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Understanding the spatial distribution of eroded areas in the former rural homelands of South Africa: Comparative evidence from two new non-commercial multispectral sensors

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ABSTRACT

In this study, we determine the most suitable multispectral sensor that can accurately detect and map eroded areas from other land cover types in Sekhukhune rural district, Limpopo Province, South Africa. Specifically, the study tested the ability of multi-date (wet and dry season) Landsat 8 OLI and Sentinel-2 MSI images in detecting and mapping eroded areas. The implementation was done, using a robust non-parametric classification ensemble: Discriminant Analysis (DA). Three sets of analysis were applied (Analysis 1: Spectral bands as independent dataset; Analysis 2: Spectral vegetation indices as independent and Analysis 3: Combined spectral bands and spectral vegetation indices). Overall classification accuracies ranging between 80% to 81.90% for MSI and 75.71%–80.95% for OLI were derived for the wet and dry season, respectively. The integration of spectral bands and spectral vegetation indices showed that Sentinel-2 (OA = 83, 81%), slightly performed better than Landsat 8, with 82, 86%. The use of bands and vegetation indices as independent dataset resulted in slightly weaker results for both sensors. Sentinel-2 MSI bands located in the NIR (0.785–0.900 μm), red edge (0.698–0.785 μm) and SWIR (1.565–2.280 μm) regions were selected as the most optimal for discriminating degraded soils from other land cover types. However, for Landsat 8OLI, only the SWIR (1.560–2.300 μm), NIR (0.845–0.885 μm) region were selected as the best regions. Of the eighteen spectral vegetation indices computed, NDVI and SAVI and SAVI and Global Environmental Monitoring Index (GEMI) were ranked selected as the most suitable for detecting and mapping soil erosion. Additionally, SRTM DEM derived information illustrates that for both sensors eroded areas occur on sites that are 600 m and 900 m of altitude with similar trends observed in both dry and wet season maps. Findings of this work emphasize the importance of free and readily available new generation sensors in continuous landscape-scale soil erosion monitoring. Besides, such information can help to identify hotspots and potentially vulnerable areas, as well as aid in developing possible control and mitigation measures.

1. Introduction

Soil plays a vital role in many economies of the world, particularly in developing countries, such as South Africa, agriculture and forestry forms the backbone of the economy (Department Of Agriculture Forestry and Fisheries, 2015). A review on the outlook of Agriculture in South Africa by the Department of Agriculture Forestry and Fisheries (2010) shows that agriculture accounts for approximately 15.2% of the country's Gross Domestic Product (GDP). Currently, the sector consisting of 82% (100 million hectares) of the South African land area whereas, in developed countries like Scotland, Europe, 79% of the land area is attributed to agriculture, accounting for 1.8% of the GDP and directly employing over 25,000 people (Scottish Environment Protection Agency, 2001). Despite their economic importance, soils in most developing countries are subject to continuous deterioration due to poor land management practices in place (Ighodaro et al., 2013), leading to severe soil degradation at a phenomenal rate (Pretorius, 1998; Garland et al., 2000; Le Roux et al., 2007). For example, in South Africa over 70% of the land is affected by soil erosion (Le Roux et al., 2007), with an estimated occurrence rate of 8–30 times faster than the rate of regeneration (Baade et al., 2012, Seutloali et al., 2017). Human activities like land clearing for farming, deforestation, overgrazing, or land abandonment coupled with climate change, accelerate the rate of land degradation (Alatorre and Beguería, 2009). In addition, the

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Table 1
Landsat 8 OLI and Sentinel-2 MSI spectral characteristics used in this study.

Landsat 8 OLI spectral bands			Sentinel-2 multispectral bands		
Band#	Bandwidth (um)	GSD (m)	Band#	Bandwidth (um)	GSD (m)
1 (Ultra Blue (coastal aerosol))	0.43–0.45	30	1 (costal aerosol)	0.433 – 0.453	60
2 (Blue)	**0.450 – 0.515**	**30**	**2 (blue)**	**0.458 – 0.52**	**10**
3 (Green)	**0.525 – 0.600**	**30**	**3 (green)**	**0.543 – 0.578**	**10**
4 (Red)	**0.630 – 0.680**	**30**	**4 (red)**	**0.650 – 0.698**	**10**
5 (NIR)	**0.845 – 0.885**	**30**	**5 (vegetation red edge)**	**0.698 – 0.713**	**20**
6 (SWIR)	**1.560 – 1.660**	**30**	**6 (vegetation red edge)**	**0.733 – 0.748**	**20**
7 (SWIR)	**2.100 – 2.300**	**30**	**7 (vegetation red edge)**	**0.765 – 0.785**	**20**
8 (Panchromatic)	0.500 – 0.680	15	**8 (NIR)**	**0.785 – 0.900**	**10**
9 (Cirrus)	1.36 – 1.38	30	**8a (vegetation red edge)**	**0.855 – 0.815**	**20**
10 (TIRS)	10.60 – 11.19	100	9 (water vapour)	0.930 – 0.950	60
11 (TIRS)	11.50–12051	100	10 (SWIR-Cirrus)	1.365 – 1.385	60
			11 (SWIR)	**1.565 – 1.655**	**20**
			12 (SWIR)	**2.100 – 2.280**	**20**

*Bold represents the bands used in this study.

