Sinkhole geodesy in the Netherlands

NCG workshop, field excursion, and network event
Berg en Terblijt, 24-25 September 2020

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Motivation

A sinkhole is an abrupt local depression (and subsequent collapse) of the ground surface, caused by the presence of underground cavity, and can geometrically be regarded as a spatio-temporal change on a small scale.

In the Netherlands, sinkholes have occurred, and probably will occur in the future in the Enschede-Hengelo region due to salt mining, in the south-Limburg mining area caused by former coal mining, and over chalk caves in other parts of south-Limburg. They may occur at unexpected locations in these sinkhole-prone regions, and are therefore a great risk for the population. There is a need for early detection methods to provide timely sinkhole warnings.

Geodetic research on sinkholes and sinkhole detection has been ongoing at UT and TU Delft since several years [1, 2, 3, 4], particularly using Interferometric Synthetic Aperture Radar (InSAR). Stakeholders of this research are scientists like geologists and geotechnologists and public organizations like municipalities and provinces that bear societal responsibility.

Aim

Through a combined workshop, field excursion, and network event, NCG provided a platform, to share the latest developments, findings and understanding of geodetic sinkhole detection methodology and monitoring. We invited scientists and researchers in (but not restricted to) the fields of geodesy, satellite geodesy, geology, geomorphology, pedology, and geophysics, as well as societal and public parties, such as municipality representatives. The objective was to strengthen the community, exchange ideas, and initiate proposals for follow-up research.

Realization and plan

The NCG talent program 2020 enabled the initiative -- Sinkhole geodesy in the Netherlands: workshop, field excursion, and network event.

The event was held on 24 and 25 September 2020 at herberg De Geulhemermolen, in Berg en Terblijt https://www.geulhemermolen.nl/. There were 11 invited talks during both days. In the afternoon of the first day, a three-hours field excursion to Geulhemmergroeve and the surrounding area was led by dr. Roland Bekendam of GeoControl, and supported by staff from stichting De Rotswoning.

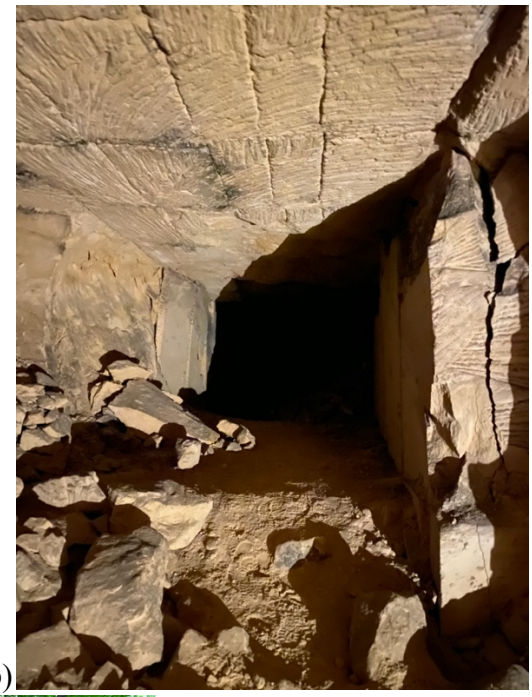
Workshop program

Time	Name	Title
24/09/2020		
11:00 – 11:30		Registration, coffee and tea
11:30 - 11:35	Ling Chang	Welcome
11:35 – 12:00	Ramon Hanssen	Sinkhole geodesy: opportunities and challenges
12:00 – 12:25	Erik van Linden and Joana Martins	The role of historical data for satellite geodesy
12:25 – 12:50	Bjorn Vink	Fault-zones and karst in South-Limburg challenges for existing and future constructions
12:50 – 13:15	Els Wijermars and Marinus den Hartogh	How a sinkhole initiated the development of the Subsidence Management Policy for salt mining in Twente
13:15 – 14:00	All	Lunch break
14:00 – 14:25	Ling Chang	What we learn from the sinkhole at 't Loon?
14:25 – 14:50/15:20	Roland Bekendam	Sinkholes and subsidence above the limestone room and pillar mines of South-Limburg
14:50 – 15:30	All	Discussion
15:30 – 15:40	All	Coffee break
15:40 – 18:00	All	Field trip, guided by Roland Bekendam
18:00 – 19:30	All	Dinner
19:30 – 20:30	All	Discussion, ideas for projects
25/09/2020		
09:00 – 09:25	Ramon Hanssen	MRSS: design of an early warning system for the detection of surface displacement anomalies
09:25 – 09:50	Hans Roest	Examples of the development of sinkholes/depressions in the Limburg coalmining area and ideas about a combined risk warning system
09:50 – 10:15	Jaap Spaans	Informatiecentrum Nazorg Steenkoolwinning; risk management of the effects of the former coal mining Limburg
10:15 – 10:40	All	Discussion
10:40 – 11:00	All	Coffee break
11:00 – 11:25	Max Felius, Freek van Leijen and Ramon Hanssen	Detection strategies for impending sinkholes based on InSAR data
11:20 – 11:45	Anurag Kulshrestha and Ling Chang	Use of RNNs for anomaly detection in Time-Series InSAR Analysis
11:45 – 12:40	All	Discussion
12:40 – 13:30	All	Lunch break
13:30 -15:00	All	Outlook, future actions, subgroups

Field sites

Geulhemmergroeve, is an underground quarry from which marl stone was previously extracted by block breakers. Photos (a) and (b) show the outside and inside of Geulhemmergroeve, and (c) shows a sinkhole (~10m diameter) above this quarry, which was caused by soil moving downward through so-called earth pipes.

