

Assessment of Drought Impact on Surface Water in the Mockes Dam of the Free State, South Africa, Using Remote Sensing Techniques



Saheed Oke  and Silent Ruzvidzo

Abstract The Free State province in South Africa is persistently affected by droughts leading to severe impacts on water bodies. In this study, remote sensing images from Landsat 8 were used to monitor the area covered with water and the density of vegetation around the Mockes dam area during the 2016 drought year in the Free State, South Africa. Short Wave InfraRed images (SWIR), together with Normalized Difference Water Index (NDWI) on the EOS (Earth Observation Satellite) hydrological models, were used to estimate the surface water in the Mockes dam over the four seasons of summer, autumn, winter and spring in 2016. The results indicated a decline in surface water in the Mockes dam between the seasons, as the year progressed and the drought intensified. Additional water was given to the Mockes dam from the Rustfontein dam in winter but the volumes also declined in spring. Throughout the summer, autumn and winter seasons, the vegetation surrounding the Mockes dam was severely stressed due to the unavailability of moisture from the soil.

Keywords Drought · Mockes dam · Remote sensing · Shortwave infrared · NDWI

1 Introduction

South Africa receives an average annual rainfall of 464 mm, well below the global average of 860 mm per annum [1]. Like most parts of South Africa, the Free State (FS) region is arid, with an annual mean rainfall of 407 mm [1]. The province is persistently affected by droughts leading to severe impacts on water availability, farm production, livestock holdings, mining and industry [2]. The consistent monitoring

S. Oke (✉)

Department of Civil Engineering, Central University of Technology, Bloemfontein 9300, South Africa

e-mail: soke@cut.ac.za

S. Ruzvidzo

Department of Life Sciences, Central University of Technology, Bloemfontein 9300, South Africa

© The Editor(s) (if applicable) and The Author(s), under exclusive license

1769

to Springer Nature Switzerland AG 2021

M. Ksibi et al. (eds.), *Recent Advances in Environmental Science*

from the *Euro-Mediterranean and Surrounding Regions (2nd Edition)*, Environmental Science and Engineering, https://doi.org/10.1007/978-3-030-51210-1_280

and management of water bodies such as dams, lakes and rivers is important for the livelihood of people, as well as for sustainable economic activities such as agriculture and industry. The South African government declared the FS province a drought disaster area in the 2015/2016 hydrological year. This negatively affected the South African economy as the province plays a crucial role in agriculture as well as having some of the major water reservoirs [3].

AghaKouchak et al. [4] classified drought into four categories including meteorological (lack of rainfall), agricultural (lack of soil moisture), hydrological (deficit in runoff, groundwater or general water storage) and socio-economical (water supply, demand and social response). Remote sensing techniques are among the effective ways of monitoring surface water dynamics. The Normalized Difference Water Index (NDWI) has been effective for the analysis of declining surface water bodies [5] and is reported to relate plant water content with a better response to drought conditions than the Normalized Difference Vegetation Index (NDVI) [6]. Colour intensity and land changes are ways in which NDWI has been used to predict the impact of drought on surface waters [7, 8].

The Mockes dam is located in the FS province in central South Africa. It is situated along the Modder River catchment which supplies water to areas in the city of Bloemfontein, via the Maselspoort Water Treatment Works [2]. The Modder River catchment provides about 60% of the potable water supply of Bloemfontein [9]. With the growing scarcity of potable water in most parts of South Africa, coupled with the persistent droughts plaguing the Southern African region, it is important to consistently monitor strategic water sources such as the Mockes Dam. This study focused on analysing the seasonal effects of drought on the surface water area in the Mockes dam by remote sensing techniques.

2 Materials and Methods

Remotely sensed Landsat 8 images of the Mockes Dam for all four seasons in the year 2016 were acquired on the EOS (Earth Observing System) land viewer website [10]. The choice to utilize the Landsat 8 satellite was made because of its improved radiometric precision which gives rise to a better characterization of land cover images [11]. Images were taken in each of the four seasons for the year 2016. The images had already undergone some pre-processing on radiometric and geometric corrections to remove distortions. The images were further processed through georeferencing to insert the geographical coordinates with respect to the Mockes dam.

