The development of a national geohazards programme for South Africa: Why, how and when?

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Abstract: The development of a National Geohazard System for the Republic of South Africa (RSA) addresses geohazard issues by using geological information held by the Council for Geoscience (CGS). The system will play a significant role with stakeholders such as planning authorities, municipalities and many other public organisations.

The importance and strategic advantage of a national geohazard system for the RSA can be understood with reference to the following observations: RSA's urbanisation is currently 54% and increasing, representing an increased exposure to both personal and national risk; whereas developed countries use insurance as a way of decreasing personal risk, the RSA is under-insured in terms of property suggesting long-term growth for which the insurance industry will require increasingly more accurate information to quantify their risk and business model; the quantity and value of property is set to continue to increase, representing a potential increase in risk. Similarly, the country's infrastructure will increase in value and complexity, which increases the risk.

Geoscience is fraught with subjectivity and this leads to considerable uncertainty on the accuracy of models that are supposed to describe and predict geological processes. Typically, a probabilistic approach is applied to geohazard phenomena in an attempt to give a sense of magnitude and recurrence of features. In response to these limitations, other methodologies, such as prior information, worst-case analysis, fuzzy-set theory, amongst others, are being applied. The importance of this is two-fold in that: geohazard predictions carry considerable legal implications; a scientific robust methodology must be developed to model geological information into a variety of appropriate geohazard knowledge representations. The principle of this project is to devise a system whereby the CGS can utilize its large amount of geological information. The aim of such a system, currently in the stages of development, would be a 'one-stop shop' for geohazard related matters.

Résumé: Le développement d'un Système National de Risques Géologiques en Afrique du Sud aborde des problématiques de risques géologiques à l'aide d'information géologique abritée par le Council for Geoscience (GCS). Le système jouera un rôle important auprès des parties intéressées tels que les autorités de planification, des municipalités et bien d'autres organisations publiques.

L'importance et l'avantage stratégique d'un système national de risques géologiques pour l'Afrique du Sud s'expliquent à partir des observations suivantes: l'urbanisation du pays qui s'élève actuellement à 54 % est toujours en hausse, ce qui représente une exposition accrue au risques personnels et nationaux ; tandis que les pays développés utilisent l'assurance pour diminuer le risque personnel, il s'avère que l'Afrique du Sud est sous-assurée par rapport aux biens immobiliers, ce qui implique une croissance à long terme au fur et à mesure de laquelle l'industrie d'assurance aura d'autant plus besoin d'information correcte afin de contraindre leur risque et leur modèle commercial ; il est probable que la quantité et la valeur des biens immobiliers continueront à s'accroître, ce qui entraînera une augmentation potentielle de risque. De même, la valeur et la complexité de l'infrastructure du pays augmenteront, ce qui implique un risque élevé.

Les géosciences sont accablées par la subjectivité, ce qui entraîne un doute considérable en ce qui concerne les modèles qui seraient censés décrire et prédire les processus. Typiquement, une démarche s'appliquerait aux phénomènes de risques géologiques dans un effort d'y attribuer un sens d'importance et de donner l'impression qu'on puisse prédire la récurrence de certains événements. Afin de compenser ces limitations, d'autres méthodologies, telles que des renseignements à priori, analyses des pires éventualités, la logique floue, entre autres, entrent en jeu. Ceci est important pour deux raisons : les prédictions des risques géologiques comportent des implications légales considérables : une méthodologie scientifique solide doit être développé afin de modéliser des renseignements géologiques selon une variété de représentations appropriées de la connaissance des risques géologiques. La raison d'être de ce projet serait de concevoir un système permettant au CGS d'exploiter son grand réseau d'information géologique. L'objectif d'un tel system, actuellement en voie de développement, serait d'établir un « guichet unique » pour les problématiques ayant affaire aux risques géologiques.

Keywords: Geological hazards, geotechnical maps, database systems, seismic risk, regional planning, terrain analysis.

