Irrigated agriculture

Monitoring soil salinity and waterlogging using satellite images

The high cost of measuring waterlogging and salt-affected soils, as well as inconsistencies in data collection and reporting methods, have resulted in incomplete and often contradictory information on the extent and distribution of salt-affected and waterlogged soils. A new study, funded by the Water Research Commission (WRC) and led by the Agricultural Research Commission (ARC) and Stellenbosch University, examined the potential of various data sources and techniques for monitoring the affected areas.

Karen Grobler reports.

All photographs courtesy Agricultural Research Council

The consequences of incorrect management or incorrect selection of irrigation areas can be disastrous, causing irrigation areas to become waterlogged and/or salt-affected, thus making them unfit for continued sustainable irrigation. It is clear from available information that the extent of degradation varies considerably between irrigation schemes in South Africa and also over time within the same irrigation scheme.

Since the late 1980s no national effort has been made to determine the extent of waterlogging and salt accumulation across irrigation schemes in South Africa. Indications are that soil and water quality are declining and these problems are in fact escalating. Quantifying the extent of waterlogging and salt accumulation is crucial to identify soils for drainage and reclamation.

Traditionally, soil salinity has been measured by collecting soil samples on-site for analysis. However, these methods are time-consuming and costly since dense sampling is required, and remote-sensing data and techniques are more efficient and cost-effective.

A recently completed WRC project by researchers from the ARC and Stellenbosch University sought to determine the

The Breede River valley was one of the study areas. Here salt accumulation is evident due to waterlogging.

potential of various data sources and techniques for monitoring waterlogging and salt accumulation. The purpose of this study was to develop a method to detect potential areas of salt accumulation or waterlogging so that in-field monitoring can be performed.

Various data sources and methodologies were investigated, which included:

- land cover mapping;
- bare soil analysis (i.e. direct approach);
- vegetation monitoring (i.e. indirect approach)
- terrain analysis;
- within-field anomaly detection; and
- decision tree analysis.

In developing a suitable methodology, the researchers applied the various data sources and techniques and compared them to reference data to determine their potential.

The researchers applied the techniques within three main strategies:

1. Using a **direct remote-sensing** approach to detect salt accumulation. Researchers used a satellite image with a very high spatial and spectral resolution to investigate the relationship between known affected areas – as determined by electrical conductivity (EC) measurements – and a range of image features.

2. Using an **indirect remote-sensing** approach to monitor salinity levels by investigating vegetation response to saline conditions. Two different data sources were evaluated in two different areas.

   The first series of experiments used a very high resolution satellite image (WorldView-2 satellite imagery) to detect changes in vegetation response within a lucerne field, while the second series of experiments used high resolution images (SPOT-5 imagery). Two dissimilar irrigation schemes – Vaalharts and Breede River – were used, to determine how the techniques are influenced by variations in how different types of crops respond to saline conditions.

3. Investigating the relationship between **terrain data** and waterlogging and salt accumulation. Statistical analyses were done to find continuous relationships between terrain features derived from 3D representations of the terrain's surface (digital elevation models).

Each technique was assessed in terms of its accuracy to find a solution for quantifying and monitoring waterlogging and salt accumulation at a national level.

Field verifications of the various satellite images were done at nine irrigation schemes – Vaalharts, Loskop (Olifants River), Vredendal (Olifants River), Makhathini, Sundays River, Tugela River, Limpopo River, Douglas (Vaal and Orange River) and Breede River.

Soil samples were taken at the observation points for analysis and quantification of the salt content. In addition, historical soil maps and reports were also used to identify problematic areas and to compare the change in salt-affected and waterlogged soils over time.

Bare soil analysis

For the direct remote-sensing approach a WV-2 satellite image was used as it had the highest possible spatial and spectral resolution available at the time of the analysis. Although such imagery is too expensive it helped to establish a "best scenario" option. Researchers could also compare how less expensive imagery might perform.

Eye in the sky – learn the lingo

- **Remote sensing:** The science of obtaining information about objects or areas from a distance, typically from aircraft or satellites.
- **World View-2 satellite:** WorldView-2 (WV-2), launched in October 2009, is a high-resolution, multispectral commercial satellite, owned by DigitalGlobe. Operating at an altitude of 770 km, WorldView-2 provides black and white (panchromatic) and colour (multispectral) digital imagery.
- **SPOT-5 satellite:** SPOT-5 is a high resolution satellite that was launched in 2002. It is owned and operated by Airbus Defence and Space and collects image data. The satellite captures both black and white and colour digital imagery. SPOT-5 was decommissioned in 2015.
- **Spatial resolution:** The pixel size of an image representing the size of the surface area (i.e. m^2) being measured on the ground, determined by the sensors' instantaneous field of view.
- **Spectral resolution:** The wavelength interval size and number of intervals that the sensor is measuring.
- **Temporal resolution:** The amount of time (e.g. days) that passes between imagery collection periods for a given surface location.

