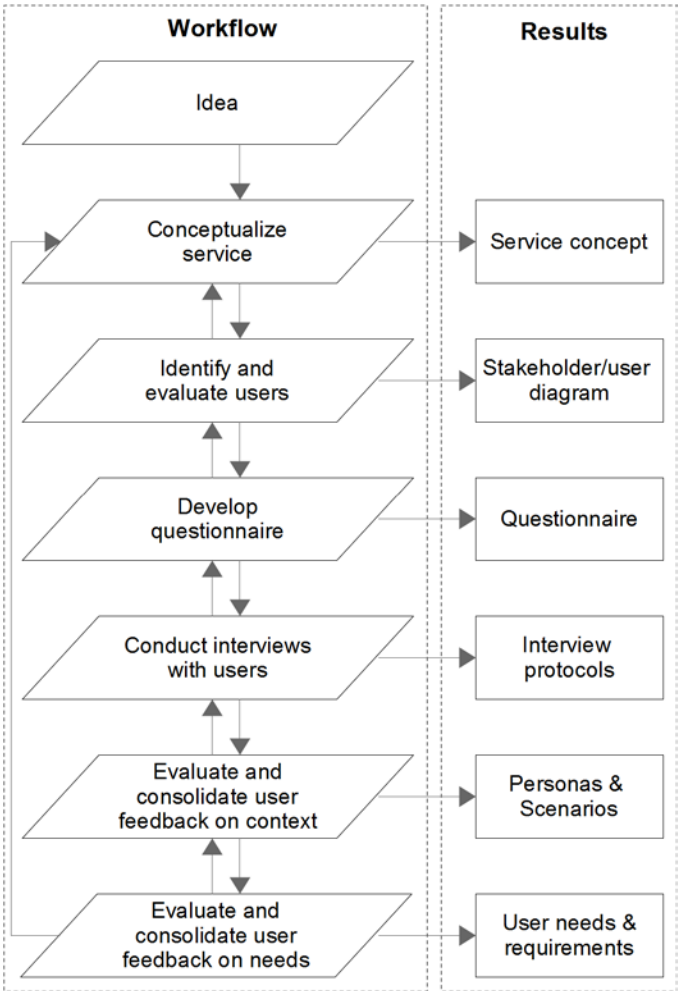

Figure 3. The task sequence for user requirements gathering.

The initial idea of the landslide information service was intended for specific users. The group of potential users has become more explicit during service conceptualisation and a list of potential users/stakeholders in the field of landslide mapping was compiled. Semi-structured interviews were conducted with the following nine users:

– GBA, Geological Survey of Austria (Geologische Bundesanstalt),
– WLV Upper Austria, Austrian Service for Torrent and Avalanche Control (Wildbach- und Lawinenverbauung, Oberösterreich),
– Geological Agency of the State of Salzburg, Austria (Geologischer Dienst, Land Salzburg),
– Vorarlberg State Office for Surveying and Geoinformation, Austria (Landesvermessungsamt Vorarlberg),
– Office for Geology and Building Materials Testingof South Tyrol, Italy (Amt für Geologie und Baustoffprüfung, Autonome Provinz Bozen Südtirol),
– Geological Survey of Bavaria, Bavarian Environment Agency, Germany (Geologischer Dienst des Bayerischen Landesamts für Umwelt),
– ÖBF, Austrian Federal Forestry Office (Österreichische Bundesforste),

– ÖAV, Austrian Alpine Association (Österreichischer Alpenverein),
– ASFINAG, Austrian Road Maintenance Agency (ASFINAG Bau Management GmbH).

For the semi-structured interviews, we prepared a presentation of the service concept and developed a questionnaire consisting of the set of questions that were identified as most relevant for documenting the users' working contexts and their requirements. The questions addressed:

– The user's organisation, its objectives and workflows,
– The relevance of landslide information to the institutional work and the type of needed information,
– Institutional expectations to EO-based landslide mapping and information products and web services, e.g. applicability of EO data for landslide mapping, reliability and usability of the information products and services and the web service interface,
– The expected impact that EO-based landslide information web services can have in the user's organisation.

