MONITORING AGRICULTURAL WATER CONSUMPTION AND IRRIGATION PERFORMANCE USING FREELY AVAILABLE MODIS IMAGES FOR A LARGE IRRIGATION SYSTEM IN PAKISTAN

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ABSTRACT

Irrigation policy makers and managers need information on the irrigation performance at various scales to devise appropriate water management strategies, in particular considering dwindling water availability, further threats from climate change, and continually rising population and food demand. In practice it is often difficult to access sufficient water supply and use data to determine crop water consumption and irrigation performance. Energy balance techniques using remote sensing data have been developed by various researchers over the last 20 years, and can be used as a tool to directly estimate actual evapotranspiration, i.e. water consumption. This study demonstrates how remote sensing based estimates of water consumption and water stress combined with secondary agricultural production data can provide better estimates of irrigation performance, including water productivity, at a variety of scales than alternative options. A principle benefit of the described approach is that it allows identification of areas where agricultural performance is less than potential, thereby providing insights into where and how irrigation systems can be managed to improve overall performance and increase water productivity in a sustainable manner. To demonstrate the advantages, the approach was applied in the Indus basin irrigation system of Pakistan's Punjab Province. Remote sensing based indicators reflecting reliability and adequacy were estimated.

MEDIA GRAB

Public domain satellite data provides and sate-of-art remote sensing techniques can be used to monitor irrigation performance at various scales in data scare regions of the world.

INTRODUCTION

Irrigation sector has played a very important role in global food productions and even in 21st century it remains an important part of the strategy to feed the global population in the future, and may often be the only option in some arid and semiarid countries, such as Pakistan. With about 16 million ha irrigated area, Indus basin irrigation system of the Pakistan is one of the largest contiguous irrigation systems in the world which plays very important role in the economy of Pakistan. To evaluate the irrigation performance and manage scarce water resources in such a large irrigation system, water policy makes and managers are often confronted with the paucity of reliable information. This paper demonstrate that how the satellite-interpreted raster maps of actual evaportranspiration and evaporative fraction can be merged with vector maps of the irrigation water delivery systems to understand the real time performance under actual field conditions. In this study, two indicators, as proposed by Ahmad et al. (2008), representing adequacy and reliability – were selected to evaluate the performance of irrigation systems in Punjab, Pakistan.

The study covers the entire canal irrigation system (about 10 Million ha cropped area) of Punjab Province fed by the five rivers. Most areas in Punjab experience fairly cool winters with December and January being the coolest, reaching sometimes below 0°C. By March, the temperature begins to rise reaching 46 to 50°C in June-July. The onset of the southwest monsoon is anticipated to reach Punjab by end May and continues until July-August. Almost 75 percent of the annual rainfall occurs during the monsoon season from mid-June to mid-September. Due to scanty and erratic rainfall, successful agriculture is only possible with irrigation from surface and groundwater. Rice, cotton, sugarcane and forage crops dominate the summer season (*Kharif – May to October*), whereas wheat and forage are the major crops in winter (*Rabi – November to April*). In some parts, sugarcane is also cultivated, which is an annual crop.

METHODS

Several models are available (Kustas et al. 2003) to compute actual evapotranspiration and evaporative fraction using satellite images. In this study, the Surface Energy Balance Algorithm for Land (SEBAL) has been used for actual evapotranspiration and evaporative fraction calculations. SEBAL is an image processing model which computes a complete radiation and energy balance along with resistances for momentum, heat and water vapour transport for each pixel Bastiaanssen et al. (1998, 2002). The key input data for SEBAL consists of spectral radiance in the visible, near-infrared and thermal infrared part of the spectrum. In addition to satellite images, the SEBAL model requires the routine weather data parameters (wind speed, humidity, solar radiation and air temperature). SEBAL is a well-tested and widely used method to compute ET_a (Bastiaanssen et al. 1998, Tasumi et al. 2003, Ahmad et al. 2008) and validated in Pakistan (Bastiaanssen et al. 2002).

Daily meteorological data on temperature, humidity, wind speed and sunshine hours for 17 stations in Punjab were collected from Pakistan Meteorological department for October 2004 to 2005 (Cropping year 2004–05). This represents the cropping seasons of Rabi 2004-05 and Kharif 2005. For the study period 19 cloud-free MODIS scenes (Table 1), covering entire Punjab, were downloaded from Earth Observing System Data Gateway (EOSDG) of NASA (currently this information available at NASA Goddard Space Flight Center website (http://ladsweb.nascom.nasa.gov/data/search.html). For SEBAL processing, only 9 bands (i.e. first 7 bands in the Visible and Infrared range and two thermal bands 31 and 32) of MODIS were used.

Daily evaporative fraction Λ and actual evapotranspiration (ET_a) was calculated employing SEBAL model using cloud/haze free MODIS images for both seasons. Then daily values were integrated at appropriate intervals to calculate monthly, seasonal and annual evapotranspiration.