Waterlogging is often linked to the incorrect application of irrigation.

Researchers found a number of significant relationships between image features and salt accumulation. However, the use of satellite imagery was found to be unreliable as it grossly overestimated salt accumulation. This was attributed to the inconsistencies in the visual appearance of salt-affected soils as in many cases there was no visible evidence of salt accumulation.

Another factor that complicates the detection of salt accumulation when bare soils are observed is the soil disturbance caused by actions such as ploughing, that can alter the soil surface. But, the main limitation of this approach is that a small proportion of fields in irrigation schemes are bare at any given time. The implication is that multiple analyses will be required to map an entire irrigation scheme, which will be costly.

Vegetation monitoring

The indirect remote-sensing approach was evaluated in the Vaalharts and Breede River irrigation schemes. A satellite image of a lucerne field at Vaalharts was used for evaluating vegetation response to saline conditions.

Several experiments were also done to investigate the effect of reduced spatial and spectral resolution, testing the hypothesis that very high spatial resolution is required for monitoring waterlogging and salt accumulation.

The results showed that there are significant and strong relationships between electrical conductivity and several features considered. Generally the strength of these relationships diminished as the spatial resolution was reduced.

The researchers concluded that the high cost of WV-2 imagery does not make it a viable option. The result shows that slightly lower resolution imagery might produce comparable results.

As crops differ in their response to saline conditions, an additional series of experiments was done to investigate how these variations will affect the results. These experiments were done in the Vaalharts and Breede River study areas using slightly lower resolution satellite imagery (SPOT-5).

It was found that the spectral response of affected crops differed considerably between the two study areas, which tended to produce many false positives.

The researchers recommended that various factors have to be considered when selecting a specific source of satellite imagery for a classification project. The spatial, spectral and temporal resolutions are important factors, as is cost.

Terrain analysis

The final set of experiments investigated the capability of elevation data to model salt accumulation. Vaalharts and Breede River were again chosen as the study areas and various elevation models, derived from aerial photography, were used as primary data sources. However, the researchers concluded that the use of elevation data is ineffective and unreliable. Most of the methods evaluated either underestimated or overestimated salt accumulation.