INTRODUCTION

Population growth and resulting urbanization causes infrastructure expansion into areas that are potentially at risk from natural threats or geohazards. There are no comprehensive systems in place in South Africa that either address the issue of geohazards or affectively translate the large amounts of basic geological information into simple geohazard based knowledge. In terms of identification and interpretation of the geohazards, or constraints to development, a geohazards programme was initiated by the Council for Geoscience (CGS), South Africa. The programme comprises 2 phases. The first phase was to set up a simple geohazard system based on the CGS geotechnical mapping programme (Richards, 2005). Because of the high detail of the geotechnical maps coverage is limited. However, Phase 1 of the geohazard system was set up quickly with a view to quickly providing a platform upon which the information could be made readily available. This would help in assisting regional planning initiatives, for example. Because of the limitations in area and content of the geotechnical maps, Phase 2, the development of a longer-term programme for a national geohazard system for the country using the geological information held by CGS, was initiated. It is envisaged that all geohazard related products would be produced from this system.

Geoscience is an inexact domain of scientific investigation. This leads to considerable uncertainty on the accuracy of models that are supposed to describe and predict geological processes. Typically, a probabilistic approach is applied to geohazard phenomena in an attempt to give a sense of magnitude and recurrence of features. In response to these limitations, other methodologies are being applied.

The importance of this is two-fold in that:

- Geohazard predictions carry considerable legal implications.
- A scientific robust methodology must be developed to model geological information into a variety of appropriate geohazard knowledge representations.

These models need to be developed as part of an overall philosophical approach to geohazards that is appropriate to South Africa, its people, and the available base of information in terms precision and accuracy.

In order to provide a comprehensive coverage of geohazards the national system is being developed to include all limitations to development. This not only includes the more classical hazards such as flooding, seismic events, dolomite related instability and slope instability, but also includes potentially damaging geohazards such as active soils, erodible soils and collapsing soils as well as financial constraints such as poor excavation conditions.

WHY? THE IMPORTANCE OF A GEOHAZARDS PROGRAMME TO SOUTH AFRICA

Geohazards can be defined as geological processes that usually occur comparatively suddenly, that threaten lives, property and strategic infrastructure. The principal driver for the increasing risk due to geohazards, which is noted both internationally and locally, is attributed to the unsustainable interaction or management of the natural hazard in relation to population fluxes and an increasing value of the building stock and increasingly complex infrastructure.

The cost of geohazards is not well defined for the RSA, Table 1 provides some estimates.

Table 1. Outline of geohazards in South Africa and relative cost estimates

Geohazard	**Loss and damages**
Dolomite related ground instability	Loss of 37 lives and $150 million damage
Earthquake related losses	Losses estimated to be over $75 million over the past 20 years Damage to individual homeowners by earthquakes is in the order of $1 million
Damages due to expansive soils	Losses are over $45 million (figure extrapolated from 1979 figures)
Other geohazards (other problem soils, mass movements etc.)	Losses are not known

The monetary costs are expressed as increased costs of construction, repair of damaged property and loss of property values. There are a number of findings that support the need to focus attention on geohazards in the RSA, these are:

- The risk from natural hazards is increasing worldwide. As urbanization continues (currently 55% of RSA's population lives in urban areas with this figure growing) and increased level of sophisticated infrastructure, the risk from geohazard phenomena will increase.
- Geohazards is an increasingly important area of activity in the broad domain of disaster management in the world. Most earth science organizations have as part of their operations and strategic intent geohazard related activities with most being focused on prediction and hazard mitigation.
- It is clear that, although of value in portraying geohazard information, the production of paper maps alone will no longer suffice for the prediction of geohazards. Total solutions are needed which investigate the larger issues around geohazards. With an estimated figure in excess of 11 000 property transactions per year, a figure growing as building stock increases, there is a high demand for technical data. Information is required regarding the ground conditions of those properties be it for insurance purposes or even the peace of mind for the potential purchaser.
- It is becoming increasingly clear that the management of natural disasters should involve the human dimension. Disaster losses are based on the complex interaction of the physical/natural environment, the built environment and social demographic issues. Earth science is normally one element of the bigger problem facing social, regional, provincial and national entities. One of the key problems facing many geological

products is that what is produced for the public is not necessarily well understood. If it cannot be understood then what is produced is not relevant.

- At present there are no systems in RSA in place that can effectively translate the large amount of basic geological information into simple and understandable geohazard-based knowledge. Where risk is appropriately expressed then issues around mitigation of risks can be addressed such as providing answers, solutions and recommendations.