The semi-structured interviews were conducted at the premises of the interview partners and lasted between one and two hours. The interviews followed a similar agenda. After a round of introduction, the service concept idea of the EO-based landslide information web service was presented. The remaining time of the interview consisted of a discussion using the questionnaire as guidance.

Based on the analysis a persona description was produced for each interview partner. A persona is the description of a typical user and wraps up the persona's responsibilities, the tasks associated to coping with landslides and the corresponding demand for landslide information. This gives a clear picture of the persona's objectives and working context. The description of the WLV (cf. section 1.1) provides a shortened example of a persona description.

Based on the personas, specific use scenarios for an EO-based landslide information web service were identified. The user-specific scenarios were grouped into generic scenarios. Each generic scenario was described by a workflow of subsequent tasks. Thereby, the scenario descriptions specified the user's context and allowed for the identification of problems that users face in their work. The problems were the basis for identifying user needs. User needs qualitatively describe the ideal scenario where the initial problems are solved. The needs are the basis for generating user requirements. They describe an ideal system that satisfies the user needs. The associated user requirements are described independently of a specific implementation, keeping them open to different implementation approaches.

3 RESULTS

3.1 *Use Scenarios*

The analysis of the nine interviews and associated personas resulted in a number of landslide-relevant applications that we grouped into generic use scenarios. Table 1 includes all identified applications associated with acquiring information about landslides, no matter if they can or cannot be served with the intended EO-based web service. The number of interested users gives an indication of the demand that exists for a specific application or generic use scenario.

Table 1. Use scenarios for landslide mapping.

Generic use scenario	Specific application	Nr of interested users (n=9)
Landslide rapid mapping		5
	Infrastructure assessment for planning/coordinating maintenance activities	3
	Planning emergency and recovery activities	2
	Timely provision of post-event imagery	2
Landslide documentation and mapping		8
	Management and planning of infrastructure that is (potentially) affected by landslides, and planning of protective measures	3
	Management of planning objectives for landslide-affected forestry stands	1
	Update of maps (hiking maps, geological maps)	2
	Publish official reports/ documentation on major landslide events	3
	Generate/update and share a (standards-conform) regional landslide inventory	3
	Landslide susceptibility mapping and establishing an appropriate basis for it	3
Monitoring of selected landslide sites		2
	Monitoring the status of debris retainers	1
	Monitoring of large slow-moving landslides and reactivated landslides that endanger infrastructure/people	3
EO data search and tasking		2

The generic scenario that has been requested the most was "Landslide documentation and mapping". The interview partners also considered this scenario as the one with the highest potential to be supported by the EO-based web service. The subsequently presented results therefore focus only on this generic scenario and do not cover the other scenarios of Table 1. Figure 4 displays a graphical overview of the scenario.

