International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Modifying a Drought Early Warning Model Using MODIS Satellite Data

Vijendra K. Boken[1]
Department of Geography and Earth Science, University of Nebraska at Kearney
Kearney, NE 68849, USA
E-mail: bokenv1@unk.edu

C.E. Haque
Natural Resources Institute, University of Manitoba
Winnipeg, Canada R3T 2N2
E-mail: haquece@cc.umanitoba.ca

ABSTRACT: An early warning model had been developed using two variables derived from rainfall data to predict agricultural drought for Jodhpur district of Rajasthan, India. The model explained up to 74.1% of the variation in the pearl millet's yield (i.e., the production per unit area). This model was later modified by including a variable derived from a soil moisture index. In this paper, an approach is described to further improve the model by including a variable derived from the MODerate Imaging Spectroradiometer (MODIS) satellite data. It was found that the 16 day Normalized Difference Vegetation Index (NDVI) derived from the MODIS data acquired during May–June could be a potential variable for further improving the model and drought management.

INTRODUCTION

Droughts occur frequently in the Indian arid zone and cause significant drops in agricultural production. Such droughts are categorized as agricultural droughts. The continuity of these droughts may lead to severe hardships for both humans as well as livestock. Recently, in 2002, India experienced a severe drought that affected more than half of its geographical area affecting 300 million people in 18 states (Samra, 2004).

Although a drought is an integral component of a climatic system and its elimination is rather impossible, a timely planning to deal with drought situations can help mitigate their impacts. In this context, Kumar (1998) developed the drought early warning models, namely, the Intermediate Warning (IW) model and the Final Warning (FW) model for Jodhpur district of Rajasthan located within the Indian arid zone. These drought models used two variables derived from the daily rainfall data and predicted the yield of pearl millet, the staple crop of the Indian arid zone. The variables included the delay in sowing and the number of rainy days in a month. While the IW predicted droughts on September 1, the FW model predicted droughts on October 1.

The IW model was considered more important from a planning point of view because it predicted drought at an early stage of the cropping season. Therefore the IW model was chosen for modification by including a soil moisture index derived from daily rainfall data (Boken, 2008). In this paper, an approach is described to further improve the IW model by including a MODIS data-based variable.

THE INTERMEDIATE WARNING MODEL

The IW model predicted droughts by predicting the pearl millet yield as follows,

$$Y = 56.356 + 22.532\,\mathrm{N} - 6.558\,\mathrm{D} \quad [R^2 = 0.74] \qquad \ldots (1)$$

where Y is the pearl millet yield (kg ha^{-1}), N is the number of rainy days in August, and D is the delay (in days) in sowing of pearl millet; if pearl millet was sown after July 1, it is considered a delay in sowing and D was computed accordingly. If the pearl millet yield was less than the average yield, a drought was said to have occurred. The pearl millet is usually sown in late June/July, with the commencement of the monsoon rains, and is harvested in September/October.

Boken (2008) improved the above model by adding a variable derived from a soil moisture index that includes the soil moisture surplus or deficit on a daily basis during the cropping season. This methodology

[1]Conference speaker

required estimation of the daily crop-water requirement using a crop coefficient and the potential evapotranspiration following a procedure developed by Doorenbos and Pruitt (1977). The predictive power of the modified model increased after the inclusion of the soil moisture index cumulative over the cropping season. The objective of the present study was to further improve the predictive power of the model by using satellite data.

MODIS SATELLITE DATA

Satellite data provide continuous images at a regular interval and hence have been found useful to monitor crop conditions. Among various types of satellite data, the Advanced Very High Resolution Radiometer (AVHRR) data have been widely used for monitoring crop conditions and agricultural droughts (Goward *et al.*, 1991; Anyamba *et al.*, 2005). The major drawback of the AVHRR data, however, is its coarse spatial resolution (~1 km) and therefore its application to small-field-size areas has been restricted. To overcome this problem, the MODIS data with 250 m resolution have been preferred to AVHRR data for monitoring crop conditions agricultural droughts.

DATA USED

The data included the 16 day MODIS-NDVI and the pearl millet yields for Jodhpur district for the period from 2000 to 2005. The MODIS data were downloaded from the Land Processes Distributed Active Archive Centre of the United States Geological Survey (http://lpdaac.usgs.gov/) for different dates during the cropping season. The starting dates for 16 day NDVI included May 25, June 10, June 26, July 12, July 28, August 13, and August 29. The MODIS data were obtained in band 1 (620–670 nm) and band 2 (841–876 nm) with a spatial resolution of 250 m. The yield data for pearl millet were collected from the district office of Jodhpur.

