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Sinkholes, Land Subsidence And Earth Fissures In Botswana

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TABLE OF CONTENTS

INTRODUCTION

Certain parts in Botswana are prone to sudden catastrophic ground collapse and instability, which may lead to death, injury and structural damage. The probable features, associated with collapse maybe Subsidence, sinkholes and earth fissures. These are likely to occur in areas where there is water abstraction (change in groundwater levels) and in areas underlain by soluble carbonate rocks, such as dolomites. The known features occurred in South eastern parts of Botswana which are underlain by Dolomites and Waterberg group sediments and Ecca group sediments of Karoo supergroup (Figure 1). These types of rocks are also good aquifers. Thus making the south eastern part of Botswana more susceptible to such collapse features.

Sinkhole are features formed by dissolution of carbonates and/or evaporites leaving out voids or large cavities in the bedrock. Sinkholes are generally circular, up to 125 m in diameter, steep sided and deep (up to 50 m) and they can occur with little warning.

Land subsidence is the gradual settling or sudden sinking of the earth's surface owing to subsurface movement of earth materials. It is caused by compaction of recently deposited sediments, shrinking of expansive soils, earthquakes, neotectonic movements, thawing of frozen ground and karst processes.

Earth fissures are long linear tensile cracks land surface with or without vertical subset. They are formed as a result of soil surface tension due to subsiding land caused mostly by groundwater pumping. Earth fissures can occur at almost any place where groundwater is being pumped to the surface. Hence there aren't many places that are completely safe from this geologic hazard.

There have been few reports on sinkholes and earth fissures reported in Botswana and in most instances with less significant damages and no loss of lives. The examples include the earth fissures in Hatsalatladi and Ditshukuidu in Kweneng District and in Kgwakgwe and Makapane area in the Southern District. Then the sinkholes reported in Lobatse town. There have also been numerous reports across boarder in South Africa (Bezuidenhout et al., 1969; Health et al., 2008; Jennings et al., 1965), of incidents that occurred in the Chuniespoort Group dolomite which extend into some parts of Botswana (Figure 2).

These incidents are an alarm to locals and calls for proper mitigation and management measures as they can be disastrous. Moreover, the cost for damages caused by these inherent land instabilities can overwhelming.