(a) 

(b) 

(c) 

Focus

The workshop was structured around the main challenge: *"How do we increase the likelihood of successful detection of impending sinkholes (before they happen) using (satellite) geodesy"*. To resolve this challenge, we defined seven specific sub-questions:

1. Why are sinkholes relevant?
2. Where should we look?
3. What should we look for?
4. What can we learn from the past?

5. How can we search for sinkhole signatures?
6. How can we detect the sinkhole signatures?
7. What should we do once we detect something?

The participants gave presentations and discussed the relevance and impact of the problems mentioned above, and shared their experience and thoughts on the best way to tackle them.

Contributions from the participants

The eleven talks contributed to resolving the seven specific sub-questions.

Sinkhole geodesy: opportunities and challenges
Ramon Hanssen, TU Delft
Abrupt catastrophic surface collapses known as sinkholes have largely been regarded as unpredictable, unless laborious and expensive in situ surface and subsurface investigations would be performed. Recently, the increased availability of opportunistic geodetic techniques such as InSAR have taught us at least two things. First, many sinkhole collapse events seem to announce themselves, as they are preceded by limited surface depressions, with varying spatio-temporal characteristics. Second, the density and repeat/revisit frequency of InSAR measurement points is dense enough to have a significant potential for early detectability and therefor warnings. This has been demonstrated in numerous cases, but mostly post factum. We discussed the current state of the art, the opportunities for early detection of pre-collapse depressions, and the challenges that need to be overcome.

The role of historical data for satellite geodesy
Erik van Linden and Joana Martins, TNO
During the industrial mining period, a vast archive was maintained detailing the mine workings, which has not yet been exploited to full potential.
Amongst all the available historical information, we use the archive of historical mine maps, upward drilling logs and supporting literature over locations where sinkholes have occurred. We identify six criteria which may play an important role in sinkhole formation.
We searched for the presence the six criteria under the entire mining concession. After a quick risk assessment we were able to pinpoint locations (buildings) outside the currently defined risk areas, some of which are showing relevant surface displacements.

Fault-zones and karst in South-Limburg challenges for existing and future constructions
Bjorn Vink, Anteagroup
In this presentation we show some new detected faults and that DTM's and the landscape show some important faults due to karst. Recent projects that encountered karst and how they dealt with the problems with karst, A2-tunnel, stability poles: High Voltage Power line Maastricht-Kerkrade, Future project Einstein Telescope, dealing with karst and Paleokarst during the feasibility study: detecting faults and karst, affected layers and possible risks/hazards during deep tunneling

How a sinkhole initiated the development of the Subsidence Management Policy for salt mining in Twente
Els Wijermars and Marinus den Hartogh, Nouryon
In 1991 a sinkhole formed over a salt cavern near Hengelo from which salt had been produced from 1962 to 1977 by solution mining. The roof of the cavern that was originally around 300 m depth had collapsed due to instability and the overlying layers followed,

leading to a 5 m deep sinkhole with a diameter of 30 m. It was known that salt mining causes subsidence, but the development of a sinkhole was unexpected. This incident has led to a series of investigations of the stability of caverns and modelling of the so-called cavern migration process that takes around 15 years. The database of subsidence measurements formed an important data source for reconstruction of cavern migration that did not end in sinkhole formation. The investigations and modelling work resulted in a method to assess the possibility of sinkhole formation for already existing caverns that was also used as a tool to design new caverns in such a way that the risk of sinkhole formation is eliminated.
Today there is still a risk of collapse for a number of caverns, some of which could create a sinkhole if no mitigating measures are taken. Nouryon has developed the Subsidence Management Policy that comprises a risk assessment for each cavern, monitoring of the situation with sonar survey and microseismic monitoring as an early-warning system and mitigating measures such as cavern backfilling.

What did we learn from the sinkhole at t' Loon?
Ling Chang, UTwente
In this talk we reviewed our study on monitoring the sinkhole at 't Loon using satellite radar interferometry techniques. In that study we demonstrated the feasibility of satellite radar interferometry to detect a migrating cavity under the city of Heerlen, the Netherlands, leading to foundation instability and the near-collapse of a part of a shopping mall in December 2011. We exploited the data archives of four imaging radar satellites, between 1992 and 2011, to investigate the dynamics of the area and to detect shear strain within the structure of the building. Time series analysis shows localized differential vertical deformation rates of ~3 mm/y during 18 years, followed by a dramatic increase of up to ~15 mm/y in the last few years. These results implied that the driving mechanism of the 2011 near-collapse event had a very long lead time and was likely due to a long-lasting gradual process, such as the upward migration of a cavity.