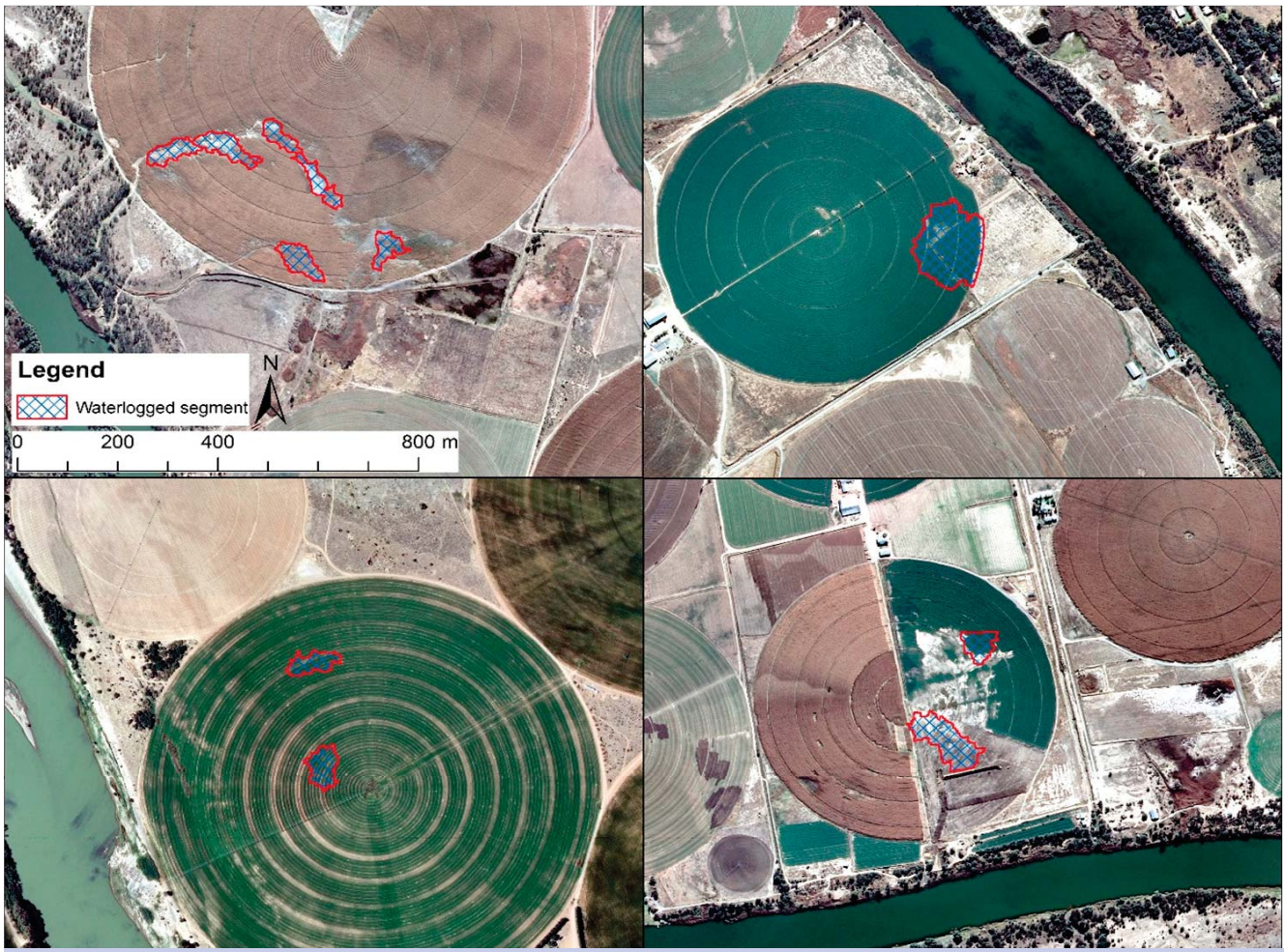
Within-field anomaly detection

The within-field anomaly detection (WFAD) method was used to produce maps of areas that were likely to be affected. This technique is based on the principle that in many cases dissimilar areas indicate waterlogging and salt accumulation. Affected areas are seen as spectrally different compared to the rest of a field, either because of a reduction in biomass or due to specific species of vegetation occurring in fallow fields.

The researchers found that although WFAD is very successful in identifying salt-affected and waterlogged areas, its main limitation is that it cannot discriminate such areas from anomalies that are caused by other factors (e.g. drought, flooding, soil compaction, disease, inadequate fertiliser application).

The researchers concluded that the WFAD method is a scoping mechanism that can direct attention to areas that are likely to be affected by salt accumulation and/or waterlogging and recommended that these areas should preferably be visited to investigate the probable causes.

On average, 3,3% of the areas considered were found to be affected and this figure was adjusted to 6,27% to include abandoned fields. If this figure is applied to the 1,5 million hectares under irrigation in South Africa, the area that is



Using various remote sensing techniques it was determined that approximately 94 050 ha of South African farmland is affected by waterlogging and salinisation.

About salt, soil and water

Soil salinity: An excessive accumulation of salts in the soil profile that causes a decline in agricultural productivity.

Waterlogging: The lowering in land productivity through the rise in groundwater close to the soil surface. Waterlogging is linked with secondary salt affected soils, both the result of incorrect irrigation management.

salt-affected and waterlogged on South African irrigation schemes is 94 050 ha.

The answer lies in a combination

The occurrence of salt accumulation and waterlogging in generally small patches in South African irrigation schemes poses unique challenges and will require a robust modelling strategy.

The researchers concluded that none of the methods stood out as being the ultimate solution, with each having some kind of limitation. The direct and indirect remote-sensing approaches show the most promise as they can be applied to high resolution, multispectral satellite imagery.

The researchers emphasised that no model based on remotely sensed data will ever replace in-field monitoring. It is consequently likely that the solution lies not in one technique but in a combination of methods.

The conclusion made in this project is that this science is still in an experimental phase, and great strides still need to be made before such an application can be operational.

The researchers suggested that in order to find the best combination of methods for monitoring waterlogging and salt accumulation, each of the most promising techniques must be evaluated in a South African context to better understand their individual strengths and limitations.

- To access the report, *Methodology for monitoring waterlogging and salt accumulation on selected irrigation schemes in South Africa* (**Report No. TT 648/15**), contact Publications at Tel: (012) 330-0340; Email: orders@wrc.org.za; or Visit: www.wrc.org.za to download a free copy.