Reconstructing Historical Mine Water Management Practices for a Portion of the East Rand Gold Field, South Africa Using Long-Term Map and Image Time Series

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Abstract

Gold and uranium have been extracted from the conglomerates of the Witwatersrand since the late 19th Century. The development of the mining industry, its related industries and the economic development which followed transformed the open farmland which had existed before mining into a highly urbanised and industrialised area, with a population of over 10 million people. While underground gold mining continues from rocks of the Witwatersrand Supergroup to the east, west and south of Johannesburg, formal mining ceased in the original three goldfields, the West Rand, Central Rand and East Rand, when the last mine stopped dewatering in 2010. Water inflows have been a challenge to mining since the early days, but in recent years, the rising water levels and consequent risk of pollution has received considerable attention. Historical and modern spatial data, covering more than a century of mining has been compiled and used to investigate the hydrological evolution of a portion of the East Rand Goldfield, too unravel the engineering measures which were used to better manage water in the mining areas and to develop recommendations for improved water management in the future.

Keywords: time series, spatial data, mine hydrology, Witwatersrand, East Rand

Introduction

History of gold mining in the Witwatersrand

Gold was discovered in South Africa's Witwatersrand – the area centred around what is now the cities of Johannesburg, Ehkurhuleni and Mogale City – in 1886. Mines developed rapidly along the strike of the outcropping Witwatersrand Supergroup conglomerates, with three main goldfields, the West Rand, Central Rand and East Rand, developing, separated by geological features referred to as the Witpoortjie Gap and Boksburg Gap, respectively. Ultimately, these three goldfields would extend along more than 100km along strike, accessing the outcropping Witwatersrand rocks in all three goldfields as well as the sub-outcrops below younger cover rocks in parts of the East Rand goldfield.

These three goldfields, along with other areas where the Witwatersrand strata are mined to the west, south west and east of the original mining areas, have produced approximately half of all the gold ever mined (Gold Wage Negotiations 2015). Figure 1 shows the contribution of different gold producing areas to world production in 1930, with the Transvaal contribution coming largely from the Witwatersrand. Multiple gold- and uranium-bearing conglomerate layers made up the total resource in these areas.

Due to practical considerations such as ventilation, access to remote areas of the workings, pumping of water and safety considerations, the mines within each goldfield are all interconnected at depth. This facilitated mining while all mines were operational, but led to problems when mines started to close. Mine closure was generally not managed with consideration of all impacts, in particular the potential of water entering one mine to flood neighbouring mines. Because of this, as underground mines started to close, the water levels within the closed mines would rise to the level of interconnection with an adjacent mine and then start to flow to that mine, increasing the volume which the remaining mines needed to pump. Over time, the burden of pumping became too onerous for the remaining mines, hastening their eventual closures.

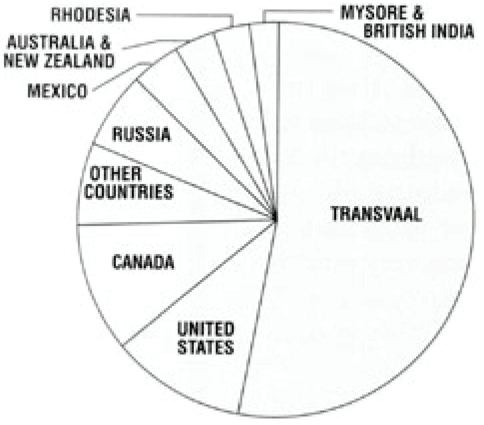

Figure 1 World gold production in 1930 (Potenza et al. 1996)

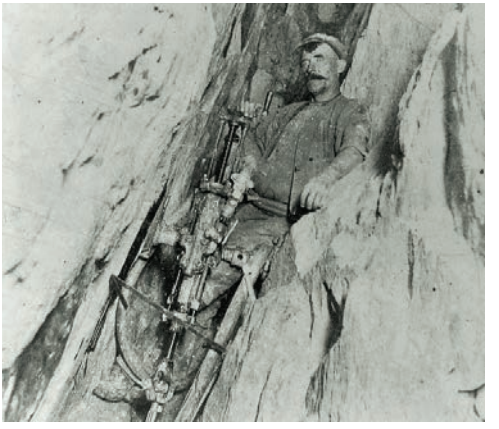

Figure 2 Steeply dipping stope in an early Witwatersrand underground mining operation (Ball 2015)

In 2010 the pumps at the Grootvlei Mine in South Africa's East Rand gold field were switched off, allowing the interconnected mine workings of the gold field to flood. This necessitated the construction, by the South African State, of expensive pump-and-treat infrastructure to maintain a safe water level in the underground workings and reduce the impact of the discharge of mine water to the surface water environment. In parallel to this process, efforts are underway to reduce the seepage of surface water to the underground mines to limit the cost of pumping and treating mine water.