An appropriate Geoportal is essential to the programme as this is the means by which information will be provided and any further transactions carried out. The maintenance of the geohazard system is key to sustainability of the system and will require continuous resources. An investigation of the legal implications and liability of providing geohazard related risk information is also required. A system that does not fulfill a legal framework will expose the provider of the information to potential claims for damages.

The system will play a significant role with stakeholders such as planning authorities, local and district municipalities, disaster management organizations and many other public organizations.

HOW? THE IMPLEMENTATION OF A SIMPLE GEOHAZARD QUERY SYSTEM AND THE DEVLOPMENT OF THE NATIONAL PROGRAMME

Background to Phase 1

The Council for Geoscience geotechnical mapping programme has been successful in completing a significant number of 1:50 000 geotechnical map sheets and a considerable amount of geotechnical information has been collected. A typical example of a geotechnical map produced by the CGS is provided in the map extract in Figure 1. It has been recognized, however, that providing this information solely as a paper map is not the most efficient way of obtaining information. The development of a commercially accessible geohazard system that is already in GIS format, will add further value to the geotechnical map series.

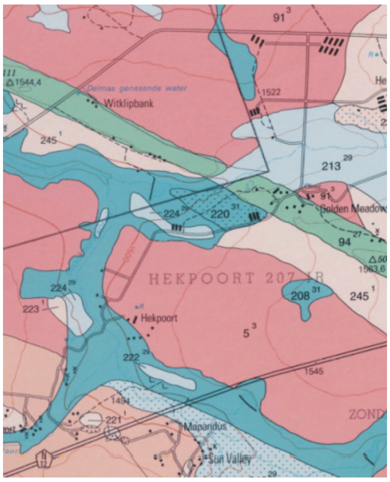

Figure 1. Example of a geotechnical map used for the geohazard query system. Clipped extract from 1:50 000 geotechnical map 2628BA Delmas (Council for Geoscience, 2001).

The primary objective of phase 1 of the project has been to develop and implement a simple geohazard query system, based on the CGS geotechnical map series, which is commercially accessible to the public using a geoscience portal.

The geohazards programme has been developed to a stage that a simple, understandable report can be generated by querying the geotechnical data in an ArcIMS format. The report contains a list of the geohazard conditions and their severities, a description of the geohazards and their implications, and recommendations for further action.

This simple geohazard system, based on the current series of geotechnical maps, enables the public to query the geotechnical data and receive a simple, yet informative report that indicates which geohazard is present in the area of interest, and what actions should be taken with respect to those geohazards. The system will represent an initial structure around which further geohazards would be included, for example seismic risk.

This project is providing valuable input and lessons into the development of a national geohazards project, the principle objective of which is to develop a detailed methodology whereby the CGS can use its large amount of geological information covering the RSA for the development of a national geohazard system.

Requirements for phase 1 of the geohazard query system

Before the query system was constructed a number of critical considerations in terms of the structure of the system and important aspects of the use of the data to be included, were addressed:

- How will the information be presented? What is the information? How was it acquired? What will be the basic steps to retrieving the information?
- Various terms and conditions must be addressed in terms of legal issues.
- What explanatory notes will accompany the information and who should be using it?
- Inclusion of copyright information, regarding copy or adaptation of results or provision of results to a third party.
- Are sample pages necessary to display the level of material available and the format of results?
- A summary of the geotechnical factors used, their definition, severity, and what they mean in terms of infrastructure, is required.
- An extract map viewer of South Africa is required which can be used to zoom into area of interest.
- Is it necessary to include a summary of the geotechnical characteristics for map polygon areas in terms of factor type and bedrock geology?
- Will the system use each map polygon area that is included in the geotechnical database?
- If payment is required for the data then an e-commerce function is required and that the information provided by the client is protected by law and will be secure.

An outline of the Phase 1 geohazards system

Geohazards are defined as geological or geomorphological processes that usually occur comparatively suddenly, that threaten lives, property and strategic infrastructure. In terms of the geohazards, or geotechnical constraints to development used in the CGS geotechnical mapping programme, the geohazards or geotechnical factors are: active, expansive or swelling soil; acidic soil; collapsing or settling of soil; compressible or poorly consolidated soil; dispersive soil; erodible soil; excavatibility of ground; inundation (flooding); karst related ground movement; liquefaction potential (thixotropic deposits); permeability of soil; shallow water table; and, slope instability.

