A METHOD TO ESTIMATE IRRIGATION EFFICIENCY WITH EVAPOTRANSPIRATION DATA

Hongwei ZENG, Bingfang WU*, Nana Yan
Key Laboratory of Digital Earth Sciences, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences
*Corresponding author, wubf@radi.ac.cn

Abstract: Irrigation efficiency is defined as the ratio of irrigation water consumed by the crops to the water diverted (W_g) from a river or reservoir or wells. This terminology serves for better irrigation systems designation and irrigation management practices improvement. But it is hard or high cost with labor intensity to estimate irrigation efficiency from field measurement. This paper proposes an estimating method of irrigation efficiency at the scale of irrigation district based on ET from remote sensing with ETWatch, a system to monitoring ET with multi-source remote sensing data, and data on water diversion: (1) ET monitoring: ET is actual water consumption of crops in the field. Irrigation water can be divided into evapotranspiration of crops and leakage to groundwater or return flow to surface water. To acquire high accuracy ET dataset is the key step for calculating the value of irrigation efficiency. Once ET data is available, it is not necessary to acquire leakage data or return flow. ETWatch with annual deviations 3.8% at sub-basin scale has been used to monitor ET; (2) Irrigation area estimation: actual irrigated areas vary with rainfall, considering rainfall is the only available water for non-irrigated field so that ET from those fields should less than irrigation area given same crop type and phenology. Irrigation area can be retrieved by using ET (ET large than rainfall) with field verification; (3) Crop classification: due to the difference of phenology, crops would show different NDVI profile, so that crop types could be distinguish through constructing NDVI time series dataset, which further divided into non-irrigated and irrigated crops. (4) Ration of ET contributed by irrigation water: Farm process model is applied to estimate transpiration ration (T_{irri}) from irrigation water, taking account of precipitation, soil types, irrigation water and crop phenology, besides, T_{irri} of crops could be obtained from may irrigation experiments; (5) irrigation efficiency estimation: the summary of ET_{irri} of different crops is water effective consumed of irrigation water, so irrigation efficiency of irrigation district could be calculate as following formulation $IE=T_{irri}/W_g$.
Shijin irrigation area is located at Ziya river basin of Hebei province, China, where groundwater is over-draft. Proposed method is applied Shijin irrigation area for year 2010-2012. Irrigation efficiency is estimated for this area in comparison with 0.574 recorded by irrigation administrator.

Keyword: irrigation efficiency, Evapotranspiration, Shijin irrigation area, ETWatch;

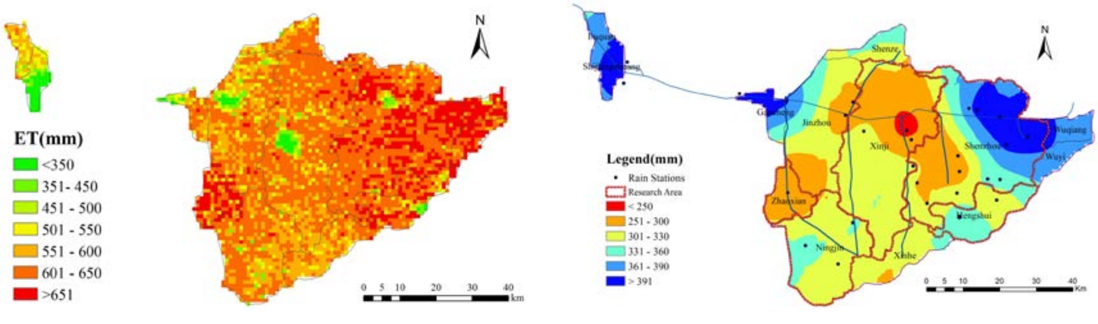
1. Introduction

Irrigation efficiency was defined as the ratio of the irrigation water consumed (evaporated) by crops to the irrigation water delivered from a surface or groundwater source to the canals or farm headwaters (Israelsen, 1950; Keller, 1995). Irrigation efficiency ignores water runoff and seepage that re-enters the water supply so that this concept is criticized by basin water resource administrator. Willardson et al. (1994) suggest use consumed fraction to replace irrigation efficiency. In order to avoid ambiguous, Keller (1995) propose “effective efficiency” concept that is the irrigation water consumed by crops to the effective use of water. The argument of irrigation efficiency is caused by its scale effects. The seepage and irrigation water runoff in field scale could be used by crops in large scale. In other words, if it is possible to monitor evaporation generated by crops, the irrigation efficiency could also be estimated at any scale. As the development of remote sensing technologies, monitoring water evaporation came true at any scale and this also provides a new solves to estimate irrigation efficiency as any scale. Wu et al. (2008) developed an ET monitoring tool based on remote sensing technology and this tool could provide accuracy ET dataset. This work focuses on irrigation efficiency estimation at Shijin Irrigation District (SID) with remote sensing evaporation data.

