# Revealing distributed geoinformation for engineering geological applications

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**Abstract:** Today geology faces new challenges but also great chances brought on by the increased use of digital information. On one hand in the last decade the increase in data volume has been enormous, on the other hand the data sources are still neither homogeneous nor widely distributed. Furthermore often the only available data for a survey were acquired for completely different purposes. Especially when tasks become more complex, the usage of distributed not homogeneous data is essential and leads to considerable problems.

One possible solution is the development of data warehouses, integrating all available and needed data. The disadvantage of this concept is a reduced flexibility and the investments to build up and run this data environment. Another solution is provided by recent developments in Geoinformatics: the use of Spatial Data Infrastructures (SDI) for management of huge amounts of spatially related data. In contrast to the data integration approach, SDIs foster the re-use of already existing data inventories for future uses that are not known yet. The approach aims at just-in-time integration of data in a distributed computing environment. The main building block of any SDI is the web service technology, an industrial standard in the field of Information Technology (IT).

Most tasks related to engineering geology are dependent on a broad variety of data, not necessarily assembled in one place In this paper problems resulting from this fact will be discussed and shown where engineering geologist may profit from the application of SDI. Typical approaches for the usage will be shown and an established case study (groundwater vulnerability assessment) is discussed to demonstrate the capabilities the potential of this technique in Engineering Geology.

**Résumé:** De nos jours la géologie envisage de nouveaux challenges apportés par l'utilisation croissante d'informations digitales.

D'un côté le volume en données a énormément évolué dans les dernières dix années, d'autre part les de donnés ne sont ni homogènes ni reparti selon une distribution normale. De plus les donnés sont souvent acquis a des fins spéciales qui sont révèlent souvent tout a fait différents de leur future utilisation. Ceci est surtout vrai pour des questions complexes, où l'utilisation de donnés distribués et inhomogènes représente une partie de travail essentielle qui souvent mène à des problèmes considérables. Une solution possible est représentée par le développement de « data warehouses », intégrant toutes les donnés exigées et existants. L'intégration ainsi que la homogénisation des donnés est assurée par des routines complexes de même que la vérification du degré de confiance des donnés et leur arrivée auprès de l'utilisateur. L'inconvénient de ce concept est une flexibilité réduite de même que le coût pour l'initiation de cet environnement.

Une autre solution est proposée grâce à de nouveaux développements dans le secteur de la géo-informatique : L'utilisation de d'infrastrucutres de donnés spaciales (IDS) pour le management de quantités substantielles de donnés relies à un espace. En contraste avec l'approche de l'intégration de donnés, IDS supporte l'emploi de donnés déjà inventarisées pour une future utilisation jusqu'à présent inconnue.

L'approche vise à une intégration « just in time » des donnés dans un environnement de computation distribué. A la place de générer des cimetières de donnés le but primaire de IDS est de génerer informations xxx avérés. La partie principale de chaque IDS est représentée par une technologie de « webservice », etant un standard industriel dans le domaine de la technologie d'information (TI).

La plupart des travaux reliés à la géologie de l'ingénieur dépendent d'une grande variété de donnés, pas nécessairement rassemblés à un endroit. L'approche mentionnée montre une méthodologie pour la recherche de donnés (locale à globale) reparties, donnant des informations de qualité facilitant des décisions.

Dans cette publication deux approches (la vulnérabilité de la nappe fréatique, ainsi que le risque de glissements de roches) sont discutées montrant leur capabilités et leur potentiel sur le domaine de la géologie de l'ingénieur.

**Keywords:** geographic information systems, data analysis, data visualisation, geodata, groundwater contamination, landslides risk assessment

# INTRODUCTION

Today geology faces new challenges but also great chances brought on by the increased use of digital information. On one hand in the last decade the increase in data volume has been enormous. On the other hand the data sources are still neither homogeneous nor widely distributed. Furthermore often the only available data for a survey were acquired for completely different purposes. Especially when tasks become more complex, the usage of distributed not homogeneous data is an essential and leads to considerable problems.

