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Potential of Using NOAA-AVHRR Data for Estimating Irrigated Area to Help Solve an Inter-State Water Dispute

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ABSTRACT

The states of Alabama, Florida, and Georgia dispute the apportioning of water from rivers that originate in Georgia and flow through the other two states. Florida and Alabama often claim that Georgia uses more water than its fair share. In order to address such a dispute, an estimation of the total amount of water used for irrigation by different crops is required. Current estimates of irrigated areas are subject to errors because they are based entirely on survey questionnaires. In this paper, the potential of Advanced Very High Resolution Radiometer (AVHRR) on-board the National Oceanic Space Administration (NOAA) satellites is examined for estimating irrigated area. Two indices: a widely used Normalized Difference Vegetation Index (NDVI) and a newer Vegetation Health Index (VHI) were regressed against irrigated area for 1986, 1989, 1992, 1995, and 2000 for selected regions in Georgia (Baker and Mitchell counties, and Seminole and Decatur counties). The average VHI during a period from third week of February to end of September was better related to irrigated area than the corresponding NDVI; R^2 was above 0.80 as opposed to 0.49. It is concluded that the VHI, derived from 3-channel AVHRR data, can be used to estimate irrigated area. By multiplying irrigated area with the application rate, the volume of irrigation used in a state can be determined, which can contribute to the solution of the water dispute.

1. INTRODUCTION

The states of Alabama, Florida, and Georgia currently are locked in a water dispute that relates to apportioning of water from the Alabama, Coosa, and Tallapoosa (ACT), and the Apalachicola, Chattahoochee, and Flint (ACF) rivers (Thomas et al. 2000). These rivers originate in Georgia and flow through Alabama and Florida who often complain that Georgia consumes more water than its fair share.

The first step to solve this inter-state water dispute requires an accurate estimation of the total volume of water used (i.e., water usage) in each state, which is the summation of the water usage in agricultural, municipal, domestic, hydro-electric power, recreational, and industrial sectors. Water usage is metered in every major sector except in agriculture sector which often consumes a significant proportion of the total water usage in a state. Bastiaanssen et al. (2000) reported that 70% of fresh water withdrawal in the world is used for irrigation. In Georgia, agricultural water usage (i.e., irrigation usage) accounts for more than 60 percent of the total water usage in the state. A recent study conducted in Georgia concluded that ground water withdrawals for irrigation might reduce stream aquifer flows in the Flint River basin (Albertson and Torak 2002). Therefore, an accurate estimation of irrigation usage is critical to estimating the total water usage and to addressing the water dispute.

Currently the data on irrigated area are collected by mailing survey questionnaires to farmers every five years (United States Department of Agriculture 1999). The area reported by farmers is subject to errors and there are additional concerns that all surveys are not returned. Therefore, there is a need to improve these estimates. In this paper, an on-going project for estimating irrigation usage in Georgia is briefly described. Subsequently, it is discussed how the NOAA-AVHRR data are related to irrigated area and could be used to estimate the latter for selected regions in Georgia.

In 1998, The College of Agricultural and Environmental Sciences at The University of Georgia initiated a five-year project, referred to as the Agricultural Water Pumping (AWP) project (www.AgWaterPumping.net), to estimate irrigation usage in the state of Georgia (Thomas et al. 1999, 2003). This estimation required data on depth of irrigation (DI) and the corresponding irrigated area for different crops. While data on irrigated area are available, the DI data are not. Under the AWP project, we measured the DI for each representative crop in the state using hour meters. These hour meters were installed at more than 400 randomly selected sites which constitute approximately 2% of the permitted agricultural withdrawals in Georgia. Using geostatistical techniques and the DI data for selected sites, projections for average DI were made for the Flint, Central, and Coastal zones in Georgia (Boken et al. 2002). Most of the traditional row crop agriculture in Georgia is practiced only in these three zones (figure 1).