How was the geohazard information acquired?

In recognizing the important role that geological information plays in regional land use planning the CGS embarked some years ago on an ambitious, high resolution 1:10 000 scale geological and geotechnical mapping programme of rapidly developing urban areas in the country. The primary objective was to provide a series of detailed geological and geotechnical maps that support a variety of regional planning policy and strategy initiatives. Attention has therefore been given in ensuring that the geotechnical or geohazard information presented is not only of importance to planners at provincial, metropolitan and municipal levels but also of value to environmental planners/consultants, engineering consultants, entrepreneurs, financing institutions, geoconsultants, conservation groups, teachers, lecturers, students, pupils and the public at large. This information is presented in a format which can transfer geoscientific knowledge to communities.

An important aspect of the geological and geotechnical mapping programme is its highly detailed nature. In the case of the geotechnical mapping no generalization of the geotechnical information collected was done to suit a particular type of development. Instead all geotechnical information compiled during mapping has been presented so that it is applicable to a wide range of potential development initiatives. In this way it is hoped that with the detailed and comprehensive geotechnical map and the most up to date geological mapping these products will be a primary reference source on many geoscience related matters.

Limitations of the information

This geohazards enquiry system is concerned with natural geological or geomorphological conditions only. The reports produced are limited to an interpretation of the geological and geotechnical data in the possession of the CGS. This data is based on 1:50 000 scale mapping. The reports should therefore be treated as indicative of the possible constraints to development for the area provided. Indications of these constraints or geohazards do not necessarily mean that the property concerned will be adversely affected by them. Such an assessment can only be made by the inspection of the area, or property by a qualified professional. The underlying limitation of the information contained in the geotechnical maps is the interpretation of the data by the end-user.

Application of the Phase 1 geohazard system

The geotechnical information required as part of the Phase 1 query system is contained in a suitable database format which has been designed specifically for the enquiry system application. Oracle tables and views have also been constructed and populated. To display the geotechnical information a web enabled report generator application has been developed which accesses both the spatial geotechnical data and the Oracle data to generate reports for each of the geotechnical polygons that were formed as part of the geotechnical mapping. When the system user selects a polygon the report for that polygon is generated on the fly from the database data.

The development of the system was done along two major parallel lines:

- The development of a map viewer for the selection of an appropriate area
- The development of a reporting system based on the information extracted directly from the *Engeode* module of the CGS *Geode* corporate database.

For the development of the viewer the sample *Extract* map viewer that ships with ArcIMS was used as a basis. This sample viewer demonstrates basic calls for a map image. These calls include displaying a map, zooming and panning functions, and selection buttons. These actions are done through an interface comprising buttons with icons (toolbar style). Each change to the toolbar implies some change to the html- and JavaScript files controlling the toolbar button functions.

The html files and functions of the *Extract* viewer had to be substantially changed for the purposes of the query system, and some files were completely discarded. The changes to the html files included re-formatting the viewer layout to accommodate a table showing the polygon selection detail, and redefinition of functions to calculate the cost of an enquiry in terms of the number of polygons selected and displaying this information. Some changes to the JavaScript files were also required including a report costing file addition in which the cost per geotechnical polygon was defined.

Simultaneous to the viewer development, a reporting system was developed in ArcGIS, whereby the system produces an interactive report of geotechnical parameters pertaining to the user-selected area based on the attributes of the database data.

The information supplied in the geohazard reports is only indicative and is not intended as a substitute for interpretations made by specialists, advice from professionals, or detailed site specific investigations. To this end, it is advised in the system that professional advice should be taken before interpretations are made on the basis of information provided. The information provided is applicable only to the area of enquiry and cannot be used to interpret conditions in other areas, even if the geological base data may be similar.

Geohazard or geotechnical interpretations are made according to the data available at the time and to the understanding of this data. The quality of the interpretations may be affected by the availability of new data, through site investigations for example, and improvements in data interpretation. The reports generated are based solely on the coverage of geotechnical information obtained during the geotechnical mapping and therefore demonstrates the limitations of the system. For the implementation of a national geohazard system some lessons can be learnt from the simple query system, namely the types of geological hazards or constraints to development that should be included in a national system and some aspects of the database design.