 

One possible solution is the development of data warehouses, integrating all available and needed data. Complex routines manage the integration, homogenisation and confidence of the data as well as the delivery to the users. The disadvantage of this concept is a reduced flexibility and the investments to build up and run this data environment. Another solution is provided by recent developments in Geoinformatics: the use of Spatial Data Infrastructures (SDI) for management of huge amounts of spatially related data. In contrast to the data-integration approach, SDIs foster the re-use of already existing data inventories for future uses that are not known yet.

The presented paper outlines an approach recently developed during a three-year research and development project, aiming to provide facilities for just-in-time data access and information retrieval. Initially developed for a case study in the field of groundwater protection, the approach is usable in a much broader way. The main building block is the hypothesis, that spatially related data are available in several, spatially distributed places: local authorities provide base data (e.g. topographical maps, digital elevation models, digital landscape models, etc.), small-to-medium sised enterprises store data from expertises (e.g. geotechnical analyses, foundation soil data, building ground date, etc.), and universities provide data collected during research projects (e. g. field trips, research reports, analytical data derived from experiments, etc.).

After introducing the underlying concepts from information technology (IT) in more detail, some potential application fields and where to apply with a maximum return are discussed. Finally an implemented case study regarding groundwater vulnerability assessment and mapping is introduced and evaluated.

## FROM LOCALLY STORED BASE DATA TO UBIQUITOUS INFORMATION – THE CONCEPT OF SPATIAL DATA INFRASTRUCTURES (SDI)

The advent of digital mapping, especially through airborne and space borne technologies like aerial photography and satellite imagery, led to a huge amount of available geodata (LILLESAND & KIEFER 2003). Those data among others are used in environmental planning tasks, during building ground expertise, for the detection of duds from World War II, or for the detection of climate change processes. Besides those applications remotely sensed geodata are also used for the derivation of cadastral base data, like topographic maps or digital elevation models (DEM).

The traditional way to acquire base data is to order them for the area of interest in form of data processing media. This leads to a major problem: this data is static. Landscapes and spatial phenomena are subject to highly dynamic changes. This means not only the morphology changes. Also settlements or infrastructure can change intensively, even in periods less than 5 years. In order to support spatial decisions the decision maker relies on the accuracy and timeliness of the data. Static data is not sufficient for high quality decision making.

Another problem arises from the process of information retrieval. Information retrieval, especially in the spatial domain, is highly related to expert knowledge. Only domain experts can turn data into information. Also the process of information retrieval relies on up-to-date baseline data. A landslide hazard analysis or survey for a dam based upon out-of-date data is worthless, if not unacceptable. Where to get the most up-to-date data? Primary acquisition is time and cost intensive and often simply impossible due to technical or economic limitations.

Information technology in general and particularly Geoinformatics offer a concept of just-in-time access to spatial data: the concept of spatial data infrastructures (SDI). According to NEBERT (2004) a spatial data infrastructure "[…] hosts geographic data and attributes, sufficient documentation (metadata), a means to discover, visualise, and evaluate the data (catalogues and Web mapping), and some method to provide access to the geographic data". Besides those technical aspects of spatial data infrastructures, McLaughlin and Nichols (in CHbAN 2001) define the components of a SDI as "sources of spatial data, databases and metadata, data networks, technology (dealing with data collection, management and representation), institutional arrangements, policies and standards and end-users".

The base of any SDI is the data. Data is provided by web services, in the spatially domain mainly according to standards published by the Open Geospatial Consortium (OGC) (PERCIVAL 2003). The OGC - formerly known as Open GIS Consortium - aims to provide open standards to share geoinformation. Base data in SDIs are mostly distributed in two forms:

- OGC Web Feature Service (WFS) (VRETANOS 2002) for the distribution of vector based data
- OGC Web Coverage Service (WCS) (EVANS 2003) for the distribution of raster based data