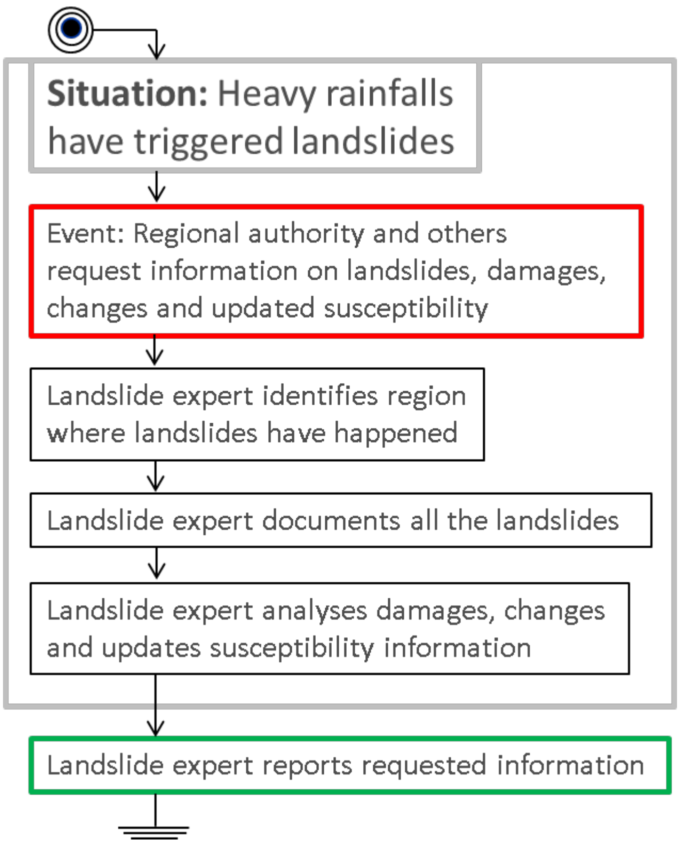

Figure 4: Overview of the generic scenario landslide documentation and mapping.

The actor in the scenario is the landslide expert that follows a sequence of documentation and mapping tasks: After landslides have been triggered, e.g. by heavy rainfall or snowmelt, there is a need for landslide information. Regional authorities and other stakeholders request: new information on harm or danger for people and on damage to assets; information where map products require an update; and an updated list/map of endangered assets. Therefore, the landslide expert needs to update the digital landslide inventory of the own organisation. At first, he/she identifies the region where landslides occurred. Based on information about the area where heavy rainfall occurred and from where damages have been reported, he/she decides on the region for which landslide documentation is required. Second, the landslide expert maps all the landslides in that region. For each landslide that he/she has identified as relevant, he/she collects the properties, e.g. location, extent, volume, etc., and also the caused damage during fieldwork and/or orthophoto interpretation. Third, the expert uses the acquired landslide information for analysing the assets that are managed by the user's organization. For identifying damages to assets, the updated landslide inventory is combined with other geodata layers such as buildings, streets, other infrastructure, agricultural fields, streams etc. For identifying a need for map updates the landslide expert compares the inventory to topographic maps, geologic maps and hiking maps. For validation, alternative landslide maps can be used. In addition, the landslide expert integrates the newly acquired landslide maps in the landslide inventory. This landslide inventory can serve as one important input dataset for creating landslide susceptibility maps that can be used for identifying potentially endangered assets. Finally, the landslide expert reports the results of the analyses to the regional authorities and other interested stakeholders.

Within the existing workflows for landslide documentation and mapping that are in place at the interviewees' institutions, the following key problems have been identified:

- Problem P1: Reliable landslide information is expensive – A landslide is a complex process. Therefore, gathering comprehensive information for documentation and for understanding the underlying sliding mechanism is a difficult task. Current approaches require a ground survey by a trained expert with appropriate geotechnical equipment for achieving a sufficiently high quality of the mapping information.
- P2: A comprehensive mapping of a region affected by landslides is time-consuming; and saving time results in an incomplete documentation – Time and cost constraints allow only a limited number of experts and a limited amount of time for mapping each relevant landslide in the field. Landslides with a low priority (e.g. because they did not cause any damage) are ignored. The workaround of prioritization leads to incomplete datasets.
- P3: Detection of landslides in remote sensing images is time-consuming, uncertain and usually needs a subsequent field survey – Currently, manual interpretation of remote sensing images (e.g. orthophotos, LiDAR DEMs, VHR satellite images) is used for pre-selection of sites for a ground survey. Uncertainty in the manual interpretation and low awareness of advanced methods for classifying satellite images cause a lack of trust in EO-based methods and prevent their full exploitation by practitioners.
- P4: Incomplete landslide documentation causes uncertainty in derived products – With errors or omissions in landslide documentation, any subse-

quent data analysis tasks, e.g. an overlay operation with infrastructure datasets such as street networks or other assets, will introduce uncertainty into the subsequent products.

- P5: Access to data of other organisations is unavailable – In Austria, several organisations collect and use information about landslides. Unfortunately, the data exchange between these organisations has not yet been implemented satisfactorily. Hence, a validation by cross-comparison of landslide databases is cumbersome.
- P6: Some organizations only partly provide their landslide information to the public yet – Although intended, a full provision of the collected landslide information to the public does currently not take place, because the strategy for communicating the reliability of that information is not yet fully developed. Without an appropriate strategy, the landslide information may not receive the trust that it deserves.