Spatial development around the Witwatersrand mines

From the outcrops, the conglomerate layers dip to the south, with very steep dips in some areas (Fig 2). This necessitated development to great depths, with the mines becoming the deepest in the world by the early 20th century, and led to a pattern of development, with urban development to the north of the outrop, extending along the mining belt to the west and east from Johannesburg. A subsidence-prone zone to the south of the outcrop has been left largely undeveloped, with the exception of some tailings storage facilities in this area. To the south of this zone, additional urban development, including the southern suburbs of Johannesburg and the township Soweto developed.

The Witwatersrand (meaning "ridge of white waters" in Afrikaans) refers to the ridge defined by quartzite layers which lie stratigraphically below the gold-bearing conglomerates. This ridge acts as a continental watershed, with the main drainage direction to the south, crossing the mining belt to the south. In parts of Johannesburg, an east-west drainage direction is also present.

Mine water management in the Witwatersrand

Water inflows have been an ongoing problem in the Witwatersrand's gold mines, back to the earliest days of mining. Scott (1995) reports that acid mine drainage was well known as early as 1903, with many later references to the problem (e.g. Hocking 1986). Scott (1995) also describes the construction of canals to carry surface water over the undermined zone, thereby reducing the ingress of water to the underground workings, in at least two locations in the Central Rand. The issue of acid mine drainage in the Witwatersrand rose to prominence around the time that the last mines were closing and the prevention of ingress was highlighted in a report to a high-level government committee appointed to address this issue (Coetzee et al. 2011). This report recommended the installation of pump-and-treat systems to maintain environmentally safe water levels in the underground workings while, inter-alia, developing and implementing measures to reduce ingress to the underground mine workings.

In addition to pumping water from the workings, the early miners developed extensive surface infrastructure to carry water over their shallow workings, reducing the volume to be pumped. Unfortunately, many of the detailed records related to this infrastructure are no longer accessible, although the remains to these structures can be identified in the field in some areas.

Time series analysis

Time series analysis is commonly carried out on spatial data sets. This may be quantitative, using measured or calculated quantities such as reflectance, vegetation indices etc. For this study, a qualitative approach has been followed due to the length of time over which changes need to be detected – more than 100 years – and the variety of spatial data available.

Study area: the East Rand outcrop zone

Background studies on mine water ingress (Esterhuyse et al. 2008) have identified a zone in the northern part of the East Rand Goldfield where the gold-bearing Witwatersrand strata outcrop (Fig 3 a) and were mined from the surface to considerable depth.

Analysis of historical spatial information

A collection of spatial information has been assembled, which has been used to attempt to reconstruct a hydrological history of the area. This includes geological and topographic maps, aerial photographs, satellite images and underground mine plans. A limited set of maps is presented (Figs 3, 4 and 5). Within this area, a number of areas of surface water accumulation have been identified, which were canalised during the period of active mining (Fig 3 b and Fig 4a).

An important feature in this area is an old clay quarry, where brick clay was mined from the younger Karoo Supergroup cover (showing in grey on Fig 3 a). On the 1939 topographic map (Fig 3 b), this is marked as Steenmakery (Afrikaans for brickworks) (in the eastern portion of the map, south of the railway line. The Main Reef sub-outcrops here below the Karoo cover and was mined via an incline shaft. By 1953 (Fig 4 a), an unvegetated area is seen at this point, while con-