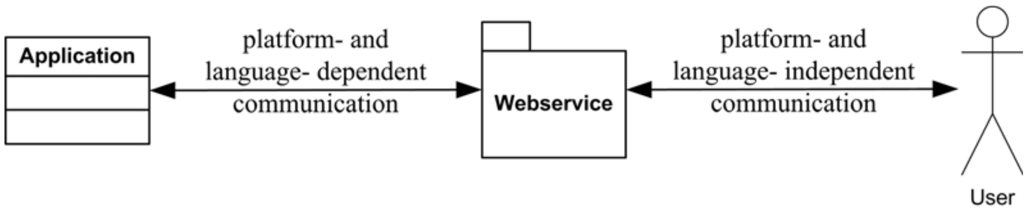


**Figure 1.** Data abstraction through web service technology

Those services add a level of abstraction to the data. Data abstraction is extremely important in distributed computing environments, because you agree to comply with a standard (here: WFS or WCS), and allow access to your data only through this layer of abstraction. The major advantage is that you can change the data (e. g. for updating purposes) without affecting any user of your service. Figure 1 shows the principle of data abstraction from the web service-oriented point of view.

Spatially related data can be published using web services, too. While the most-commonly used spatial web service, the Web Map Service (DE LA BEAUJARDIERE 2004), is mostly used for presenting cartographic content in form of spatially referenced images, WFS and WCS allow publication of spatial data. Spatial data are building blocks of spatial information as needed in environmental and engineering planning. While GIS were often used in the past to integrate all available information for a specific problem, nowadays the advent of web technologies allows the distributed storage and access of data. This aspect comes with several advantages:

- the amount of available data rises significantly,
- the facilities to share data are archived more easily,
- the re-use of data is fostered, because once acquired, data can be published and re-used by anyone who has access to those data,
- regularly updated data (e.g. climate, cadastral) can be accessed more easily, because potential users consume the web service, and not the data directly,
- data quality becomes better, which results in more concise information.

Non-spatial data, like textual information, images, etc. can be provided by web services based on mainstream IT protocol SOAP (W3C, 2003) while spatially related data can be provided by web services based on Open Geospatial Consortium specifications. Table 1 summarises some of the most important ways to publish data through web technologies.

**Table 1.** Preferred technologies for publication of data by web technologies

| Data type | Preferred technology | Technology provided by |
|---|---|---|
| Geographical Metadata | ISO 19115 | ISO |
| Service Metadata (spatial and non spatial) | ISO 19115 | ISO |
| Spatially related vector data | Web Feature Service | OGC |
| Spatially related raster data | Web Coverage Service | OGC |
| Spatially related aerial and satellite imagery | Web Coverage Service | OGC |
| Digital elevation data / Terrain data | Web Terrain Service | OGC |
| Web Cartography | Web Map Service | OGC |
| Spatially related search | Catalogue Service Web | OGC |
| Geocoding Applications | Web Gazetteer Service | OGC |
| Non-spatial data | SOAP / WSDL | W3C |

According to the high level of standardisation, web services are usable in several, independent contexts. Figure 2 summarises the concept of SDI from a high level technical point of view. Distributed data inventories, either distributed across an organisational network or worldwide across the internet, are published as web services (data tier) and used for information generation (business logic tier) of several clients. The clients (presentation tier) could be users accessing a web information system, a portable device or a fully-featured GIS.