3.2 *Users' information needs*

From the scenario description and the associated problems, a list of specific needs of the landslide expert for a landslide information service has been compiled:

- Need 1 (N1): Information about all new landslides – There is a need for comprehensive, reliable and timely information about all triggered landslides within the affected area. Such information would ensure an effective performance of all subsequent analysis tasks. Most of the analysis tasks require a certain minimum quality of the input information. The relevant problems that have to be overcome are P1, P2, and P3.
- N2: Ways for collecting landslide information – There is a need for easy-to-use tools that make the collection of information about new landslides easier, less time-consuming, and potentially less likely to omit landslides. This would contribute to solve the problems P1, P2, P3 and P4.
- N3: Ways for analysing landslide information – Once the landslide information has been acquired there is a need for tools that analyse the landslide information in combination with other geodata. By that, damages to assets can be identified and it can be checked if topographic or hiking maps require an update. For validation, the landslide documentation can also be overlaid with reference information. This would contribute to solve problem P4.
- N4: Access to reference information – There is a need for any available external reference data and reference landslide information being readily accessible and usable. This would solve problem P5.
- N5: Communicating landslide information to stakeholders – There is a need for communicating landslide information to the authorities that asked for it and to the public. The responsible authorities want to make the public aware of the current knowledge on landslides and associated risks. This would solve problem P6.

3.3 *Description of user requirements*

From the interviews and the scenario development that identified problems and user needs, an initial set of high level user requirements has been derived:

- User Requirement UR1: Interface for landslide documentation and mapping – The landslide expert requires a way that allows him to express his demands for landslide information and for operations to be performed on landslide information. He requires feedback, if his demands can be provided. And he requires a way for receiving or viewing the requested demands.
- UR2: Landslide triggering event information – The landslide expert requires a description of the event for his information collection task.
- UR3: Data model for landslide information – The landslide expert requires a template of the landslide information product that he/she can use as a guideline for documentation (i.e. the set of relevant properties that describe a landslide such as area, etc.).
- UR4: Criteria for landslide identification – The landslide expert requires a set of rules (like minimum area etc.) that allow deciding if an identified object is a relevant landslide.
- UR5: Tools and functions for identifying landslides in image data – The landslide expert requires a way that allows him to identify landslides in image data, to manually correct them, to verify them and to document them.
- UR6: Tools and functions for integrating landslide data with other geodata – The landslide expert requires something that allows him/her to integrate the produced landslide information with other geodata (e.g. infrastructure data) and to produce map results and reports.
- UR7: Tools for accessing external geodata – The landslide expert requires a way that allows him to access and use external geodata together with his/her own landslide information.
- UR8: Tools for publishing landslide information – The landslide expert requires something that allows him to show others the information that he/she produced.

These high level user requirements show the diversity of aspects that have to be considered for developing an EO-based landslide information web service.

4 DISCUSSION AND CONCLUSIONS

The requirements analysis for an EO-based landslide information web service provides a thorough overview of different application scenarios. It also provides a detailed insight of the scenario of landslide documentation and mapping and points out the problems that exist in practice. The landslide experts' needs and the associated high-level requirements to an EO-based landslide information service have been identified. This research confirms the needs of practitioners for landslide information and the opportunities of EO-based methods as already pointed out in the literature (e.g. Tofani et al. 2013, SafeLand 2011). Beyond that, our research explicitly states the needs and requirements that landslide experts face in their landslide documentation and mapping tasks. These needs and requirements are relevant for implementing and demonstrating a solution to practitioners. Some of the user requirements may appear to be unspecific when they are formulated with term like "something" or "a way that allows". This wording has been chosen on purpose in order to avoid the user requirements being suggestive in solving them with a certain solution. The requirements then can be useful for other solutions as well.