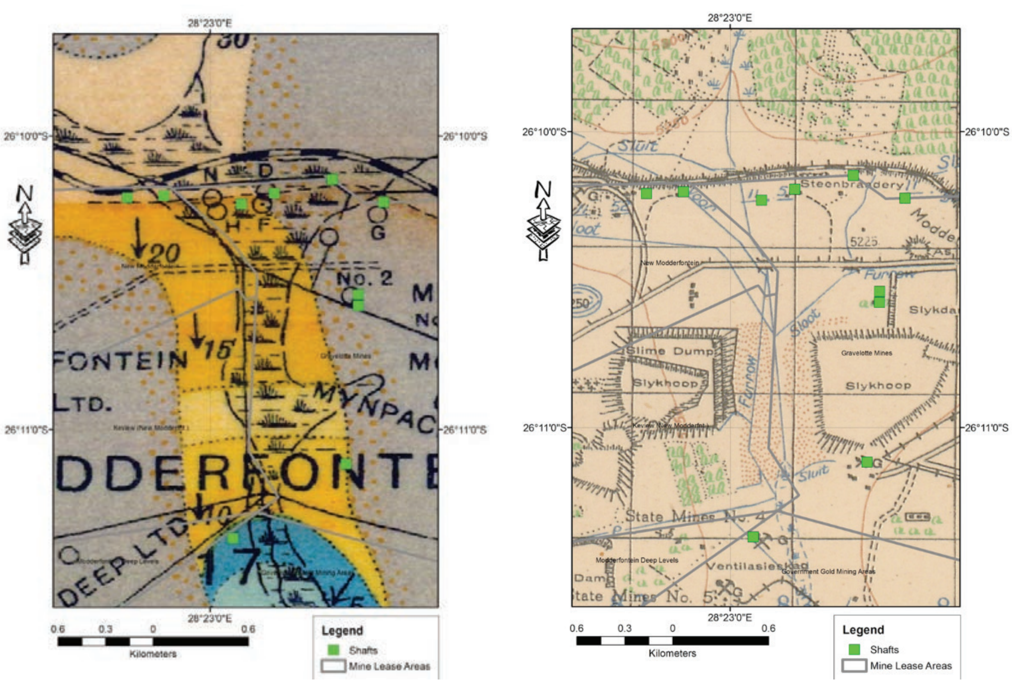

Figure 3 a. Geological map from 1916 (Mellor 1916), showing an area of wetland development, perpendicular to the strike of the Witwatersrand strata (orange colour with the Main Reef showing by a dashed line immediately south of the railway. b. Extract from a topographic map of the same area in 1939, showing the development of canals, conveying water across the mining area (south of the Main Reef outcrop). Identified mine shafts shown as green blocks.

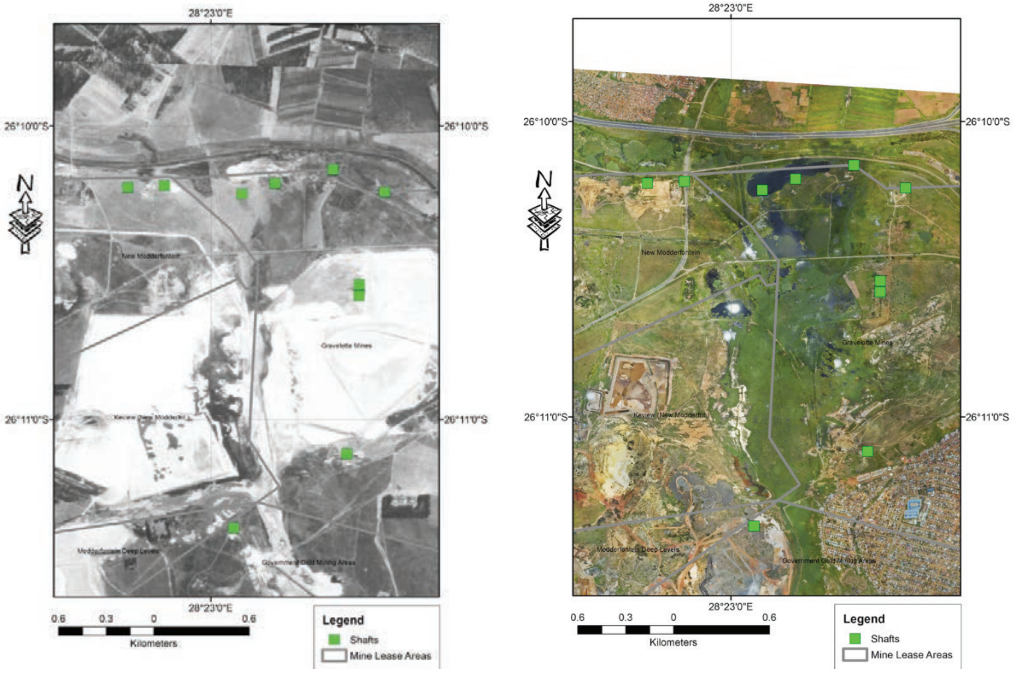

Figure 4 a. Aerial photograph of the study area from 1953. b. Colour aerial photograph from 2016.