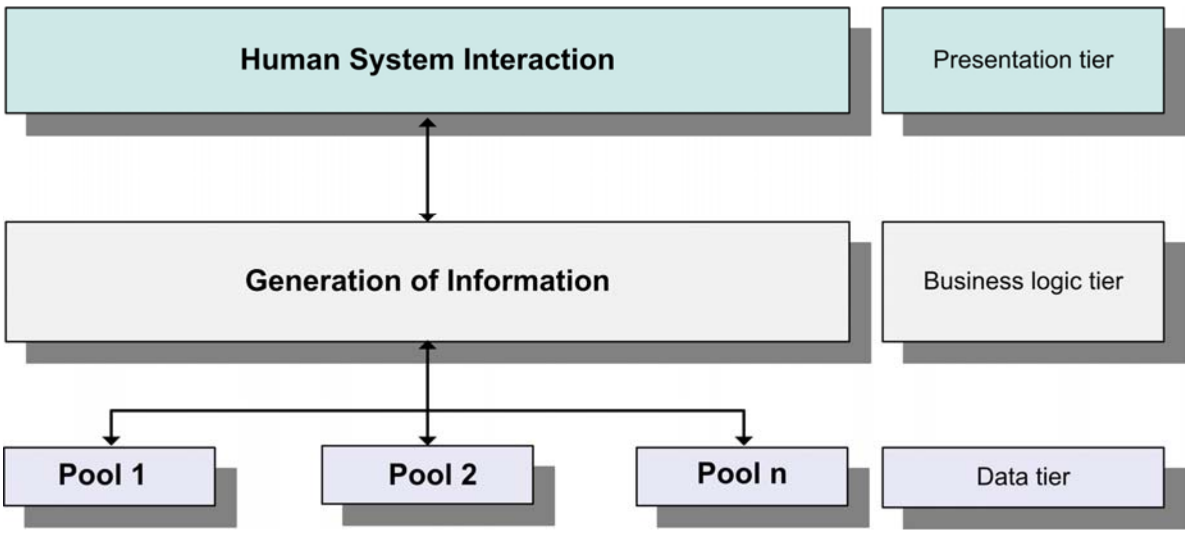


**Figure 2.** High-level technical view of a spatial data infrastructure

Generalised, the concept of spatial data infrastructure based on web services provides ubiquitous access of spatial and non-spatial data. This allows the integration of distributed and heterogeneous data for the generation of information to serve different clients with information, e.g. in the field of environmental planning or geological engineering.

## GENERATING INFORMATION

One of the most powerful aspects of web service technology is the easy integration of several, independent web services into service chains. A service chain consists of several web services which are specialised for a specific task, e.g. the spatial intersection of two features or the transformation of geodetic coordinate systems. The chaining of those services leads to complex information generation tasks, which is the main subject for spatial decision making.

In fact, the process of generating information from data, is the most recource intensive and challenging aspect. Using web services, this process can be encapsulated and annotated by service-metadata, allowing easy integration in any kind of information system (e.g. GIS, decision support systems or engineering information systems) due to its self-describing nature.

To describe a web service the eXtensible Markup Language (XML) or derived data formats are used, allowing humans as well as computer application to identify and use a specific service. Any service is at least described by an explicit address which in turn is connected to some sort of service-metadata facilities (e.g. http://geotech.lih.rwth-aachen.de/gwv/services/Gwv?wsdl. This publishes the web service definition language (wsdl), an XML-dialect for describing the capabilities of an W3C compliant web service of the provided interface description (see http://www.w3.org/TR/ for more details on wsdl). This service is easily consumed through the publish-find-bind paradigm: A service developer creates a web services and publishes this service through a service registry (*publish*). A service registry is simply a searchable yellow-pages directory for web services. The service registry provides information about what a specific service is capable of and how to access this service (*find*). Finally the service consumer can use this service as intended (*bind*). Figure 3 gives an overview of the publish-find-bind paradigm. Essentially, any information generation process can be encapsulated in a web service layer, as well as any dataset, as depicted in figure 4.