Table 1 Selected MODIS images for ET_a calculation using SEBAL method.

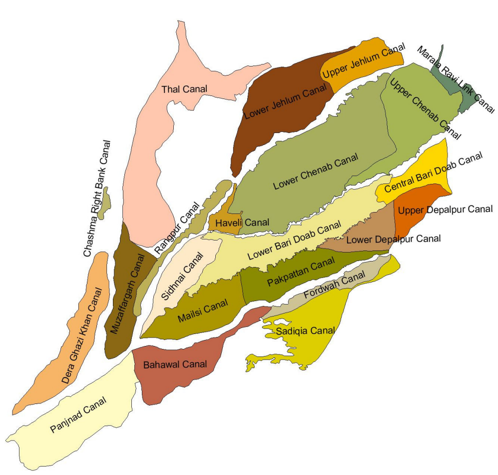
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004										25	12	5
2005	14	22	29	4 & 16	18	1, 14 & 23	19	10 & 22	2	4, 11 & 27		

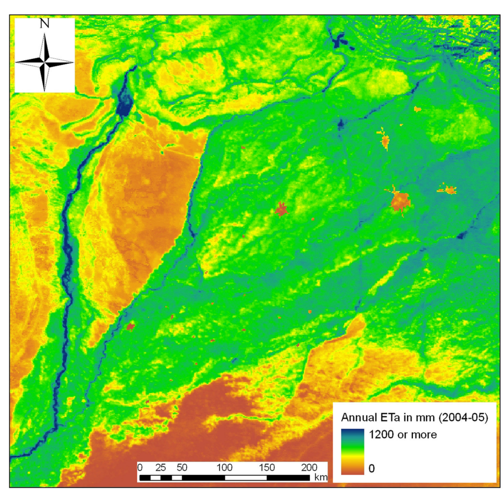
Finally two indicators, as proposed by Ahmad et al. 2008, representing *adequacy* and *reliability* – were used to evaluate the performance of irrigation systems in Punjab, Pakistan.

RESULTS AND DISCUSSION

Daily evaporative fraction Λ and $ET_\mathbf{a}$ were calculated for all MODIS images listed in Table 1. Then daily values were integrated at appropriate intervals to calculate monthly, seasonal and annual evapotranspiration. The resultant map showing the annual variation in $ET_\mathbf{a}$ in October 2004-05 is presented in Figure 1.

The annual $ET_\mathbf{a}$ varies from less than 100 mm/year in desert/barren areas to about 1650 mm/year over large water bodies in the processed image covering entire canal commands of Punjab. However annual $ET_\mathbf{a}$ from cropped areas ranges between 400 to 1200 mm/year. Due to heterogeneous cropping pattern it was difficult to identify pure pixels for particular crops. However, for the Punjab rice-wheat area the annual average $ET_\mathbf{a}$ is 896 mm in the cropping year of 2004-05 whereas it is in generally much lower (i.e. 766mm/year in Panjand) in lower Punjab due to lower cropping intensity, less water intensive crops and possibly the effects of salinity. The average $ET_\mathbf{a}$ over all canal commands is about 805 mm in 2004–05. Anyhow it was observed in many canal commands that irrigated areas close to the main canals or river have higher $ET_\mathbf{a}$ due to better access to canal water and groundwater for agriculture, gradual decrease in $ET_\mathbf{a}$ towards tail. The canal command level seasonal and annual results are presented in Table 2.





a) b)

Figure 1 Irrigation canal commands in Punjab (a) and spatial variation in annual actual evapotranspiration (ET_a) in Punjab for year 2004-05 (b).

Table 2 Canal command level seasonal and annual ET_a in Punjab Pakistan.

Canal Name	Annual 2004-05		Kharif 2005		Rabi 2004-05	
	Mean ET_a (mm)	Gross Volume (10^6 m^3)	Mean ET_a (mm)	Gross Volume (10^6 m^3)	Mean ET_a (mm)	Gross Volume (10^6 m^3)
Upper Jehlum Canal	867	2488	561	1609	306	878
Lower Jehlum Canal	808	6092	494	3723	314	2369
Marala Ravi Link Canal	897	863	558	537	339	326
Upper Chenab Canal	923	6443	594	4150	328	2293
Lower Chenaba Canal	792	12357	491	7670	300	4686
Centeral Bari Doab Canal	803	2082	509	1321	294	762
Upper Depal Pur Canal	885	1758	580	1152	305	606
Lower Bari Doab Canal	851	6689	547	4304	303	2385
Lower Depalpur Canal	913	2312	595	1507	318	805
Pakpattan Canal	858	3844	566	2535	292	1308
Fordwah Canal	794	1560	530	1041	264	519
Sadiqia Canal	504	2672	323	1709	182	962
Haveli Canal	891	849	578	550	313	299
Sidhnai Canal	858	2985	543	1891	315	1095
Mailsi Canal	804	3713	518	2391	286	1322
Bahawal Canal	456	2391	279	1464	177	927
Thal Canal	477	5343	266	2983	211	2360
Chashma Right Bank Canal	774	201	492	128	282	73
Rangpur Canal	831	1432	526	907	305	525
Muzaffar Garh Canal	781	3263	499	2085	282	1178
Dera Ghazi Khan Canal	675	3677	440	2400	234	1277
Panjnad Canal	705	5833	486	4021	219	1812