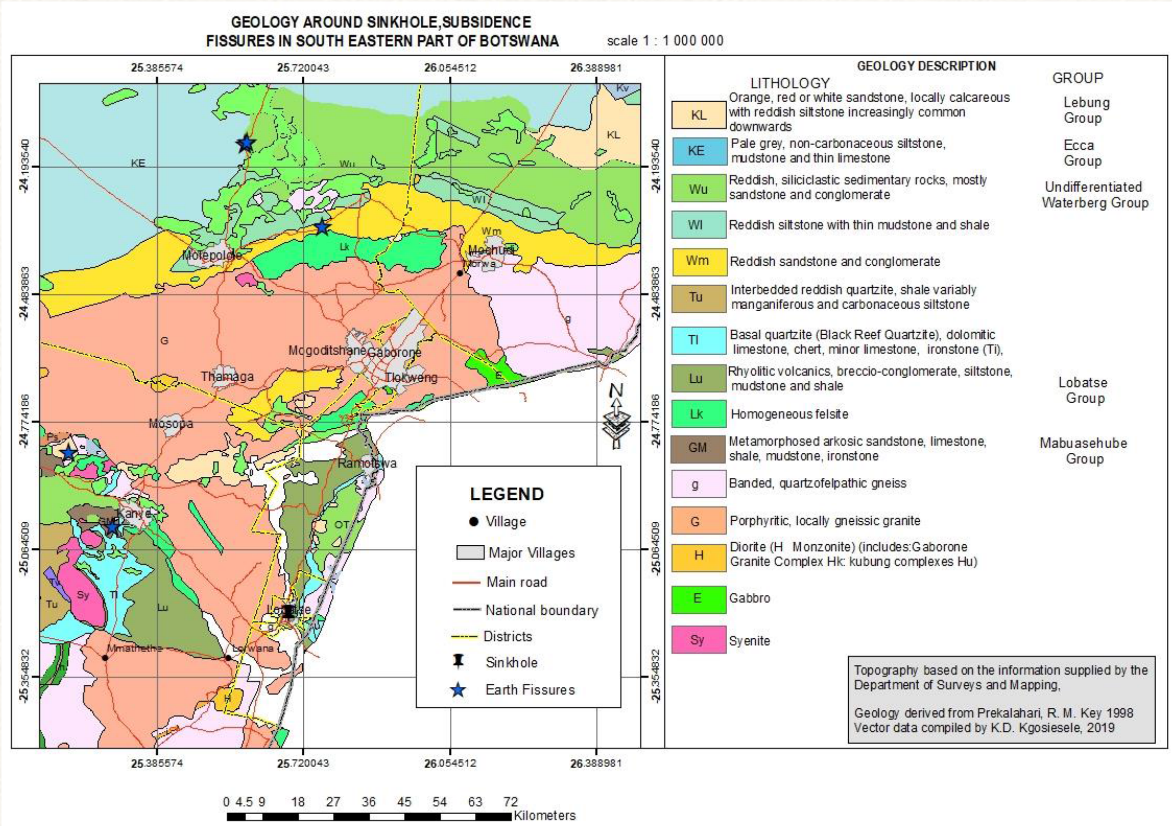

Figure 1: The known land instabilities in relation to local geology.

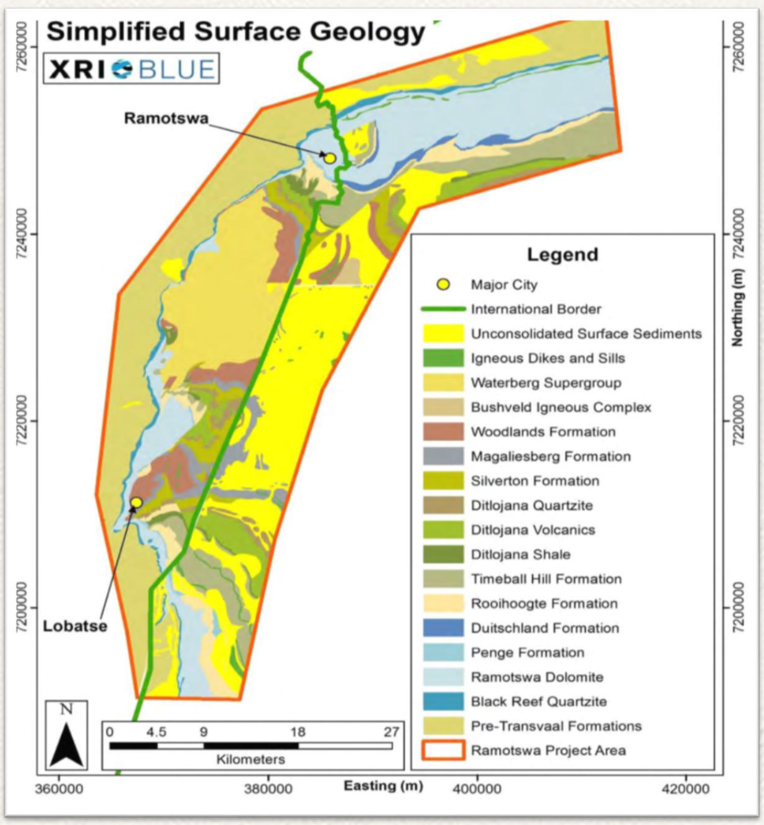

Figure 2: Chuniespoort Dolomite extent into the South East District of Botswana (XRI Blue 2016).

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MECHANISM OF SINKHOLE FORMATION

Dissolution and Collapse

Sinkholes are sudden and sometimes catastrophic collapse of a ground surface in the form of a cup-shape (Shaqour, 1992). Sink holes are generally circular in shape and steep sided, with diameter and depth up to 125 m and 50 m respectively. Classification of sinkholes in terms of diameter size has been proposed by Buttrick et al., (1995) as follows;

- < 2 m Small sinkhole
- 2 – 5m Medium-size sinkhole
- 5 – 15m Large sinkhole
- 15m Very large sinkhole

Sinkholes occurs when there are cavities formed by dissolution of soluble rocks predominantly evaporites (gypsum, salt) and carbonate rocks (dolomites and limestones).