2. Methods, materials

2.1 Research Area and Materials

As the largest irrigation district in Hebei Plain, Shijin Irrigation District plays a key important role on water resources management and crop production in Ziya sub-basins in China. Monsoon is the main climate of Shijin irrigation district and nearly 80% rainfall concentrated from June to September and little rainfall dropped in spring season. Winter wheat and cotton depend on irrigation during growing period. The ET dataset in 2010 was estimated from ETWatch (Wu et al., 2008). The assessment of ETWatch model indicated the good accuracy of ET dataset (Wu et al., 2012). The overall deviation for individual fields on a seasonal basis was 12% and decreased to 6% for an annual cycle and the deviation for a large area (>3000km2) reduced to 4% for an annual cycle. The precipitation data were collected from 28 rain stations that are relatively evenly distributed over Shijin irrigation district. The irrigation water data in 2010 was provided by the administrator bureau of the Shijin irrigation district.



3. Fig 1 spatial distribution of ET and Rainfall in Shijin irrigation district in 2010

2.2 Methods

Only transpiration of crops is effective consumption of irrigation water so that irrigation efficiency could be estimated by

$$IE = \frac{T_{irri}}{W_g}$$

In here, T_{irri} is the total crop transpiration from irrigation water during the whole growth period, Pe is the effective precipitation, W_g is the total amount of surface irrigation water and groundwater irrigation entering irrigation district, IE is the efficiency of irrigation water of research area. The main crops in Shijin irrigation district include winter wheat, cotton, and maize, so the IE could also be estimated as following:

$$IE = \frac{\sum (T_{w\_irri} + T_{c\_irri} + T_{m\_irri})}{W_g}$$

In here, T_{w_irri}, T_{c_irri}, T_{m_irri} is transpiration from winter wheat, cotton, and maize due to irrigation water. The fraction of transpiration in different growing stage could be estimated through field experiment or to simulate based on modeling technology, such as Farm Process Model. As the important grain producing area in China, there are a lot of field irrigation experiments on estimating the fraction of T in different crop growing stages, this work make use of those results for calculating the amount of transpiration from irrigation water.

3. Results and discussion

3.1 ET monitoring

This work collected remote sensing ET dataset from ETWatch. In Hai basin, ETWatch has been verified many times at different spatial scales, against field measurement, lysimeter, eddy covariance system, LAS, water balance of the sub-watershed and independent third party estimates, the good accuracy has been described in section 2.1. There are two peak of ET in May and July (Fig 3), it is the main growing peak of winter wheat in May, and the peak of ET is caused by irrigation due to deficiency of rainfall in this period.

3.2 Irrigation Area

Irrigated crops and non-irrigated crops were distinguished according to threshold method as following: if monthly ET larger than rainfall in the growth peak of crops, those crops be classified into irrigated crops, otherwise crops would be classified into non-irrigated crops. The rainfall amount from March to May only takes 8.17% of the total amount precipitation in 2010 of Shijin irrigation district. It is the water requirement peak of winter wheat in the same period, it is obvious that winter wheat should be irrigated during this period, otherwise, winter wheat would not be survived, so that this work consider the actual planted area of winter wheat as the irrigated areas of winter wheat.