Sinkholes and subsidence above the limestone room and pillar mines
Roland Bekendam, GeoControl
In South-Limburg about 250 room and pillar mines have been excavated in weak limestones to produce building stone. Several types of instability, like local and large-scale pillar collapse, collapse of the limestone overburden and earth inflow from organ pipes, do not only create a hazard for visitors of the mines but also result in extensive surface subsidence, faulting and sinkhole formation. In this presentation the mechanisms of mine instability and the resulting surface subsidence were explained and the possibilities of prediction of effects at the surface using satellite geodesy were explored.

MRSS: design of an early warning system for the detection of surface displacement anomalies
Ramon Hanssen, TU Delft
A Monitoring and Risk Signaling System (MRSS) has been designed to detect anomalous ground motion in the province of Limburg, in a collaboration between TU Delft, Kragten, SkyGeo, and GeoConsult. In this presentation we discussed the main findings of the corresponding system, and presented the outline of the MRSS.

Examples of the development of sinkholes/depressions in the Limburg coalmining area and ideas about a combined risk warning system
Hans Roest, SodM
This talk gave an introduction in the process of sinkhole development with the typical mechanisms like water transport, underground erosion, void migration, settlement, etc.

Examples were given of sinkholes in the mining and post-mining period along mining 'steps'; sinkholes and a depression in areas with shallow industrial mining and a sinkhole developing during exploration (and remediation) of an old shaft. Different types of signals and deformation patterns were addressed. An example of preventive measures in a sinkhole risk area with improved foundation was discussed. The presented examples show the importance of early warning and prevention of escalation. It was proposed to use combined monitoring techniques, a risk signalling system and proportional control measures, especially in areas with a high population density.

Informatiecentrum Nazorg Steenkoolwinning; risk management of the effects of the former coal mining Limburg
Jaap Spaans, Kragten BV
The beautiful landscape of Limburg hides its mining history well. Arguably too well. It is difficult to raise awareness for mining related problems when it's hardly visible. Today, more than 50 years after the mines closed, the effects are still noticeable. The mine water levels rise, causing the ground level to rise. Uneven ground lift can cause damage. There is also the risk of mine shafts becoming unstable etc.
After 50 years after the mine closures there is an urgency to start with an information centre. Possibly 50, 100 or even 150 years of aftercare are still in our future. The goal of the regional centre as it currently stands is to support the responsible authorities (province, municipalities, *veiligheidsregio*) with their risk management. A small expert team is responsible for new data collection, management, monitoring and safeguarding.

Detection strategies for impending sinkholes based on InSAR data
Max Felius, Freek van Leijen and Ramon Hanssen, TU Delft
Identifying impending sinkholes is very difficult, since (i) the location and time of occurrence is not known a-priori, (ii) the signs at the surface are often very limited, and (iii) lead times can be very short. Various in situ methods such as coring, GPR and seismic reflection are expensive, spatially limited, and do not take the temporal changes into account.
InSAR is able to detect subsidence cheaply and over a wide area. However, detecting impending sinkholes using InSAR is still a challenge due to the limited spatio-temporal extent of the phenomenon, the slow buildup of expertise, the lack of methodology, and the limited understanding of the signals of interest.
We used InSAR scatterers to try to find a relationship that would suggest the presence of an impending sinkhole. The research focuses on the spatial and the temporal characteristics of an impending sinkhole. For the spatial characteristics we used empirically derived relationships such as influence functions to describe and approximate the surface expression. For the temporal characteristics we looked at irregular behavior of a scatterer. Combining these methods should result in a system that would be able to generate a warning whenever certain conditions for an impending sinkhole are discovered in the InSAR data.

Use of RNNs for anomaly detection in Time-Series InSAR Analysis
Anurag Kulshrestha and Ling Chang, UTwente
PS-InSAR derived deformation time series data has been used for studying (precursory) subsidence patterns over sinkholes. Deep learning can be useful in identifying such patterns which could be difficult to find otherwise, when dealing with extremely large-volume datasets. In this study, it was assessed whether the recurrent neural network (RNN) based Long short term memory (LSTM) models can identify sinkhole-related anomalies in deformation time series.

The ideas and propositions related to the presentations and man/sub-questions were collected by using post-it's (see a photo below) and discussed during the discussion sessions.

Output

The presentation abstracts were shared with all participants. Follow-up on collaboration and proposal writing is under discussion. The joint collaboration via MSc graduation research is under discussion as well.

Organization committee

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Dr. Roland Bekendam (GeoControl, info@geocontrol.nl)

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[3]. Dick A. Hordijk (2012). Dossier Hageman 7998-4-1 sinkhole winkelcentrum 't Loon in Heerlen. Rijswijk, the Netherlands.

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