Dissolution these soluble rocks takes place in a form of chemical weathering. Rainwater (H2O) reacts with carbon dioxide (CO2) in the atmosphere and soil to form a weak carbonic (H2CO3) groundwater. The aggressive dissolution as acidic groundwater is concentrated in preexisting openings in rocks such as fractures, joints, faults and zone of water table fluctuation. The weakening of subsurface support due to weathering leads to a sudden collapse of overburden material into cavities or nearest slot.

TRIGGERING MECHANISM FOR SINKHOLES

Given adequate time and the precise triggering mechanisms, instability may occur naturally, but is accelerated in many cases by anthropogenic factors. This includes prime triggering mechanisms such as:

- Groundwater level drawdown.
- The ingress of water from leaking water-bearing services;
- Poorly managed surface water drainage

Here the likely trigger mechanism could be exacerbated by leakages from reticulation lines, excessive withdrawal of groundwater which removes support from roofs. Ramotswa, Kanye, Lobatse and Moshaneng possibly relates to this scenario.

During long periods of drought or in areas where groundwater extraction is in excess, groundwater levels will decline, meaning cavities that were once supported by the water and filled with water may become weaker, thus equilibrium disturbed. The rate of active subsurface erosion may be accelerated as well. Then Headward erosion finally results in collapse at surface level.

SINKHOLE FORMATION SCENARIOS

Jennings et al., (1965) described the mechanism of sinkhole formation in terms of two scenarios; i.e ingress of water and de-watering.

Ingress Mechanism

- Existing cavities within bedrock or the overburden may be in a state of equilibrium.
- Concentrated ingress water from poorly managed surface water or leaking services will result in active subsurface erosion mobilising materials into the nearest cavity.
- Consequently an arch develops in the residual material overhead the cavity and headward erosion leads to successive arch collapse until the surface is breached and sinkhole transpires. The last arch may be stable for a considerable length of time and is sometimes supported by a near-surface layer of hardpan ferricrete.
- A triggering mechanism leads to the breaching of the last arch (Figure 3).

Dewatering Mechanism;

- Existing cavities within bedrock or the overburden which may be in a state of equilibrium are filled with groundwater.
- The equilibrium is disturbed by lowering groundwater which leads to loss of buoyant support
- Headward erosion and compression leads to collapse at surface level (Figure 3).