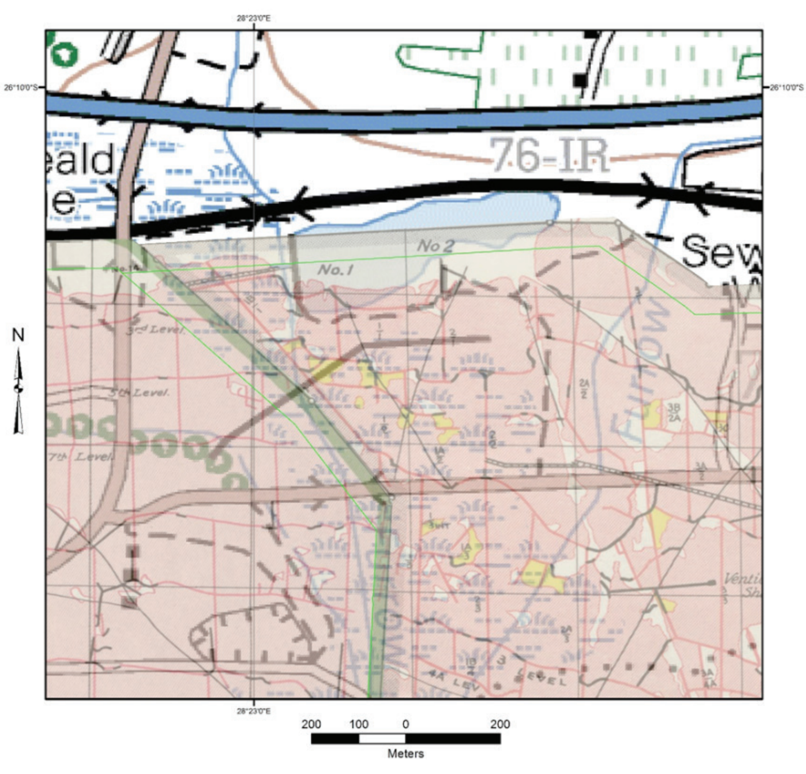

Figure 5 The flooded clay quarry at Modderbee, from a topographic map from 2010, with a plan of underground mine workings (mined out areas in pink). Note the positions of two shafts (shown as No.1 and No.2, relative to the flooded area).

temporary topographic maps show this as a quarry. Now, with underground gold mining having ceased in this area, and the clay quarry having closed, the quarry is flooded, while the canals have degraded to the point where the undermined zone is now covered by shallow lakes and wetlands (Fig 4 b and Fig 5).

This analysis can then be incorporated with other information, such as additional water inputs from upstream urban areas and sewage treatment (approximately 28,000 m^3 is discharged into the are daily by two sewage treatment plants (ERWAT 2018) upstream), topographic information which could assist in hydrological modeling, the locations of known mining features, anecdotal information regarding historical water inrushes related to flooding (Scott 1995, pers. comm. H Trouw, GoldOne) etc.

Discussion

Over more than a century, mining transformed the landscape from what Mellor (1917) described as follows:

"The country possesses many natural attractions. For the greater part of the year it is thickly covered with grass, while even in the face of the rocky escarpments of the north slopes of the Rand, is diversified by numerous evergreen shrubs and trees."

Today, Johannesburg and the surrounding towns are an industrial and residential metropolitan area with a population of more than 10 million people. This has led to substantial increases in the amount of run-off and discharged water entering the surface water environment, particularly as most of the water used in the domestic and industrial sectors is sourced from outside the local catchments, but discharged into local streams and rivers after use and treatment. This increased volume of surface water is believed to contribute to the ingress of water to the underground mine workings.

Conclusion

A spatial time-series dating back to 1916, comprising geological maps, topographic maps, aerial photographs, satellite images and mine plans was assembled with the objective of unravelling the history of mine water management structures constructed over the past century. This has allowed the reconstruction of historical surface hydrology as the cities and towns in the area grew, showed how mining developed and how surface water was diverted away from undermined areas and how, as mines closed, this infrastructure fell into disrepair. Understanding the historical measures used to reduce water ingress to the underground mines while they were still operating, it has been possible to recommend the reconstruction of some infrastructure to limit the costs of water management in this area in the future.

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