The Normalized Difference Water Index (NDWI)—which makes use of the reflected near-infrared radiation and visible green light—was used to provide estimations on the surface water covering the Mockes dam. The NDWI is calculated as follows [10]:

$$\text{NDWI} = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \quad (1)$$

Land cover along the Mockes Dam and Modder River, the primary source of water into the dam, was delineated on the NDWI images. The ability of the EOS system to process images of surface area covered with water was used, together with the delineated areas along with the dam areas, in predicting the surface water in the Mockes Dam.

3 Results

The surface water in the dam area gradually decreased throughout the 2015/2016 year as the drought persisted. In the month of February 2016, the dam surface water covered an estimated area of 462 000 m² (Table 1). This gradually decreased to 389 700 m² of water by the end of May 2016. By August 2016, the drought was so severe that it made the local authorities request additional water from the Department of Water Affairs. The surface water increased its coverage to 1 044 000 m² which amounts to a total volume of approximately 0.954 million m³ as validated by data from the Department of Water Affairs [2, 12]. This water volume is not enough considering that the municipality supplies around 0.2 million m³ of water per day to Bloemfontein residents.

The evidence that the Mockes dam received additional water from the nearby Rustfontein dam can be seen through the severely stressed vegetation surrounding the Mockes Dam and the greater Modder River catchment as shown in the images (a), (b) and (c) of Fig. 1. In November 2016, the surface water in the Modder River was at 547 200 m², an indication that the area might have received some precipitation. The rain also contributed to an increased vegetation coverage from sparse vegetation to moderate vegetation as indicated in image (d) of Fig. 1. Table 1 shows the detailed data of the surface water and seasons as well as vegetation cover. The rainfall validates the vegetation and the NDWI prediction of surface area covered with water. Rainfall decreases with decreasing surface water area and vegetation. No surface water level

Table 1 Estimated impact of drought on the surface water area with validated rainfall and actual surface water volume level (# means no record.)

Season	Month	Surface water area (m ²)	Actual surface water volume (Million m ³)	Rainfall (mm)	Vegetation
Summer	Feb	462,600	#	25.8	Sparse vegetation
Autumn	May	389,700	#	19.2	Sparse vegetation
Winter	Aug	1,044,000	0.954	10.6	Sparse vegetation
Spring	Nov	547,200	#	69.4	Moderate vegetation

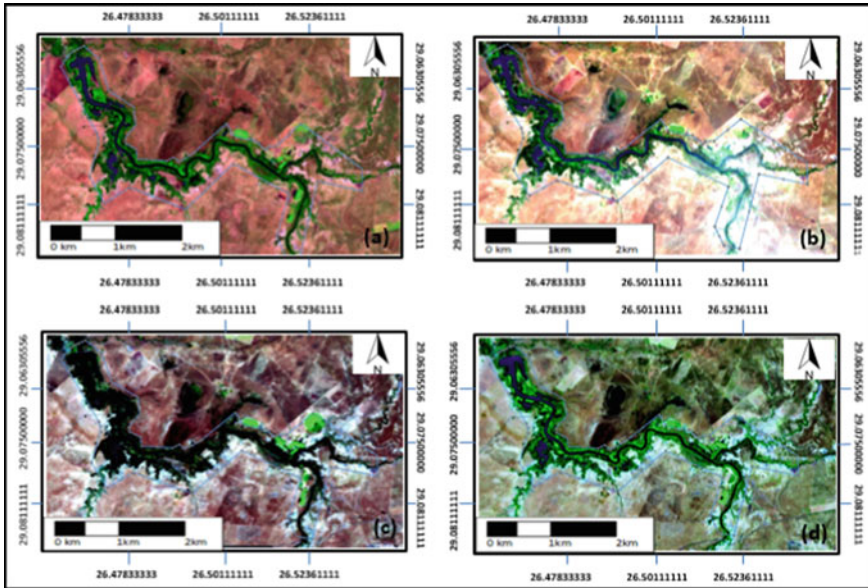


Fig. 1 Shortwave Infrared images of the Mockes dam in the year 2016. The images are in the following order; **a** Summer—Feb, **b** Autumn—May, **c** Winter—Aug, **d** Spring—Nov

values were recorded in Summer, Autumn and Spring because of no or low water volume in the river.