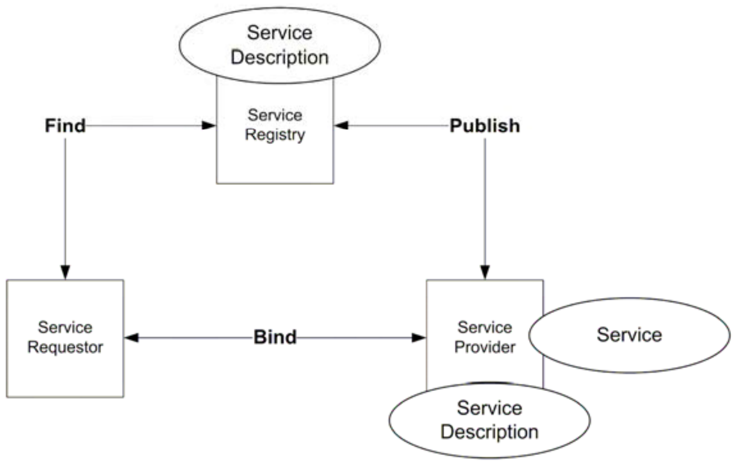


**Figure 3.** The publish-find-bind paradigm

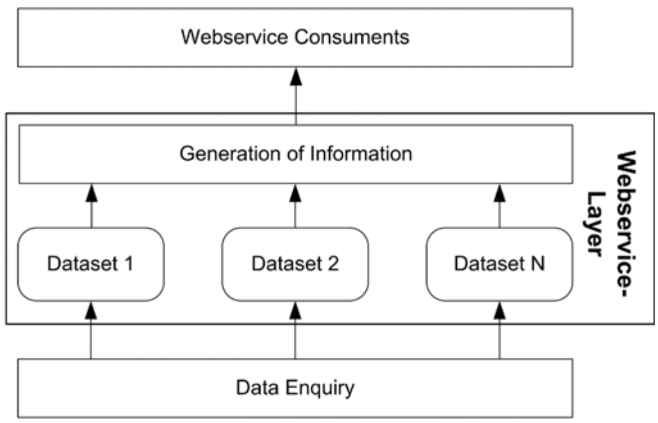


**Figure 4.** Providing information generation capabilities through a web service layer

## APPLICATION POTENTIAL IN ENGINEERING GEOLOGY: LANDSLIDE HAZARD MAPS.

Typical applications of this technology in engineering geology may be found where large data sets of high quality and accuracy are needed. Obviously the advantages of this technology are even bigger, if data or information has to be updated regularly in a heterogeneous date environment. Therefore, one promising application for example is hazard analysis.

Beside the already noted short-termed data actuality, legislative regulations and the state of knowledge may change over time. This shows, that data and information virtually imaging these processes, change at least with the same dynamics. In fact, the changes are even more rapid as products, quality, and the resolution of geodata improves continuously, accelerating this effect. This results in the fact that often time consuming analysis and surveys are out-of-date at the moment of closure.

A good example to describe this dilemma and the advantage of using SDI and web service technology are landslide susceptibility or risk maps. Especially focusing on aspects of data acquisition and preparation, specialists are facing considerable problems. ALEOTTI & CHOWDHURY (1999) described the process of data collection and storage in landslide hazard assessment as an important, but also “most burdensome” aspect. LEROI (1996) stated that 70-80 percent of project cost account for data collection and management. This is not surprising as in economics comparable rates are stated (PYLE 1999). As many other analysis processes in engineering geology besides landslide analysis are also data driven, this shows the advantages of an open technology for data retrieval and preparation.

Having a close look on base data in susceptibility mapping as part of landslide hazard analysis, the diversity of data types and sources is quite high (Tab. 2), as data is provided traditionally from different sources. Some of this base data and their derivates have been established as input parameters in most data driven landslide susceptibility and risk models, such as the digital elevation model, infrastructure, vegetation and geology. Today engineering geologists have to collect and recode this data for every study. As nearly all models use this data, it would be an advantage if data could be provided continuously in an open, self describing format. Furthermore this could happen without substantial financial investments and efforts by data providers, as the necessary web services for data preparation can be set up by experts in close collaboration with the later user. This enables other users to benefit from this service to derive the desired data.

**Table 2.** Typical base data and derivates in landslide hazard analysis

| base data | derivates |
|---|---|
| digital elevation model | slope aspect |
| | slope angel |
| | slope length |
| | watershed, drainage |
| | slope curvature |
| Geology | lithology |
| | faults |
| Hydrology | stream net |
| | distance to erosion base |
| Soil | soil thickness |
| | soil type |
| | soil drainage |
| Geophysics | ground acceleration and motion |
| Climate | average precipitation |
| | spatial distribution precipitation |
| | intensity distribution precipitation |
| vegetation | vegetation cover |
| | vegetation type |
| | land use |
| infrastructure | settlements |
| | roads, railway |

As many of the recently favoured technologies for analysis are data driven, the coding of data for analysis becomes more and more important. Coding means the process of transforming data to an appropriate format for mathematical or soft computing analysis, e.g. transformation of linguistic features to numerical values. In this case, not only the feature (e.g. rock type) is of importance, but also the character of coding has substantial impact on the results (YESILNACAR & TOPAL 2005, LEE et al. 2003, FERNANDEZ-STEEGER, 2002). Sharing this information makes it much easier to understand and assess new models or technologies. Even more the repeatability of tests is hardly possible without this information. Here web service technology offers the chance to share research results and techniques without sharing data.