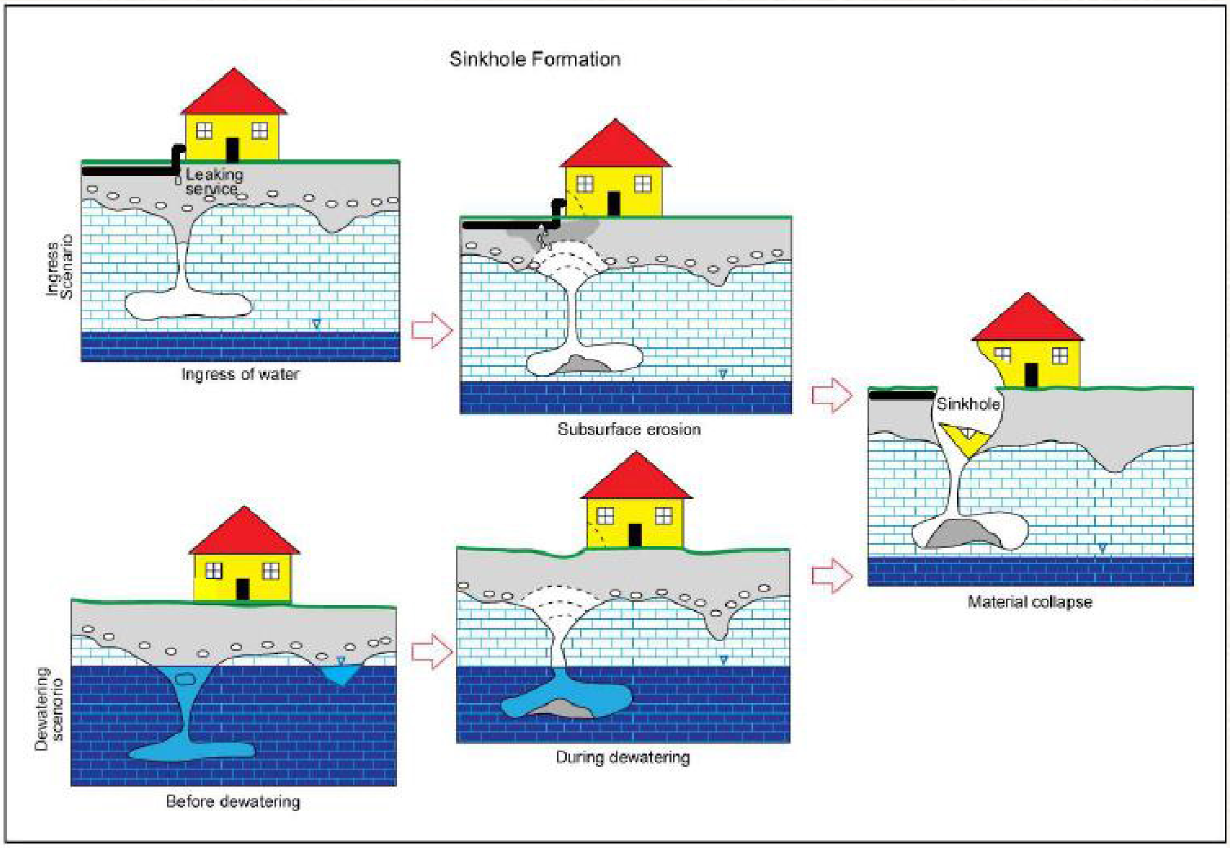

Figure 3: Schematic diagram Depicting mechanism of sinkhole formation (Oosthuizen et al,2011)

MECHANISM OF LAND SUBSIDENCE FORMATION

Subsidence is an enclosed depression due to gradual settling or lowering of ground surface as a result of underground changes and earth movement. It is generally a slow process, develop gradually and typically widespread. Land Subsidence is less obvious than catastrophic sinkhole formation. It is defined as endogenic, if associated to geologically-related motions (i.e., volcanism, isostatic adjustments), or as exogenic, when an anthropogenic or natural cause leads to the removal of underground materials that trigger ground subsidence (Prokopovich, 1986).

TRIGGERING MECHANISM FOR LAND SUBSIDENCE

Factors that cause land subsidence may be natural and may be accelerated by anthropogenic activities. The natural factors include;

- Shrinking of expansive soils
- Neotectonic movements
- Sea level changes
- Hydrocompaction in collapsible soils
- Earthquakes

The anthropogenic induced subsidence is caused by;

- Withdrawal of fluids (oil and groundwater)
- Collapse over underground mine.
- Load of high building
- Removal of support e.g Drainage of wetlands causing oxidation of organic soils.
- Compaction of recently deposited
- Collapse of karst cavities due to dewatering of unconfined acquirer

The compaction of unconsolidated aquifer systems that can accompany excessive ground-water pumping is by far the largest cause of subsidence (USGS ,2000) (Figure 4). A typical dewatering type subsidence is shown in figure 5. The water released during compaction cannot be reinstated by allowing water levels to recover to thei r predevelopment status. Thus resulting in a permanent ground deformation and failures.

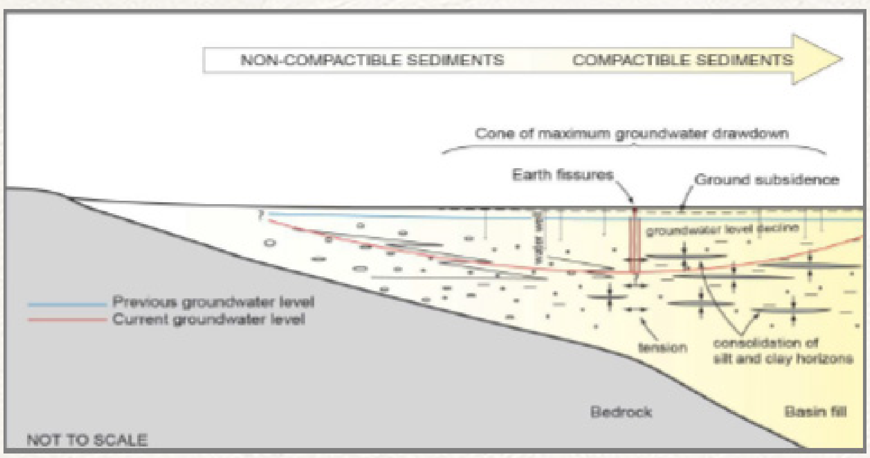

Figure 4: Schematic illustration showing effect of groundwater level decline on compaction of fine particles (Lund, 2016).