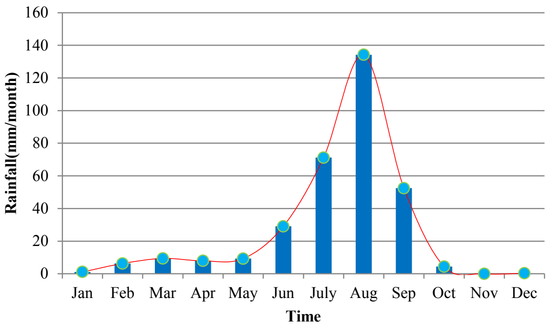


Fig 2 Rainfall profile of Shijin irrigation district in 2010

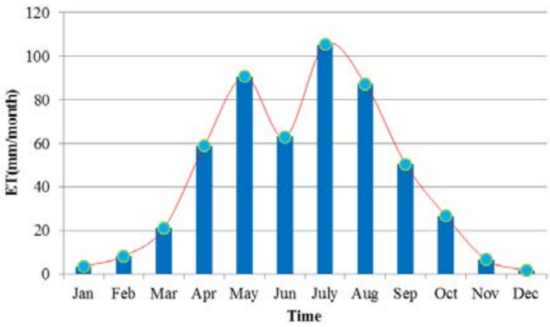


Fig 3 ET profile of Shijin irrigation district in 2010

3.3 Crop Classification

In generally, winter wheat was planted in October and harvested in the early of June, cotton was plated in the late of April and harvested in the early of October, and maize was planted in the late of June and harvested in the late of September. The differences of phonology of crops provide the way for classification and in this work used Chinese satellite images– HJ in April, the late of June, and August to class the crops in research areas into winter wheat, cotton, and maize. This work collected HJ satellite images on 20100523, 20100708 and 20100816 for crops classification in Shijin irrigation district. On May 23rd, winter wheat stay from grain filling stage to mature, the cotton only stays at seeding stage. Through setting NDVI threshold with 0.4, this work class winter wheat from crops at first. On July 8th, winter wheat was harvested completely; maize only just finished sowing, but cotton stay at blooming stage. This work set NDVI threshold with 0.3 and extract from crops. In Shijin irrigation district, the main crops structure is winter wheat – summer maize rotated, the planted area of maize is the same as winter wheat. The classification was shown in Fig 4. The area of winter wheat-maize rotation is 2531km^2 and the area of cotton is 637km^2, the total area cropped land is 3168km^2. The cultivated land of SID is 2900km^2 in 2009, the relative errors of classification is 9.24%.

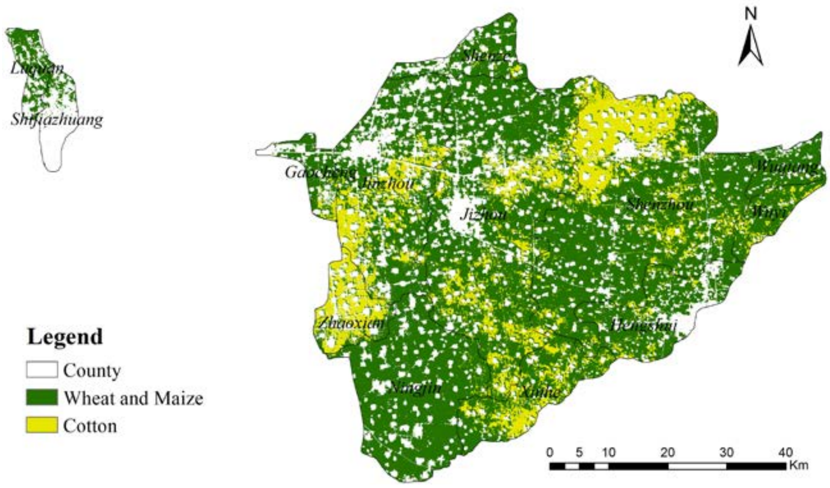


Fig 4 the crop classification of Shijin irrigation district

3.4 Ration of ET contributed by irrigation water

In Shijin irrigation district, 2/3 ET is consumed by cotton with transpiration. To winter wheat, the 61.2% to 73.4% of total ET is transpiration and the annual average fraction is 68.9% (Hu et al., 2009). Liang et al. (2011) estimated the fraction of T in different growing stages of winter wheat (Table 1) and the total fraction of T in the whole period of winter wheat is 67.92%.

Table 1 the fraction of T in different growing stages of winter wheat

Items	Sowing-Tillering	Tillering-Overwintering	Overwintering to reviving	Reviving to Jointing	Jointing to Heading	Heading to Grain filling	Grain filling to Maturity	Whole Period
Time	1016-1117	1118-1219	1220-0305	0306-0328	0329-0423	0424-0516	0517-0606	1016-0606
T/ET	32.08%	37.86%	38.75%	64.54%	80.32%	87.25%	81.06%	67.92%

3.5 Irrigation efficiency estimation

According to irrigation water records for Shijin Irrigation District, only winter wheat and cotton are irrigated, maize is rain fed crop due to abundant rainfall during the whole growth period from July to September. Winter wheat irrigated 2 times, the first time from 11th March to 9th April and the second time from 27th April to 19th May. The average irrigation water of winter wheat in Shenzhou, Zhaoxian, Hengshui, and Xinji is 367, 324, 525, 450, 339mm, respectively (Table 1).