METHODS

Creating a Shape File

MODIS data were imported using a remote sensing software and georeferenced using a rectified map showing *tehsils* (i.e., counties) of Jodhpur district. Subsequestly, a shapefile showing different *tehsils* of Jodhpur district (i.e., Phalodi, Shergarh, Bhopalgarh, Osian, Jodhpur, Luni, and Bilara) was created using a Geographic Information System (GIS) software.

Spatial Analysis

The Spatial Analyst module of the GIS software was used to compute the NDVI value averaged for a *tehsil.* The objective was to examine the relationship between the average NDVI and the pearl millet yield. However, the tehsil-wise data could not be received by the time of writing this paper. Hence the tehsil-based analysis could not be performed.

Relationship between NDVI and Crop Yield

In the absence of the data on pearl millet yield for different *tehsils*, only the district-based analysis could be possible to examine the potential of MODIS-NDVI based variable for inclusion into the IW model. The correlation analysis was done using the MODIS-NDVI and yield data. The coefficient of correlation varied from 0.01 to 0.50 as shown in Table 1.

Table 1: The correlation between the NDVI averaged for the district and the pearl millet yield for the district of Jodhpur, Rajasthan based on the 2000–2005 data

Date	*Coeff. Corr.*	*Date*	*Coeff. Corr.*
May 25	0.50	July 28	0.13
June 10	0.10	August 13	0.13
June 26	0.00	August 29	0.12
July 12	0.22		

DISCUSSIONS

It is evident from Table 1 that the average NDVI for May–June period (May 25–June 9) has the strongest relationship with the pearl millet yield. May–June is usually the time prior to sowing and the soil moisture conditions during this period will influence the time of sowing. Crops sown within the desired time-window are expected to reach an optimum level of yields. Hence the NDVI value prior to sowing could be a potential variable that can be added in the IW model for further improvement. A detailed analysis is required to develop the modified model. The weather and crop data for desired years could not be available in time and hence the modified drought early warning model could not be developed. Besides, the data were available only for a single weather station for the entire district, which is not adequate for the tehsil-based analysis. The data for multiple years and at a higher spatial resolution are required to develop a modified model based on the MODIS data. Use of a crop simulation model (Boken and Shaykewich, 2002; Boken *et al.*, 2008) can also help identify a cropping phase that is most significantly related to crop yield and can help improve the drought model using satellite data.

SUMMARY

MODIS satellite data have the potential to improve the drought early warning model for Jodhpur district. However, weather data with improved spatial resolution are required to develop and test the improved model. Using the modified model, the drought planners in the study area would be able to provide more accurate warning of agricultural drought in the middle of the growing season which, in turn, will allow an effective implementation of drought-mitigating measures.

ACKNOWLEDGEMENTS

The authors thank Dr. N.K. Kalra of the State Remote Sensing Application Centre, Jodhpur, Rajasthan for collecting and sending the yield data for pearl millet.

REFERENCES

Anyamba, A., Tucker, C.J., Huete, A.R. and Boken, V.K. (2005). "Monitoring drought using coarse-resolution polar-orbiting satellite data". In "Monitoring and Predicting Agricultural Droughts: A Global Study" edited by V.K. Boken, A.P. Cracknell, and R. L. Heathcote, Oxford University Press, New York, pp. 57–78.

Boken, V.K. (2008). "Improving a drought early warning model for an arid region using a soil moisture index". *Applied Geography* (In Review).

Boken, V.K., Hoogenboom, G., Williams, J.H., Diarra, B., Dione, S. and Easson, G.L. (2008). "Monitoring peanut contamination in Mali (Africa) using the AVHRR satellite data and a crop simulation model". *International Journal of Remote Sensing*, 29(1), 117–129.

Boken, V.K. and Shaykewich, C.F. (2002). "Improving an operational wheat yield model for the Canadian Prairies using phenological-stage-based normalized difference vegetation index". *International Journal of Remote Sensing*, 23 (20), 4157–4170.

Doorenbos, J. and Pruitt, W.O. (1977). *Crop Water Requirement.* Irrigation and Drainage Paper 24, Food and Agriculture Organization, Rome, Italy.

Goward, S.N., Markham, B., Dye, D.G., Dulaney, W. and Yang, J. (1991). "Normalized difference vegetation index measurements from the advanced very high resolution radiometer". *Remote Sensing of Environment*, 35, 257–277.

Kumar, V. (1998). "An early warning system for agricultural drought in an arid region using limited data". *Journal of Arid Environments*, 40(2), 199–209.

Samra, J.S. (2004). "Review and analysis of drought monitoring, declaration, and management in India". Working Paper 84, International Water Management Institute, Colombo, Sri Lanka.