Figure 5: Typical Dewatering subsidence (CSGS 2011).

MECHANISM OF EARTH FISSURE FORMATION

Earth fissures are long linear tensile cracks on land surface with or without vertical subset. They are formed as a result of soil surface tension due to differential subsiding land. The tensional cracks tend to occur in transition areas between subsidence zone and more rigid ground formation where there is changing sediment characteristics and density resulting in differential settling (Figure 6). As the ground slowly settles, cracks form at depth and propagate towards the surface. Cracks are narrow, steep sided with hidden fissure flow, (Shipman et al., 2008). Surface expression of earth fissures vary from hairline cracks to several meters long and few meters wide. Gullies may develop along fissures can be enlarged due to erosion of the side walls.

TRIGGERING MECHANISM FOR EARTH FISSURES

Excessive groundwater withdrawal over recharge is by far the largest cause of subsidence that manifests as earth fissures (the primary triggering mechanism).

Other causes include;

- mine induced seismicity
- active tectonism
- To a small fraction natural lowering of the water table or drying of soil and sediment due to natural, long-term changes in climate.
- Torrential monsoon rains can rapidly widen and deepen fissures resulting in hazardous conditions to people, livestock and infrastructure

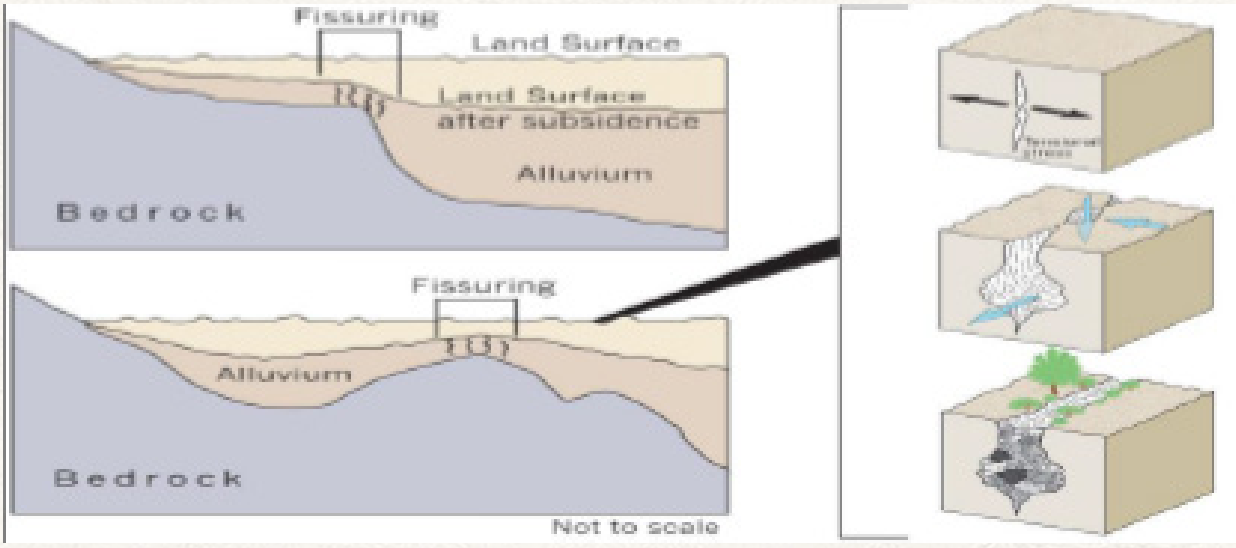

Figure 6: Schematic section showing effect of buried bedrock topography on formation and location of earth fissures (Lund, 2016).