One can obtain irrigation usage for a crop in a zone by multiplying an average DI for the crop with its irrigated area. Summation of the irrigation usage for all of the crops in a zone provides estimates for total irrigation usage for that zone. The reliability of these estimates however is as good as the data on irrigated area. Unfortunately, the sample set is directed toward sites that are "permitted" to withdraw water, not sites that are actually using water. There is a need to generate more reliable estimates for irrigated areas in order to enhance the reliability of estimates for irrigation usage and thereby to address the water dispute more satisfactorily. In this study, we are exploring the potential of two indices derived from NOAA-AVHRR satellite data for obtaining more reliable estimates for irrigated area.

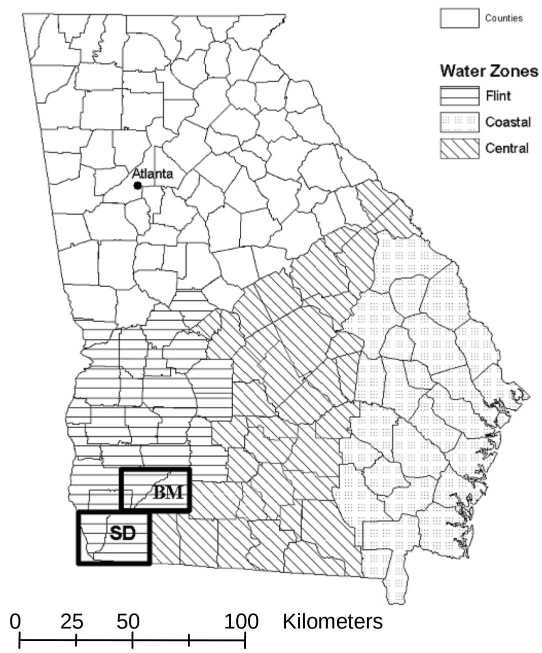

Figure 1. Study regions in Georgia: Baker & Mitchell (BM) Counties and Seminole & Decatur (SD) counties.

2. AVHRR DATA AND ITS INDICES

The AVHRR data are collected in five spectral bands (channels): i) 0.58 - 0.68 µm (Ch1), ii) 0.725 - 1.10 µm (Ch2), iii) 3.55 - 3.93 µm (Ch3), iv) 10.3 - 11.3 µm (Ch4), and iv) 11.5 - 12.5 µm (Ch5). Various indices have been developed using AVHRR data to monitor crop or vegetation conditions over large areas (Tarpely et al. 1984, Tucker et al. 1984, Gallo and Flesch 1989, Kogan 1990, Gutman 1991, Weigand et al. 1991, and Leprieur and Kerr 1996). Out of these indices, the Normalized Difference Vegetation Index i.e., NDVI (du Plessis 1999, Boken and Shaykewich 2002) has been widely used for vegetation monitoring.

2.1 Normalized Difference Vegetation Index

The NDVI is defined as:

$$NDVI = (IR-R) / (IR+R) \qquad [1]$$

where R and IR are the reflectance in Ch1 (i.e. Red) and Ch2 (i.e., Infrared), respectively.

The NDVI is derived from only 2-channel data. Lately, another index that is relatively more complex and is based on 3-channel data of AVHRR has been developed. This index is called Vegetation Health Index i.e., VHI (Unganai and Kogan 1998, Kogan 2001, and Dabrowska-Zielinska et al. 2002).

2.2 Vegetation Health Index

Vegetation conditions depend on both moisture (greenness) and temperature of vegetation. While the NDVI has been found very useful to monitor greenness of vegetation, thermal band (10.3 – 11.3 µm, Ch4 of AVHRR) values can be used as a measure of radiative temperature (Brightness Temperature, BT) of vegetation. Kogan (2001) developed VHI by combining greenness and thermal conditions of vegetation in order to determine its overall health. The VHI is defines as:

VHI = a*MI + (1-a)*TI [2]

where *a* is a coefficient, MI is Moisture Index, and TI is Thermal Index, as defined in the following equations. It is assumed that the contribution of MI and TI in determining vegetation health is equal (i.e., *a* = 0.5).