Another advantage is the usage of encapsulated web services in complex information environments. Accepted procedures or index rating systems in form of algorithms can easily be shared in larger teams. The separation of data, algorithms, and subsequently rules open the opportunity to work in distributed teams, as every team may develop its tools separately.

One aspect today in sharing data and information is the confidence of data and security of information. At the moment base data from land survey is sold or made available directly to customers. As regular data sets are shared (e.g. distributed through CD-ROM) access constraints by providers is impossible. This leads to complicated legal regulations for further use. As web services provide only derivates (i.e. a conceptual view on data), the base data are still under control of the owner. In case of aggregated or processed data even a back analysis to base data is not possible without further data.

A last point is the expertise of data users. Management and manipulation of geodata is not necessarily associated with strong mathematical or analytical skills and vice versa. In data driven analysis, raster data is commonly the preferred data format due to its processing capabilities using map algebra. To develop or improve analysis models the process of data management and delivery is not a core skill. Here, web services providing data are a useful application.

Later the model can be combined with any other web service to offer analysis tool. The technology ensures that specialists can easily cooperate and concentrate on their skills. Finally it reduces the costs of software as the teams only need tools for the area of their key skills.

The following case study presents the realisation of information retrieval including data delivery and analysis realised by web service technology.

## CASE STUDY FOR GROUNDWATER VULNERABILITY

As part of a research and development project the authors implemented a spatial data infrastructure to derive geoinformation for the assessment and mapping of groundwater vulnerability from distributed, heterogeneous geodata inventories. Serving users from environmental protection agencies and local planning authorities, the goal was to assess the groundwater vulnerability in the catchments areas of rivers Rur/Erft, Inde, and Saubach situated in North Rhine- Westphalia, Germany. The groundwater vulnerability concept from HÖLTING et al. (1995) used in this case study has been fed with about twenty different data sets (raster data, vector data, textual and numerical data) to produce three distinct groundwater vulnerability maps.

The first step was the setup of the base data as OGC compliant web services; in case of vector data the web services used OGC WFS technology, raster data were published using OGC WCS technology, and non-spatial data were published using W3C compliant SOAP web services.

This very fist step leads to the world wide availability of the provided data, which can be password-protected if needed.

The next step has been taken in identifying and implementing the main information generation tasks. According to HÖLTING et al. (1995) the data has to be aggregated to five factors, representing the main characteristic responsible for groundwater protection (i.e. soil, lithology, leachate rate, depth to first groundwater table, and general supplements for special hydrological situations). Those factors represent protecting properties as dimensionless point-values with a spatial relation (i.e. elementary raster cell). The risk of groundwater contamination according to (HÖLTING et al., 1995) is determined by

$$P = \left( S + \sum_{1}^{n} D_n \cdot G_n \right) \cdot R + Q + A$$

- P: overall protective effectiveness
- S: rating points according to the effective field capacity of the soil
- D: depth of the unsaturated zone above the aquifer
- G: rock type (G=OF), O is a factor for rock type and F is the degree of faulting, fracturing and karst formation
- R: factor reflecting the long-term groundwater recharge
- Q: bonus points for perched aquifer systems (500 points)
- A: bonus points for hydraulic (artesian) pressure conditions (1.500 points)

This formula is easily coded using Java programming language and afterwards provided as a web service. The web service has to be provided with the required data to calculate the overall protective effectiveness of the groundwater overburden, resulting in a simple map-like illustration (figure 5).