HAZARDS ASSOCIATED WITH, SINKHOLES SUBSIDENCE, AND FISSURES

- Cracked or collapsing roads
- Cracked building foundation and walls (Figure 7).
- Loss of human settlement, infrastructure and agricultural land
- Loss of life and injuries to animals and human.
- Broken pipes & utility lines
- Damaged borehole casing
- Contaminated groundwater aquifer
- Changes in elevation and slope of the ground surface, possibly affecting drainage

Figure7: Diagonal, Tapering cracks, typical sign of subsidence on buildings (Hossein Rahnema, Sohrab Mirasi,2012).

SINKHOLE, SUBSIDENCE AND EARTH FISSURES INCIDENCE IN BOTSWANA

The most common earth collapse or instability in Botswana is earth fissuring. There are several occurrences reported around the country as shown in figure 8 below, where they have caused a variety of infrastructural damages and land management problems. A non-catastrophic sinkhole(s) have been reported so far. covers approximate- ly 26 square metres.

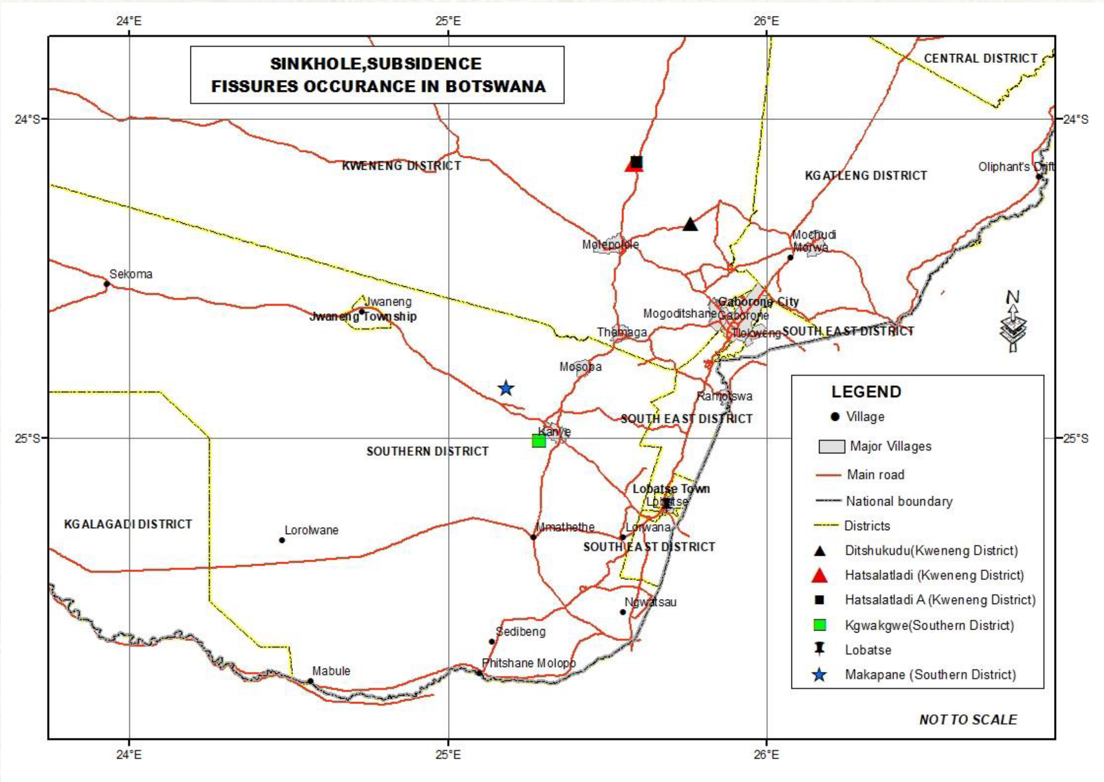

Figure 8: Occurrence of sinkholes, subsidence and earth fissure in Botswana

A linear earth fissure affected a dirt road leading to cattleposts around Makapane lands,12km south west of Moshaneng village in Ngwaketse west, Southern District (figure 9). The observed fissures affected about 0.18hactres of the area, however GPR results, a geophysical method showed that there were other concealed fissures over an extensive 0.48hactres coverage. Although the fissures are not extensive they may pose threat to road users and livestock in the area.

It is significant to note that these fissures occur in Waterberg sediments underlain by cherts and dolomitic rocks. In the long run these fissures may act as conduits for water ingress which may trigger an extensive collapse within dolomitic rocks. However, the causes of these earth fissures is unknown and yet to be established.