The development of Phase 2, the national geohazards programme

The underlying principle of a national geohazards programme for the RSA is that further development of the geohazard system should incorporate interpretations of conditions made by known geological, geomorphological and geotechnical relationships and the continuation of these relationships into areas where the geological and geotechnical base data is similar.

The methodology for the development of the second phase of the national geohazards programme comprises a comprehensive review of risk assessment and geohazard modelling systems developed for various geohazard scenarios and the collection of relevant working geohazard systems, such as that developed by the British Geological Survey (BGS) and by the Australian Geological Survey Organisation (AGSO) for community risk in Mackay (Middleman & Granger, 2000). A review of these systems is focussed on their applicability to South African conditions and their applicability in respect of the detail and accuracy of geological data held by the CGS. Some experience from the development of Phase 1 of the programme will provide further input in the evaluation.

The geotechnical information in terms of phase 1 of the programme was gathered using a number of data sources. The most detailed of these data sources is the geological spatial information from which a number of interpretations can be made. Some interpretations can be made by correlating geological data with terrain morphology. Thus the use of digital terrain models is regarded as an important component of the system, particularly in respect of slope instability issues. However, additional data sources are required in the GIS environment to establish a basis for modelling and applications. Seismic data, for example, is integral to the development of the system.

The major goal of the project in the first instance is to capture, analyze and provide, in visual format, geohazard data. To assess geohazard data effectively, an up-to-date interdisciplinary database should be available. The first step is the conceptual design of a spatial data infrastructure. The model should provide an integrated view of a variety of data sets and the provision of this data should then enable an analysis of risk.

The analysis of risk should involve assessing all levels of hazard and developing an understanding of the vulnerability of the various elements at risk. This is a common approach among most risk models. To put this into a national context, areas can be ranked to determine the total risk by hazard.

The use of historical data and local knowledge of all geohazard occurrences and their effects can provide the basis for understanding of what could happen in the future. The history is therefore an important component for establishing levels of probability for future events, bearing in mind, however, that predictions based solely on past events may prove inaccurate or misleading (Chowdhury *et al.*2001). Improved assessments of hazard and risk require that detailed knowledge of geology, soil types, terrain morphology, local flood prediction, and potential triggering factors (important in landslide prediction) be obtained through various investigations and observations prior to analysis and interpretation. In their work on landslide occurrence and effects, Chowdhury *et al.* (2001) recognized the importance of uncertainties in ground conditions and in the nature and occurrence of triggering factors. The model for the development of the South African geohazard programme should also recognize these uncertainties for incorporation into a risk assessment framework. The risk assessment must involve the development of the relevant databases, modelling and simulation, and should be based on a flexible GIS system.

WHEN? THE INTRODUCTION OF A NATIONAL GEOHAZARDS PROGRAMME

The second phase of the national geohazards programme is currently in the developmental stages. The initial product will be a detailed methodology stating exactly how the CGS should produce its national geohazard model. A scientific robust methodology must be developed to model the CGS geological information into a variety of appropriate geohazard knowledge representations. The methodology for the production of the national model should be completed mid-2006. Thereafter, the application of the modeling system including database development will take the programme into 2007. The system will be reliant on an appropriate Geoportal through which the geohazard information will be provided.

CONCLUSIONS

Because there are no comprehensive systems in place in South Africa that either address the issue of geohazards or affectively translate the large amounts of basic geological information into simple geohazard based knowledge, the need for an appropriate geohazard programme was recognized. Therefore, in terms of identification and interpretation of the geohazards, or constraints to development, a geohazards programme was initiated by the CGS, South Africa. The programme comprises 2 phases. The first phase was to set up a simple geohazard system based on the CGS geotechnical mapping programme. Because of the high detail of the geotechnical maps coverage is limited and there is therefore a need for a system which incorporates all the geohazard factors on a complete national level. Phase 1 of the geohazard system was set up quickly with a view to providing a platform upon which the current information could be made readily available. This would help in assisting regional planning initiatives in those areas where information was available. Because of the limitations in area and content of the geotechnical maps, Phase 2, the development of a longer-term programme for a national geohazard system for the country using the geological information held by CGS, was initiated. It is envisaged that all geohazard related products would be produced from this system. The national geohazard system is currently under development stages and the methodology for the national geohazard model should be completed by mid-2006.

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