Adequacy and Reliability

Adequacy is the quantitative component, and is defined as the sufficiency of water use in an irrigation system. In contrast, *Reliability* has a time component and is defined as the availability of water supply upon request. Both, a*dequacy* and *reliability* of water supplies to cropped area can be assessed using the evaporative fraction maps, as they directly reveal the crop supply conditions (Alexandridis *et al.*, 1999; Bastiaanssen and Bos, 1999). In this study, *adequacy* is more specifically defined as the average seasonal evaporative fraction and *reliability* as the temporal variability, temporal coefficient of variation, of evaporative fraction in a season. Evaporative fraction values of 0.8 or higher indicates no stress (Bastiaanssen and Bos, 1999), and below 0.8 it reflect increases in moisture shortage to meet crop water requirements as a result of inadequate water supplies. Similarly the lower values of coefficient of variation represent the more reliable water supplies throughout the cropping season. The seasonal adequacy and reliability for different canal commands is calculated (Figure 2 and 3).

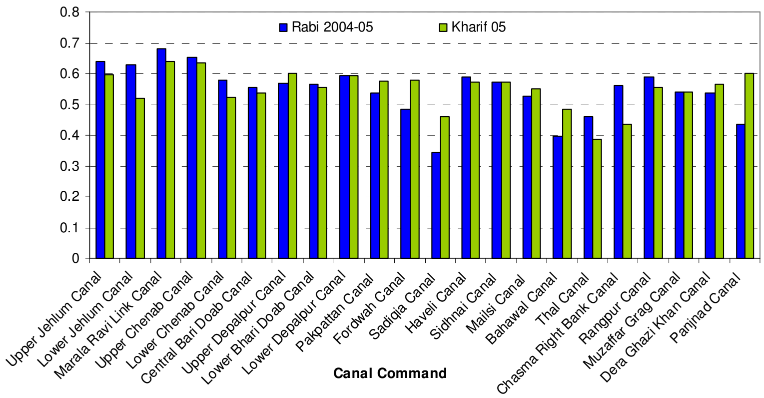


Figure 2 Adequacy of the cropping season Rabi 2004-05 and Kharif 2005 for each canal command in Punjab.

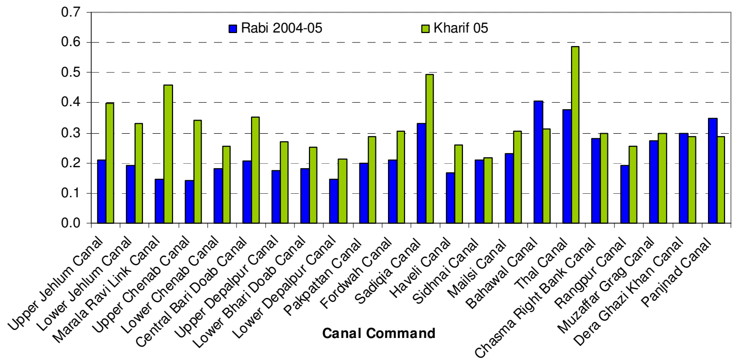


Figure 3 Seasonal variation of the reliability of the each canal command in Punjab.

The analysis reveals that in most of the canal commands rabi has more adequate and reliable water availability than kharif. This is largely related to low evaporative demand in the winter season and as a result famers are managing their limited surface and groundwater resources in efficient manner. Highest level of adequacy (and reliability in rabi) was found in Marala Ravi link and Upper Chenab Canal command area in both cropping seasons. This is because of better canal water supplies and good quality groundwater which is used for irrigation in conjunction with surface water. Sadiqia, Bahawal and Thal canal can be ranked lowest in terms of adequacy and reliability of water consumption. Their lower performance could be related to poor groundwater quality and/or relative lower water holding capacity of soils.

CONCLUSIONS

This paper shows the application of surface energy balance techniques to map spatial and temporal variation in actual evapotranspiration (ET_a) and evaporative fraction using freely available MODIS images and routine climatic data. And demonstrates how the satellite driven maps can be effectively combined with vector maps of the irrigation water delivery systems to understand the real time performance, in terms of adequacy and reliability, under actual field conditions. Although, the procedure does not allow for a detailed insight into the reasons for high and low performance, but it does show the bigger picture and shows where policy makers and water managers need to look improve the effectiveness of water consumption. The approach presented in this paper can be applied in other irrigation systems

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