HYDROGEOLOGY

Urban vadose zone: The hidden water cycle beneath our cities

The hidden world beneath our cities is constantly reshaped by urban development, influencing groundwater recharge, contaminant movement and infrastructure stability. Recent Water Research Commission (WRC) funded research reveals why understanding the urban vadose zone may be one of the most important steps towards securing South Africa's groundwater future. Article by Dr Yazeed van Wyk


Every year, South African municipalities lose billions of litres of treated drinking water through leaking infrastructure. These losses place enormous pressure on already strained municipal finances, reducing the revenue available for maintaining ageing infrastructure and investing in water services. Yet from a hydrogeological perspective, the story does not end once that water escapes a pipeline. It becomes part of the urban subsurface, infiltrating soils and fractured rock, mixing with natural recharge and interacting with the geology beneath our cities. In doing so, it may raise groundwater levels, mobilise contaminants, weaken foundations or even contribute to sinkhole formation. What begins as an infrastructure problem ultimately becomes a groundwater problem.

Few components of the water cycle are as overlooked as the vadose zone. Situated between the land surface and the groundwater table, this unsaturated layer is where every drop of rain destined to become groundwater must first travel. Although unfamiliar outside specialist circles, the vadose zone is increasingly recognised as playing a fundamental role in protecting water resources, maintaining resilient infrastructure and sustaining the ecosystem services upon which society depends. It is here that water is stored, redistributed and, in many cases, naturally filtered before reaching an aquifer. It is also where anthropogenic activities leave their first and often most enduring imprint on the subsurface.

As pressures on land and water resources continue to grow, understanding the urban subsurface has become an international research priority. Urbanisation, climate variability, changing land use and contaminants of emerging concern all interact within the vadose zone, influencing how water moves through the ground and ultimately determining the quality and quantity of groundwater available for future use.

Recognising the importance of these processes, the WRC funded the recently completed study titled *Framework for natural and anthropogenic changes to the urban vadose zone* (**WRC report no. TT 954/1/25**). The study demonstrates that urban development does far more than replace natural landscapes with roads and buildings. In doing so, it fundamentally reorganises the movement of water beneath the surface, altering recharge pathways, contaminant transport and the interactions between engineered infrastructure and the natural subsurface environment.

Perhaps the most important insight emerging from the research is that cities do not simply consume water. They reshape the urban water cycle itself.

The common perception is that urbanisation reduces groundwater recharge because concrete and asphalt seal the land surface. While this is partly true, the reality is considerably more complex. As cities expand, natural recharge processes are increasingly supplemented and reshaped by anthropogenic recharge generated through leaking infrastructure, stormwater systems and other engineered pathways. Roads redirect runoff, stormwater systems concentrate infiltration, leaking water mains create unintended artificial recharge and ageing sewer networks introduce entirely new contaminant pathways. Quarries, excavations, basements, buried services and irrigated green spaces further modify the movement of water beneath our cities. Rather than simply reducing groundwater recharge, urban development redistributes where, when and how recharge occurs, fundamentally rewriting the urban water cycle.

This shift in perspective has important implications for groundwater management. Traditionally, hydrogeological investigations have focused on the aquifer itself in terms of how much groundwater is available, where it occurs and whether it can sustain future abstraction. These remain essential questions. However, a growing body of research shows that the quality and quantity of groundwater are determined long before water reaches the water table. The journey through the vadose zone influences how much recharge ultimately reaches an aquifer, how quickly contaminants move through the subsurface and how resilient groundwater resources remain under increasing environmental pressure.

Leaking municipal infrastructure provides one of the clearest examples of this hidden water cycle. For municipal engineers, a leaking water main represents wasted treated water and lost revenue. For hydrogeologists, however, it represents an unintended recharge experiment. Water that was intended to remain within the distribution network instead moves through soil, weathered rock and fractured geological formations. Where sewer networks leak, the concern extends even further. Nutrients, pathogens, pharmaceutical residues and other contaminants may migrate through the vadose zone towards groundwater. Depending on the local geology and the presence of preferential flow pathways, these contaminants may be retained, transformed or transported over considerable distances before eventually reaching an aquifer.

For a country that is placing increasing emphasis on groundwater as a strategic component of long-term water security, these findings carry an important message. The recently announced National Water Action Plan includes proposals to expand groundwater development through the drilling of additional boreholes to serve approximately 250 000 households over the next two years. While this represents an important investment in water security, groundwater development cannot simply be measured by the number of boreholes drilled. Just as South Africa recognises the importance of protecting its Strategic Water Source Areas for surface water, safeguarding groundwater recharge areas is equally important for ensuring the long-term sustainability of our aquifers. Protecting groundwater therefore begins long before water reaches the aquifer. It begins with understanding the processes occurring within the vadose zone.

Fortunately, the scientific knowledge required to address these challenges already exists. Hydrogeologists, engineering geologists, water-quality scientists, geotechnical engineers and municipal engineers have developed the expertise and technical know-how needed to investigate groundwater recharge, contaminant transport and subsurface flow. The challenge is seldom a lack of scientific understanding. More often, it lies in bringing these different disciplines together when planning, maintaining and expanding urban infrastructure.

Cities are complex systems, and so too is the ground beneath them. Roads, pipelines, stormwater systems, buildings and groundwater are often planned and managed separately, despite interacting continuously below the surface. Recognising these connections allows problems to be anticipated before they become costly failures, including groundwater contamination, infrastructure damage and rising groundwater levels.

Much of what happens beneath our cities remains invisible. Water may migrate through fractures for years before its effects become apparent. Contaminants may move unnoticed through the subsurface long before they are detected in a monitoring borehole. Yet these hidden processes are already shaping the resilience of South Africa's cities and the security of the groundwater resources on which millions of people increasingly depend.

Understanding the urban vadose zone requires a shift in how we think about groundwater. Aquifers cannot be viewed in isolation from the subsurface processes that sustain them. Cities have transformed the landscape above ground, and research increasingly shows that they have transformed the water cycle below it as well. As South Africa increasingly turns to groundwater to strengthen water security, protecting aquifers cannot begin at the borehole. It begins by protecting the recharge environment that sustains them.

To download the report, ***Framework for natural and anthropogenic changes to the urban vadose zone*** (**WRC report no. TT 954/1/25**), visit: https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/TT%20954%20final%20web.pdf