4 Discussion

The summer of the year 2016 had very little surface water as indicated by the NDWI images and confirmed by the surface water level volumes from the Department of Water Affairs. As the seasons of autumn and winter approached, the drought worsened as the water dam levels continued to decline and the surrounding vegetation along the Modder River catchment became further stressed due to a lack of moisture. By the end of winter, the Mangaung Metropolitan Municipality (MMM) authorities managing the dams decided to replenish the water supply for the Mockes dam by using the water from the nearby Rustfontein dam. This helped in raising the Mockes Dam water levels but did not benefit the surrounding vegetation as the water was localized only within the river channel. Moderate amounts of rainfall were received during the end of spring, resulting in a moderate distribution of vegetation across the Modder River catchment.

The study findings indicated that there was some correlation between the surface area of water detected by NDWI and the surface water level volume measured by the Department of Water Affairs. However, further studies are needed to understand the

relationship between NDWI and its effectiveness in estimating water volume. The dimensions of the river or dam depth should be among the factors to consider in such studies when using NDWI for estimating water volume.

5 Conclusions

The study estimated the areas in the Mockes Dam affected by drought in the 2015/2016 season using remote sensing techniques of NDWI. The remote sensing data were validated by rainfall data received in the Mockes area and ground surface water level volume data from the Department of Water Affairs. The 2015/2016 drought season had a significant impact in reducing the surface areas covered with water and the subsequent volume of water in the Mockes Dam. The drought also inflicted a lot of stress on the vegetation cover along the Modder River catchment surrounding the Mockes Dam due to a lack of moisture. The study has shown that the impact of drought on surface water can be effectively monitored with less costly remote sensing techniques.

References

1. Stats SA, Water Management Areas in South Africa, Environmental Economic Accounts Statistics South Africa. Discussion Document Do405.8. (2010).
2. Department of Water Affairs (DWA). Interventions Report for the Large Bulk Water Supply Systems of the Greater Bloemfontein Area. Water Reconciliation Strategy Study for the Large Bulk Water Supply Systems: Greater Bloemfontein Area. DWA Report No. P WMA 14/C520/00/0910/03 (2012).
3. Botai, C.M., Botai, O.J., Dlamini, C.L., Zwane, N.S., Phaduli, E.: Characteristics of Droughts in South Africa: A Case Study of Free State and North West Provinces, pp. 1–2. MDPI, Basel, Switzerland (2016).
4. AghaKouchak, A., Farahmand, A., Melton, F.S., Teixeira, J., Anderson, M.C., Wardlow, B.D., Hain, C.R.: Remote sensing of drought: Progress, challenges and opportunities. *Rev. Geophys.* **53**, 452–480 (2015)
5. Rokni, K., Ahmad, A., Selamat, A., Hazni, S.: Water feature extraction and changes detection using multitemporal landsat imagery. *Remote Sens.* **6**, 4173–4189 (2014)
6. Amalo, F.B., Ma'rufa, U., Permatasari, P.A.: Monitoring 2015 drought in West Java using normalised difference water index (NDWI), *IOP Conf. Ser.: Earth Environ. Sci.* **149**, 012007 (2018)
7. Huang, C., Chen, Y., Zhang, S., Wu, J.: Detecting, extracting, and monitoring surface water from space using optical sensors: a review. *Rev. Geophys.* **56**, 333–360 (2018)
8. Schaffer-Smith, D., Swenson, J.J., Barbaree, B., Reiter, M.E.: Three decades of Landsat-derived spring surface water dynamics in an agricultural wetland mosaic; Implications for migratory shorebirds. *Remote Sens. Environ.* **193**, 180–192 (2017).
9. Koning N.J., Roos J.C. and Grobbelaar J.U. Water quality of the Modder River, South Africa. *African Journal of Aquatic Sciences*, Vol. 25, Issues 1. Pp. 202–210 (2010).
10. EOS Homepage. <https://eos.com/landviewer>, last accessed 2019/05/11

11. United States Geological Survey, https://www.usgs.gov/land-resources/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con, last accessed 2019/06/26.
12. Department of Water Affairs, <https://www.dwa.gov.za/hydrology/Verified/HyData.aspx?Station=C5H003100.00&DataType=Monthly&StartDT=2014-07-01&EndDT=2019-05-09&SiteType=RIV&Format=Old>, last accessed 2019/06/16.