Table 2 irrigation water of crops in SJD (unit: mm)

Item	Shenzhou	Zhaoxian	Ningjin	Hengshui	Xinji
Irrigation Water	367	324	525	450	339

The amount of rainfall from January to June in Shenzhou, Zhaoxian, Hengshui, and Xinji is 83.55, 64.75, 68.15, 70.6, 73.72mm, respectively (Table 2). The period January to May, rainfall is far less than water requirement of winter wheat and the amount of effective rainfall is nearly equal to 0 that indicated rainfall lost from field through evaporation process. After late of May, winter wheat was stepping into maturity stage, main part of rainfall lost through winter wheat transpiration, refer to research result from Liang (2011), this work consider 81.06% of rainfall in June as transpiration.

Table 3 monthly average rainfall of winter wheat from January to June (unit: mm)

County	Jan	Feb	Mar	Apr	May	June	Total
Shenzhou	2.34	9.48	6.08	9.10	11.34	45.21	83.55
Zhaoxian	2.25	6.99	5.15	7.79	13.56	29.01	64.75
Ningjin	3.26	7.25	5.96	8.15	13.60	29.93	68.15
Hengshui	2.75	9.21	5.98	8.92	11.00	32.74	70.6
Xinji	3.00	4.79	8.47	9.66	10.01	37.79	73.72

The amount of ET from January to June in Shenzhou, Zhaoxian, Hengshui, and Xinji is 306.74, 288.55, 286.32, 304.33, 279.08mm, respectively (Table 3). From March to June, ET of winter wheat increases greatly and arrives at the peak on May.

Table 4 monthly average ET of winter wheat from January to June (unit: mm)

County	Jan	Feb	Mar	Apr	May	June	Total

Shenzhou	4.38	10.23	26.43	80.23	113.30	72.17	306.74
Zhaoxian	3.85	9.08	23.14	54.05	101.11	97.32	288.55
Ningjin	3.69	8.48	23.89	68.48	102.27	79.51	286.32
Hengshui	4.44	9.90	27.80	77.77	109.01	75.41	304.33
Xinji	3.88	9.65	23.79	67.82	105.58	68.36	279.08

In combination the fraction of T and the amount of effective rainfall in different growing stages of winter wheat, the fraction of T contributed by irrigation water is calculate as 207.90mm (Shenzhou), 206.97mm(Zhaoxian), 204.58mm(Ningjin), 215.68mm(Hengshui), 192mm (Xinji), respectively. The irrigation efficiency is 0.57(Shenzhou), 0.64(Zhaoxian), 0.39(Ningjin), 0.48 (Hengshui), and 0.57(Xinji). Compared to 0.574 irrigation efficiency from SID, Ningjin and Hengshui is below average, Shenzhou and Xinji is average, and Zhaoxian is above average.

4. Conclusion

In combination remote sensing dataset from ETWatch, irrigation water dataset from SID, this work simply estimated the irrigation efficiency of winter wheat of Shijin irrigation district in 2010. The irrigation efficiency is 0.57, 0.64, 0.39, 0.48, and 0.57 in Shenzhou, Zhaoxian, Ningjin, Hengshui, and Xinji, respectively. In future, some filed irrigation experiments should be undertaken to improve and verify the accuracy of estimation.

Acknowledgments

This work was supported by the international Science and Technology Cooperation Program of China (Grant No. 2012AA12A307). China Grains Administration Special Fund for Public Interest (Grant No. 201313009 - 02).

Reference

Hu Y., Yang Y., Yang Y., Wang Y.2009. Effect of irrigation on winter wheat yield, evapotranspiration and water use efficiency in North China Plain. Eng ineering Journal of Wuhan University, 42(6):701~705. (In Chinese)

Israelsen, O.W., 1950. Irrigation Principles and Practices. John Wiley and Sons, Inc., New York, 471.

Keller, A. A., Keller, J. 1995. 22 Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources.

Liang W., Cai H., Wang J. 2011. Research of Evapotranspiration and Evaporation for Winter Wheat. Journal of Irrigation and Drainage, 30(6): 93-96. (In Chinese)

Willardson L S, Allen R G, Frederiksen H D. 1994. Elimination of irrigation efficiencies[C]//13th Technical Conference on USCID. Denver.

Wu B, Xiong J, Yan N, et al. 2008. ETWatch for monitoring regional evapotranspiration with remote sensing. Advances in Water Science, 19(5): 671-678.

Wu B, Yan N, Xiong J, et al. Validation of ETWatch using field measurements at diverse landscapes: A case study in Hai Basin of China. Journal of hydrology, 2012, 436: 67-80.

Wu, B., L. Jiang, N. Yan, C. Perry, H. Zeng.2013. Basin-wide evapotranspiration management: Concept and practical application in Hai Basin, China. Agricultural Water Management.