Figure 9: Earth fissure in Makapane

Extensive linear earth fissures occurred in Kgwakgwe wellfield, in Ngwaketse area, south of Kanye major village. These fissures were 300 ,2.2 and 1.8metres long,wide and deep respectively (Godirilwe et al., 2017) affecting around 0.4ha area within the wellfiled (figure 10) . Kgwakgwe wellfiled have been established to supply water for major villages such as Kanye and Moshupa villages.

According to DWA, 2006, the wellfiled is established in a karstified dolomitic aquifer. Godirilwe et al., 2017, concluded that the these fissures were a result of high abstraction rate of groundwater that exceeded natural recharge occurred in a karstified acquirer thus causing an instability that manifested as ground fissures.

This groundwater lowering due to over abstraction could result into sinkholes formation.The receptacles could be created when removing the water that initially filled the karst cavities hence causing the blanketing layer to collapse in pursuit of filling the gaps , leaving holes at surface (a typical dewatering sinkhole scenario).

Figure 10: Ground fissures around kgwakgwe wellfield .

In Hatsalatladi/ Ditshukudu in Kweneng District, earth fissures have been identified.

The ground fissures in Hatsalatladi occurred along and besides the tarred Lephephe-Molepolole road causing a significant damage as shown in Figure 11a. This at some point caused solemn disruption of transport system as the road had to be temporarily closed for road users safety. Another set of fissures occurred in a local primary school just few meters east of the main tarred road (Figure 11b). In both cases the discontinuities that were observed,posed a geohazard risk to the roadusers, public, school staff and students.

The Hatsalatladi area is underlain by predominantly meta-sediments of the Waterberg Group. Just few kilometers north of Hatsalatladi exists karoo rocks which hosts Ecca aquifers of recently Botlhapatlou wellfield (Lekula., 2018).

However, the cause of these earth fissures is unknown and yet to be established.

Ground deformation in Ditshukudu occurred in the form of three different cluster trends that seemed to fall into circular arcs (Tobani et al,. 2016). The fissures were upto 1metre wide with sub vertical scarps on either sides.The other set of fissure were linear persistent for 5-10m.Based on the trends of cracks, it is indicative of possible emergent subsidence manifesting itself as visible earth fissures and depression (Figure 12).

Figure 11: a) A Damaged road in Hatsalatladi due to fissuring: b) Earth fissures within Hatsalatladi primary school premises.

The cause of this subsidence and earth fissure is currently unknown in Ditshukudu, however hydrocompaction and shrinkage of exapansives soils have been hypothesised.

Figure 12: a) a depression observed in affected area: b) tripple junction of different trends of earth fissures in Ditshukudu, Kweneng District.

The occurrences of ground cracking in the Kweneng District is not particularly a new phenomenon since it has occurred in the Letlhakeng area where a Kgotla and a school infrastructure set up were damaged beyond repair and had to be relocated and replaced.

Earth Fissuring has affected a number of roads around Botswana namely; Letlhakane-Morwamosu highway, Ditshegwane access road and Boatle- Mmankgodi road (Laletsang et al., (2013 & 2014). Occurrence of earth fissures has also developed along Middlepit- Bokspits Trans Molopo Highway in the South Kgalagadi area.

A non-catastrophic small sinkhole occurred in a parking lot of the Civic Centre in Lobatse (Figure13). The affected area is underlain by dolomites as verified by Total magnetic intensity (TMI) results (Ramaselaga, 2012) in the same study GPR results confirmed presence of subsurface void at a shallow depth.

Figure 13: A sinkhole that occurred in Lobatse, South East District.

MONITORING AND MITIGATION MEASURES

Literature has shown that these land instabilities and collapses are triggered primarily by anthropogenic and seldomly natural processes. Therefore, precautionary steps are required to lessen the potential adverse impacts of land instability development associated with sinkholes, land subsidence and earth fissures, to the pertinent infrastructure and lives.