$$MI = \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})} * 100 \quad [3]$$

$$TI = \frac{(BT_{\max} - BT)}{(BT_{\max} - BT_{\min})} * 100 \quad [4]$$

where $NDVI_{max,}$ $NDVI_{min,}$ BT_{max}, and BT_{min} are the maximum (max) and minimum (min) NDVI and brightness temperature, respectively, over a multi year period (1985-2000, in the present case). Prior to the computation of MI and TI, we processed the AVHRR data using an algorithm explained in detail in Kogan (1997). Here, we briefly describe important steps. First, high frequency noise was completely removed from NDVI and BT annual time series, using a compound median filter. This eliminated erratic temporal variation in NDVI and BT related to cloud, aerosol, non-uniformity of the land surface, geometry of sun and sensor, bi-directional effect, random noise etc. Second, we approximated seasonal cycle and enhanced medium-to-low frequency fluctuations associated with weather variation such as drought or non-drought which continued for several weeks in a row. Finally, we computed maximum and minimum values of NDVI and BT for each pixel over the multiyear period.

3. OBJECTIVE

The NDVI and VHI have capability to monitor crop conditions. The crop conditions depend on the amount of soil moisture available to the crop during the growing season. The source for the soil moisture is either precipitation or irrigation. Due to the spatial and temporal variation in precipitation, the conditions of rain-fed crops vary spatially, which is reflected by VHI (Kogan 2001, and Dabrowska-Zielinska et al. 2002). When crops are irrigated and their soil moisture requirements are completely met, the spatial distribution of their health conditions is rather uniform. Hence, when the proportion of irrigated area increases in a region, it is expected that NDVI and VHI will reflect that change. The overall objective of this study was to examine the relationship between the AVHRR indices (NDVI and VHI) and the irrigated area in selected regions of Georgia. Further we aimed to find out which index was a better candidate to estimate irrigation usage and thereby to contribute to the solution of the inter-state water dispute. We attempted to meet these objectives by analyzing data for selected regions in Georgia.

4. STUDY AREA

The study area included two regions in the state of Georgia. The first region, denoted as BM, encompassed Baker and Mitchell (BM) counties (31.07° to 31.43°N, and 84° to 84.63°W). The second region, denoted as SD, comprised Seminole and Decatur (SD) counties (30.69° to 31.07°N, and 84.37° to 85.01°W) as shown in figure 1. We selected these four counties because the irrigated areas for these counties was among the highest in Georgia. According to the 1997 irrigation survey (United States Department of Agriculture, 1999), the irrigated area was 55239 *ha* for the BM, and 56776 *ha* for the SD region. Irrigated area was the highest (35126 *ha*) for Mitchell County followed by Decatur County (33467 *ha*).

The cropland and woodland are two main land use categories in both BM and SD regions but their proportion (percentage of the total agricultural land of the county) differed from one region to another. While woodlands were in higher proportion in the BM region (33% versus 29%), the SD region had higher proportion of croplands (46% versus 41%). Cotton occupied the largest area in both regions – about 40% of the total agricultural land, followed by peanut (about 20%) and maize (about 15%). Other crops in these regions include rye, wheat, oat, soybean, tobacco, vegetables and orchard (mainly pecan) crops. The pecan area is significantly higher in the BM region (10% versus 1.5% of the respective agricultural lands). The average (1970-2000) annual rainfall is about the same (135 *cm*) for both regions.

5. DATA COLLECTION

We required data for irrigated area and the AVHRR indices (i.e., NDVI and VHI) for the study regions to examine the relationships between them. The data on irrigated area were obtained from the Georgia county reports (Boatright and Bechtel, 2000) for 1986, 1989, 1992, 1995, 1998, and 2000. The weekly NDVI and VHI data were generated at the NOAA's National Environmental Satellite Data Information Services (NESDIS) in Camp Springs, Maryland, USA, using the second generation Global Vegetation Index (GVI) product (Kidwell 1997). Ch1 and Ch2 data were post-launch calibrated to albedo (Kidwell 1997, Rao and Chen 1999). Ch4 data were converted to brightness temperature and a non-linear correction was applied (Weinreb et al. 1990). High frequency intra-annual noise (variation in illumination and viewing conditions, sensor degradation, satellite navigation and orbital drift, atmospheric and surface conditions, communication and random errors) was completely removed with statistical filtering (Kogan 2001).