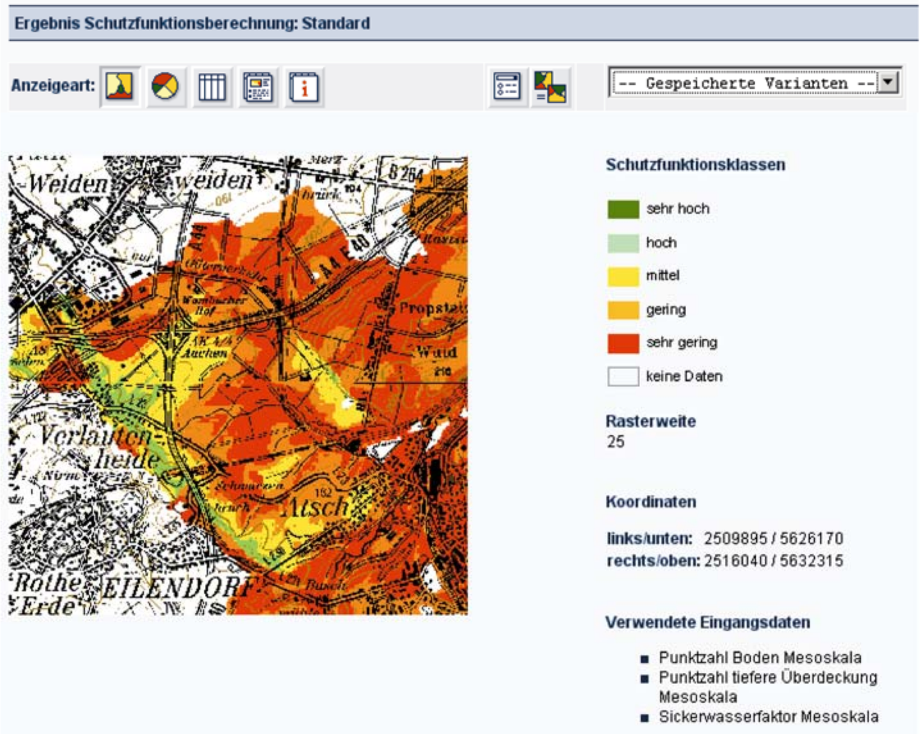


**Figure 5.** Information generated using a web service based on distributed, heterogeneous data

# CONCLUSIONS

The planner, expert or decision maker needs information in order to make a spatially related decision. Whether it is the foundation of a bridge, ground improvement to protect historical buildings or construction of infrastructure facilities: The more information is available, the better the results are. In order to supply the needed information, all data has to be collected and stored in one place, which is an extensive task.

Adjusting the concept of spatial data infrastructures (SDI) to engineering geology purposes opens up the alternative of easier and less cost intensive information access. Especially in tasks where large volumes of heterogeneous data are needed the entry barrier is very high, and for example even highly developed countries often have no national coverage of landslide hazard maps. By separating tasks and distributing them, even large projects can be managed by small and medium enterprises or university teams.

The data storage and preparation is located with the data providers (local authorities, small-to-medium-sized enterprises, universities, etc.). The task of data preparation, manipulation and retrieval is carried out using standard technologies provided by information technology, namely web services (World Wide Web Consortium) and spatial web services (Open Geospatial Consortium). The concept of web services allows access to spatially distributed data inventories. The services themselves can be published and found by searchable service registries.

The advantages for data modellers and providers:

- exact data query
- up-to-date data
- just in time integration of data and information
- distributed working in teams becomes possible
- reusability of data and services
- improved comparability of models and data sets
- algorithms and analysis may be set up as encapsulated processes for re-use

Having analysed typical problems related to landslide hazard analysis and groundwater vulnerability, it is obvious that this technology offers many possibilities to improve and simplify the process of data retrieval and analysis in distributed environments. The case study in groundwater vulnerability mapping shows that it is a mature technology, which can easily be adapted to different tasks. This case shows not only the application of services for data and information retrieval, but further more the analysis and visualisation of the results, based on the described technology.

Finally the technology allows the development of widely available, highly customisable, highly reliable, and most of all high quality distributed Geo Information Systems (GIS) and accompanying analysis tools.

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