More confirmation of the user requirements can become available by providing the users a test service and asking them for feedback. For the development of a respective service, the study's high-level user requirements have yet to be subdivided into elementary low-level requirements. For example, the landslide triggering event information (UR2) ought to consist of an area of interest as polygon (UR2-01) and the date of the landslide triggering event as an attribute (UR2-02). The to-be-developed service can be evaluated by checking, if these specific requirements have been fulfilled. We consider the documented user requirements well suited for developing a pre-operational web service that we will test for selected study areas in the Alps (Austria, Italy), which are highly susceptible to weather-induced landslides. The service will be tested together with the interview partners that contributed to this research.

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6 REFERENCES

Aksoy, B. & Ercanoglu, M. 2012. Landslide identification and classification by object-based image analysis and fuzzy logic: An example from the Azdavay region (Kastamonu, Turkey). *Computers & Geosciences*, 38**,** 87-98.

Albrecht, F., Lipok, F., Dittrich, J. & Logemann, V. Year. Geo-Information in the Cockpit : Safe Emergency Landing in Alpine Terrain. *In:* German Institute of Navigation (Dgon), ed. CERGAL 2014 : International Symposium on Certification of GNSS Systems & Services, 2014 Dresden. Göttingen: Cuvillier, 148-152.

Atzl, C. 2013. Nutzerzentrierte Präsentation mobiler Multimediainhalte in Raum und Zeit – Local C&C View *In:* Strobl, J., Blaschke, T., Griesebner, G. & Zagel, B. (eds.) *Angewandte Geoinformatik 2013.* Salzburg, Austria: Wichmann Verlag.

Barlow, J., Franklin, S. & Martin, Y. 2006. High spatial resolution satellite imagery, DEM derivatives, and image segmentation for the detection of mass wasting processes. *Photogrammetric Engineering and Remote Sensing*, 72**,** 687-692.

Borghuis, A., Chang, K. & Lee, H. 2007. Comparison between automated and manual mapping of typhoon-triggered landslides from SPOT-5 imagery. *International Journal of Remote Sensing*, 28**,** 1843-1856.

Cheng, K. S., Wei, C. & Chang, S. C. 2004. Locating landslides using multi-temporal satellite images. *Advances in Space Research,* 33**,** 296-301.

Dedman, B. 2014. *How Politics Buries Science in Landslide Mapping* [Online]. Washington: NBC News Digital. [Accessed October 14 2015].

Fu, P. & Sun, J. 2011. *Web GIS - Principles and Applications,* Redlands, California, ESRI Press.

Galli, M., Ardizzone, F., Cardinali, M., Guzzetti, F. & Reichenbach, P. 2008. Comparing landslide inventory maps. *Geomorphology,* 94**,** 268-289.

Granica, K., Almer, A., Hirschmugl, M., Proske, H., Wurm, M., Schnabel, T., Kenyi, L. W. & Schardt, M. Year. Generation and webgis representation of landslide susceptibility maps using VHR satellite data. *In:* Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International, 23-28 July 2007 2007. 2455-2458.

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M. & Chang, K. T. 2012. Landslide inventory maps: New tools for an old problem. *Earth-Science Reviews*, 112**,** 42-66.

Harp, E. L., Keefer, D. K., Sato, H. P. & Yagi, H. 2011. Landslide inventories: The essential part of seismic landslide hazard analyses. *Engineering Geology,* 122**,** 9-21.

Hölbling, D., Friedl, B. & Eisank, C. 2015. An object-based approach for semi-automated landslide change detection and attribution of changes to landslide classes in northern Taiwan. *Earth Science Informatics*, 8**,** 327-335.

Hölbling, D., Füreder, P., Antolini, F., Cigna, F., Casagli, N. & Lang, S. 2012. A Semi-Automated Object-Based Approach for Landslide Detection Validated by

Persistent Scatterer Interferometry Measures and Landslide Inventories. *Remote Sensing,* 4**,** 1310-1336.

Lebensministerium 2013. *Ereignisdokumentation 2013 - Bericht über die Wildbachereignisse im Juni 2013,* Wien, Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW).