6. DATA ANALYSIS

Regression analyses were performed between the AVHRR indices and irrigated area using the statistical software program JMP-IN, version 3.0 for windows (SAS Institute Inc., Cary, NC 27513).

6.1 Relationship between AVHRR data and Irrigated Area

We selected irrigated area as a dependent variable and the NDVI or VHI as an explanatory variable to perform the regression analyses. The data on irrigated area were available only for 1986, 1989, 1992, 1995, and 2000. Therefore, the NDVI and VHI data were used for the same years to perform the regression analyses. We derived two variables each from the weekly NDVI and VHI data: an annual-average variable (52-week average; $NDVI_{aa}$ and VHI_{aa}) and a seasonal-average variable (31-week average i.e., Week 8-38; $NDVI_{sa}$ and VHI_{sa}). The period for seasonal variable (i.e., from third week of February to the end of September) was selected keeping in mind the typical vegetative phases of crops in Georgia. Table 1 presents the values of the above variables and TI and MI values that led to the determination of the VHI.

As seen from table 1, the irrigated area (in thousand) fluctuates from year to year considerably – from 38 to 55 in the BM region and from 46 to 60 in the SD region. During the investigated years, the lowest area was in 1986 and the highest in 1998 and 2000. The correlation analyses are presented in figure 2 and table 2.

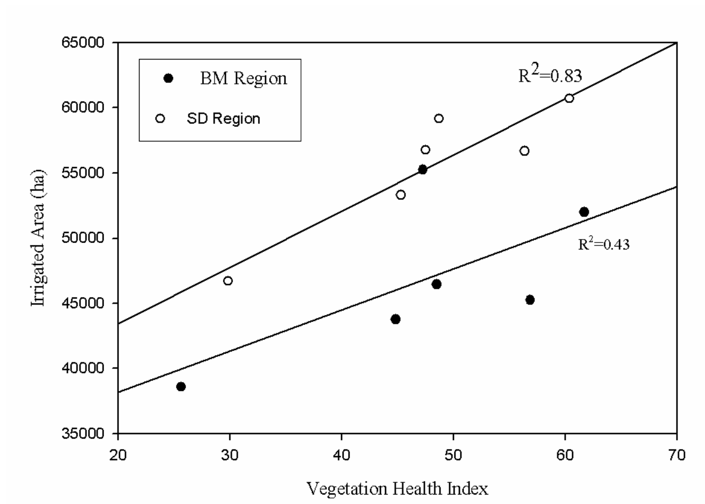

Figure 2. Relationship between the seasonal (Week8-38 i.e. from third week of February to the end of September) Vegetation Health Index and the irrigated area for the Baker & Mitchell (BM) and Seminole & Decatur (SD) regions in Georgia.

General observations are: i) The correlation is positive, i.e. larger irrigated areas were associated with higher index values; ii) For both BM and SD regions, the seasonal variables of NDVI and VHI produced higher R^2 compared to the annual variables; iii) Among the seasonal variables, VHI_{sa} had a stronger correlation with irrigated area compared to $NDVI_{sa}$; iv) The above relationship was even stronger for the SD region compared to the BM region; v) The Thermal Index (TI) had stronger correlation with the irrigated area in the BM region while the relationship of Moisture Index with the irrigated area was stronger in the case of SD region; and vi) Standard errors were much higher in the case of NDVI as opposed to TI, MI, or VHI (table 2). These errors were lower and R^2 higher for the SD region, for all the variables except TI.

Table 2. Coefficient of determination, R^2, and standard error (in parentheses) for regression analysis between irrigated area and an AVHRR-data based variable for the study regions in Georgia.