Land subsidence and earth fissures allied to groundwater withdrawal are human-caused geologic hazards (resultant of human activity). Thus land subsidence and earth fissures are also subject to human management such as;

- Implement best aquifer management practices to bring balance between water pumping and discharge. This will immensely slow or halt culminate land subsidence and earth fissure formation

In areas predominantly susceptible to subsidence and/or sinkhole risk, must consider;

- A mitigation plan that includes a periodic inspection program for existing building settlement, foundation cracks, maintenance of underground pipes/utilities to avoid leaks.
- In Dolomitic areas, some dolomite stability investigations should be carried out prior to construction and developments. This will advise on proper site management and building codes prior to development.
- Any new construction projects should review and comply with building codes and stringent construction practices that address subsidence and sinkhole hazards in the area. If the location is in a susceptible area and the local building codes do not address this hazard, it is essential to develop more stringent codes and practices beyond local building codes.
- Further recommendations related to mitigating sinkholes, land subsidence and earth fissures are;
- Conducting hazard-characterization practices such as; Mapping and zoning susceptible areas to aid in future development planning and prevent damage to existing and future infrastructure.
- Employing focused and robust early warning monitoring system (such as INSAR (Interferometry Synthetic Aperture Radar) to spatially evaluate the ground displacement due to subsidence, fissures, sinkholes. The system should be a ble to identify existing defects and determine the extent, and rate of ground displacement.
- However, use of differential GPS (Global positioning System) for providing continuous temporal monitoring of ground lowering can be considered.

Where possible, any signs of settling or subsidence require prompt repairs, maintenance and mitigation to avoid further damage. In utmost cases, relocation should be considered.

REFERENCES

Bezuidenhout, C.A., and Enslin, J.F. (1969). Surface Subsidence and Sinkholes in the Dolomitic area of the Far West Rand, Transvaal,Republic of South Africa." Proc Int. Symp on Land Subsidence, Tokyo, Government Printer, Pretoria, pp8.

Buttrick, D.B. and Van Schalkwyk, A. 1995. The method of scenario supposition for stability evaluation of sites on dolomitic land in South Africa. Journal of South Africa Institution of Civil Engineers

DWA. (2006). Ramonnedi Wellfield Recharge Feasibility Study. Unpublished report, Groundwater Division.

Godirilwe, J., Ntibinyane, O., & Seiphemo, O. (2017). Investigation on the causes of ground fissures in kgwakgwe wellfield (Unpublished report). Botswana Geoscience Institute. Botswana.

Jennings, J.E., Brink, A.B.A., Louw, A., Gowan, G.D 1965. Sinkholes and subsidences in the Transvaal dolomite of South Arica. In; Proc 6th International conference of soil Mech. And found. Eng., Montreal, pp 51-54, 1965.

Laletsang, K., Moffat, L., Montshiwa, B. (2013). Seismic Reflection, Refraction, and Ground Penetrating Radar Imaging (GPR) to Investigate Cracking of the Road Surface at Chainage 17 km on the Boatle-Mankgodi Road. Department of Roads, Ministry of Teansport and Communication.
Laletsang, K., & Moffat, L. (2014). Mapping Spontaneous Ground Fissures using Seismic Refraction, Reflection, and Ground Penetrating Radar in the Letlhakeng Area, Kweneng District, Botswana. J Geol Geosci 3:175. doi:10.4172/2329-6755.1000175

Lekula, M. (2019). Multiple data sources and integrated hydrological modelling for groundwater assessment in the Central Kalahari Basin (Doctoral thesis). University of Twente, Netherlands.

Lund, W. (2016). Guideline for Evaluation of Land Subsidence and Earth-Fissures Hazards in Utah, Guidelines for investigating geologic hazards and preparing engineering-geology reports

Oosthuizen, A.C. and Richardson, S. (2011). Sinkholes and subsidence in South Africa. Council for Geoscience. South Africa

Prokopovich, N.P. (1986). Classification of land subsidence by origin.Land subsidence. Proc. 3rd symposium, Venice, 1984.

Ramaselaga, M. (2012). GPR report on Lobatse Sinkhole. (Unpublished report). Department of Geological survey.

Rahnema, H., & Mirassi, S. (2016). Study of land subsidence around the city of Shiraz. Scientia Iranica. Transaction A, Civil Engineering, 23(3), p.882.

Richardson, S. (2013). Sinkhole and subsidence record in the chuniespoort group of dolomite,Gauteng,South Africa (masters'thesis).University of Pretoria.Pretoria.South Africa.

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