Lebensministerium 2015. *Technische Richtlinie für die Wildbach- und Lawinenverbauung,* Wien, Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW).

Leffingwell, D. 2010. *Agile Software Requirements - Lean Requirements Practices for Teams, Programs, and the Enterprise,* Upper Saddle River, NJ, Addison-Wesley Professional.

Lu, P., Stumpf, A., Kerle, N. & Casagli, N. 2011. Object-oriented change detection for landslide rapid mapping. *IEEE Geoscience and Remote Sensing Letters,* 8**,** 701-705.

Mantovani, F., Soeters, R. & Van Westen, C. 1996. Remote sensing techniques for landslide studies and hazard zonation in Europe. *Geomorphology,* 15**,** 213-225.

Martha, T. R., Kerle, N., Jetten, V., Van Westen, C. J. & Kumar, K. V. 2010. Characterising spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods. *Geomorphology,* 116**,** 24-36.

Martha, T. R., Kerle, N., Van Westen, C. J., Jetten, V. & Kumar, K. V. 2012. Object-oriented analysis of multi-temporal panchromatic images for creation of historical landslide inventories. *ISPRS Journal of Photogrammetry and Remote Sensing,* 67**,** 105-119.

Mondini, A. C., Guzzetti, F., Reichenbach, P., Rossi, M., Cardinali, M. & Ardizzone, F. 2011. Semi-automatic recognition and mapping of rainfall induced shallow landslides using optical satellite images. *Remote Sensing of Environment,* 115**,** 1743-1757.

Moosavi, V., Talebi, A. & Shirmohammadi, B. 2014. Producing a landslide inventory map using pixel-based and object-oriented approaches optimized by Taguchi method. *Geomorphology,* 204**,** 646-656.

Safeland 2010. Review of Techniques for Landslide Detection, Fast Characterization, Rapid Mapping and Long-Term Monitoring. *In:* Michoud C., A. A., Derron M.-H. And Jaboyedoff M. (ed.) *Reports of the SafeLand European project.*

Safeland 2011. Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides. *In:* Michoud C., A. A., Derron M.-H. And Jaboyedoff M. (ed.) *Reports of the SafeLand European project.*

Saffer, D. 2007. *Designing for interaction - creating smart applications and clever devices,* Berkeley, Calif., New Riders.

Singhroy, V. 2005. Remote sensing of landslides. *In:* Glade, T., Anderson, M. G. & Crozier, M. J. (eds.) *Landslide Hazard and Risk.* West Sussex, England: Wiley.

Stoffel, M., Tiranti, D. & Huggel, C. 2014. Climate change impacts on mass movements — Case studies from the European Alps. *Science of The Total Environment,* 493**,** 1255-1266.

Stumpf, A. & Kerle, N. 2011. Object-oriented mapping of landslides using Random Forests. *Remote Sensing of Environment,* 115**,** 2564-2577.

Thies, G. & Vossen, G. 2008. Web-oriented Architectures: On the Impact of Web 2.0 on Service-oriented Architectures. *2008 Ieee Asia-Pacific Services Computing Conference, Vols 1-3, Proceedings***,** 1075-1082.

Tofani, V., Segoni, S., Agostini, A., Catani, F. & Casagli, N. 2013. Technical Note: Use of remote sensing for landslide studies in Europe. *Nat. Hazards Earth Syst. Sci.,* 13**,** 299-309.

Van Westen, C. J., Castellanos, E. & Kuriakose, S. L. 2008. Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview. *Engineering geology,* 102**,** 112-131.

Wealands, K., Benda, P., Miller, S. & Cartwright, W. E. 2007. User Assessment as Input for Useful Geospatial Representations within Mobile Location-Based Services. *Transactions in GIS,* 11**,** 283-309.

Zamg. 2013. *Juni 2013: Nass und trocken, kühl und heiß* [Online]. Wien: Zentralanstalt für Meteorologie und Geodynamik. Available: https://www.zamg.ac.at/cms/de/klima/news/juni-2013-nass-und-trocken-kuehl-und-heiss [Accessed 1st December 2015].