Explanatory Variable		Baker & Mitchell region	Seminole & Decatur region
NDVI	Annual average	0.19 (82198)	0.43 (60687)
	Seasonal average	0.25 (97659)	0.49 (71952)
TI	Annual average	0.14 (292)	0.02 (306)
	Seasonal average	0.49 (222)	0.11 (421)
MI	Annual average	0.21 (122)	0.35 (90)
	Seasonal average	0.25 (132)	0.43 (87)
VHI	Annual average	0.44 (221)	0.73 (146)
	Seasonal average	0.43 (180)	0.83 (98)

Note: Annual average refers to week 1-52 period, seasonal average refers to week 8-38 period, AVHRR is Advanced Very High Resolution Radiometer, NDVI is Normalized Difference Vegetation Index, TI is Thermal Index, MI is Moisture Index, and VHI is Vegetation Health Index.

From the above observations it is evident that the 3-channel based VHI is a better variable than the 2-channel based NDVI for estimating irrigated area for the study area. The scatter plots for the BM and SD regions are illustrated in figure 2 and can be summarized by the following regression equations:

$$A_{ir} = 31909 + 315.10 * VHI_{sa} \quad (R^2 = 0.43; \text{for the BM region}) \qquad [5]$$

$$A_{ir} = 34838 + 431.11 * VHI_{sa} \quad (R^2 = 0.83; \text{for the SD region}) \qquad [6]$$

where A_{ir} refers to irrigated area (*ha*) in the region. The value of R^2 for BM region is low because of an apparent outlier i.e. irrigated area (55243 *ha*) for BM region in 2000 (figure 2). It is likely the area in 2000 may be erroneous. We eliminated this value from the dataset, conducted the regression analysis again and obtained the following model for the BM region:

$$A_{ir} = 30092 + 317.83 * VHI_{sa} \quad (R^2 = 0.84; \text{for the BM region}) \qquad [7]$$

Now a question arises: what distinguishes the VHI from NDVI that has strengthened the relationship between irrigated area and VHI? Theoretically, there is only one difference: VHI, unlike NDVI, derives additional information from the thermal channel. The contribution of thermal data can be studied from the viewpoint of crop physiology. An irrigated crop tends to have a lower canopy temperature than a non-irrigated crop because the non-irrigated crop is likely to experience moisture stress during its cropping season.

Although VHI had a stronger correlation with irrigated area, the degree of strength in relationship varied from one region to another. This variation in R^2 could be explained by the difference in the proportion of dynamic and stable vegetation in these regions. The SD region comprised a higher proportion of cropland (i.e., dynamic vegetation, 46% as opposed to 41%) and a lower proportion of woodlands (i.e., rather stable vegetation, 29% as opposed to 33%) when compared to the BM region (table 1). Depending on the landuse composition, it is likely that the strength of relationship between irrigated area and VHI will differ for regions other than those studies in this paper.

There are numerous factors, such as the cost of irrigation, drought occurrence, market-price for crops, and state laws enforcing restrictions on irrigation at the time of droughts, that influences the farmer's decision to irrigate. These factors are not adequately understood at present and their improved understanding, if incorporated in the regression model, will enhance the model accuracy.

7. CONCLUSIONS

Based on the results from this study it can be concluded that the Vegetation Health Index (derived from 3-channel data of the AVHRR) is a better variable than the Normalized Difference Vegetation Index (derived from 2-channel data of the AVHRR) for estimating irrigated area in Georgia. It was found that the thermal channel (10.3 – 11.3 µm) of NOAA_AVHRR provides information useful for detecting irrigated area. A positively strong relationship was discovered between VHI and the irrigated area for study regions in Georgia, USA. R^2 was 0.84 for the region encompassing Baker and Mitchell counties and 0.83 for the region that included Seminole and Decatur counties. With the VHI data available for the period ending September, one can estimate irrigated area, for the study regions, in a year. Using VHI data, one could estimate irrigated area every year and make it available as early as October. This will significantly enhance the temporal resolution of the irrigation data and will also improve their reliability. Currently, the irrigation data are available every five years and are subject to errors.

Use of the VHI data will help estimate water usage more accurately and contribute to finding a solution for satisfactory river-water distribution among the states of Alabama, Florida, and Georgia.

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