Table 2
Selected spectral vegetation indices derived from Landsat-8 OLI and Sentinel-2 images applied in the validation of eroded surface mapping.

Parameters	Computation	Reference
Normalized Difference Vegetation Index (NDVI)	$\frac{NIR - RED}{NIR + RED}$	Rouse et al. (1974)
Soil Adjusted Vegetation Index (SAVI)	$\frac{(NIR - RED)}{NIR + RED + 0.5}*(0.5 + 1)$	Huete (1988)
Simple Ratio Index (SRI)	$\frac{NIR}{RED}$	Rouse et al. (1974)
Ratio Vegetation Index (RVI)	$\frac{RED}{NIR}$	Richardson and Wiegand (1977)
Transformed Vegetation Index (TVI)	$\sqrt{\frac{NIR - RED}{NIR + RED}} + 0.5$	Deering et al. (1975)
Modified Soil-adjusted Vegetation Index (MSAVI)2	$((2*(NIR+1)) - (((2*NIR)+1)^2 - 8(NIR\text{-}RED))^{.5})*0.5$	(Qi et al., 1994)
Enhanced Vegetation Index (EVI)	$\frac{NIR - RED}{NIR + 6 * RED - 7.5 * BLUE + 1}$	Huete et al. (1999)
Normalized Difference Water Index (NDWI)	$\frac{(GREEN \# XPS \# ndash; NIR)}{(GREEN + NIR)}$	McFeeters (1996)
Normalized Difference Water Index (NDWI)	$\frac{(NIR - SWIR2)}{(NIR + SWIR2)}$	Gao (1996)
Renormalized Difference Index (RDI)	$\frac{(NIR * 1 - RED)}{(NIR * 1 + RED)^{0.5}}$	Roujean and Breon (1995)
Normalized Ratio Vegetation Index (NRVI)	$\frac{\left(\frac{RED}{NIR} \# XPS \# ndash; 1\right)}{\left(\frac{RED}{NIR} + 1\right)}$	Baret and Guyot (1991)
Visible Atmospherically Resistant Index (VARI)	$\frac{(GREEN - RED)}{(GREEN + RED - BLUE)}$	Gitelson et al. (2002)
Visible Green Index (VGI	$\frac{(GREEN - RED)}{(GREEN + RED)}$	Gitelson et al. (2002)
Green Normalized Difference Vegetation Index (GNDVI)	$\frac{(NIR \# XPS \# ndash; GREEN)}{(NIR + GREEN)}$	Gitelson et al. (1996)
Global Environmental Monitoring Index (GEMI)	$\left(\frac{[2(NIR^2 - RED^2) + 1.5NIR + 0.5 * RED]}{(NIR + RED + 0.5)}\right)*\left(\left(\frac{1 - 0.25\left(\frac{[2(NIR^2 - RED^2) + 1.5NIR + 0.5 * RED]}{(NIR + RED + 0.5)}\right) \# XPS \# ndash; (RED - 0.125)}{(1 - RED)}\right)\right)$	Pinty and Verstraete (1992)
Pigment Specific Simple Ratio (Chlorophyll b) (PSSRb)	$\frac{NIR * 1}{RED}$	Blackburn (1998)
Green Index (GI)	$\frac{NIR}{GREEN} - 1$	Gitelson et al. (2005)
Red Index (RI)	$\frac{NIR}{RED} - 1$	Gitelson et al. (2005)

Table 3
Adopted soil erosion analysis approach.

Analysis stage	Data type	Data source	Details
1	Image spectral information (ISI)	Landsat 8 OLI	6 bands (blue, green, red, NIR, SWIR I & II)
		Sentinel-2 MSI	10 bands (2 (blue, green, red vegetation red edge (I,II & III), NIR, vegetation red edge, SWIR(I & II)
2	Spectral indices (SIs)	OLI	18 Indices (NDVI, SAVI, SRI, RVI, TVI, MSAVI, EVI, NDWI 1, NDWI 2, RDI, NRVI, VARI, VGI, GNDVI, GEMI, PSSRb, GI, RI)
		MSI	18 indices (NDVI, SAVI, SRI, RVI, TVI, MSAVI, EVI, NDWI 1, NDWI 2, RDI, NRVI, VARI, VGI, GNDVI, GEMI, PSSRb, GI, RI)
3	ISI + SIs	OLI	(6 bands) + (18 indices)
		MSI	(10 bands) + (18 indices)