Original Scientific paper
10.7251/AGRENG2202020M
UDC 633:631.67(510)

ASSESSMENT OF REGIONAL IRRIGATION WATER REQUIREMENTS AND ACTUAL SUPPLY IN BAODING, CHINA

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ABSTRACT

Nowadays, water resources scarcity has become a severe issue that interferes with economic, social, and ecological development. As the most significant use of water resources in agriculture, irrigation plays a crucial role in ensuring agricultural production when rainfall is insufficient to maintain the growth of crops. In this paper, estimation of water resources in irrigation practices was carried out in Baoding since the area suffers from water scarcity, and the situation there is worsening, especially after the founding of Xiongan New District. This study aimed to evaluate the supply and demand balance of irrigation at the municipal and county levels through the climate information and crop pattern summarization in Baoding. Data provided by Agricultural Machinery Bureau was integrated with CLIMWAT 2.0 to compute crop water requirements, irrigation requirements, and irrigation schemes in CROPWAT 8.0. Results show that an estimated sum of 1881.3 mm annual crop water requirements comprising the vast majority of crops in agricultural production led to 1493.5 million m^3 irrigation requirements, creating an irrigation deficit of 119.2 million m^3. The greater cutdown on annual water supply compared to the irrigation requirements led to a consecutive exacerbation of annual irrigation deficits. Suggestions, including physical and political measures, were provided to improve the current situation in Baoding.

Keywords: *Crop water requirements, Irrigation requirements, CROPWAT 8.0, Baoding.*

INTRODUCTION

Water is a precious natural resource for ecology and the environment, and it plays an irreplaceable role in economic and social development. Due to climate change, it aggravates existing pressures on water-stressed regions and intensifies the competition between the ecosystem and human beings. As the targeted area, Baoding in Hebei Province has experienced rapid social and economic developments under the Beijing-Tianjin-Hebei synergetic strategy, which aims to alleviate government functions unrelated to the capital city Beijing and enhance adaptabilities among socio-economic development, population resources, and environment (Fang et al., 2018; Chu et al., 2018). Moreover, Xiongan New District formed inside Baoding is conspicuous and has boosted ecological development since 2017 (Xiongan, 2022). Meanwhile, agricultural production is crucial in Baoding since it plays an essential role in maintaining the local grain supply and the supply of areas under the synergetic strategy. Baoding has recently experienced industrial transformation and improvement by shifting its singular agricultural production pattern to the coordinated development between agriculture and industry. The newly established Xiongan District also brings the demand for ecosystem sustainability (Liu et al., 2020). Hence, it requires Baoding to rationally allocate water resources with a diminishing total annual supply. As a principal means, irrigation ensures sufficient water is supplied to crops, which is the primary source of water resource consumption in agricultural production. Further, water scarcity and unfavourable climate conditions intensify the pressure on the irrigation system. An inefficient management system will cause issues in irrigation, negatively influencing the sustainable development of water resources.

Studies were carried out to assess the crop water requirements (CWR), irrigation performance, and management to improve the current situation in Baoding. Yang et al. confirmed that the piedmont region has serious water resource sustainability problems as agricultural production intensifies and groundwater tables in Hebei Province decline (Yang et al., 2014). Feng et al. estimated that CWR for maize was 445.3mm in Hebei Province, and two to three times irrigation should be scheduled for maize cultivation (Feng et al., 2007). Wang et al. analyzed ETc (Crop Evapotranspiration) of wheat and the impact of water consumption under the shrunken wheat cultivated areas (Wang et al., 2014). Yang et al. found that the plain region of Baoding has the highest irrigation requirements, where wheat, maize, and cotton altogether account for 64% of total irrigation requirements in Hebei Province (Yang et al., 2010).

In this study, besides all previous research on Hebei province, the assessment was provided by adopting CROPWAT 8.0 to evaluate the sum of CWR based on the crop pattern on a regional scale, instead of focusing on a particular crop in Baoding. Estimation of annual overall irrigation requirements and irrigation requirements of different counties were carried out to evaluate the supply and demand balance to develop suggestions for improvement of the current irrigation performance and management.

MATERIALS AND METHODS

Baoding is located in the temperate continental monsoon climate zone. It consists of 43% piedmont and 57% plain areas, covering a total area of 22,000 km^2 (BMPGO, 2022). The surface runoff mainly situated in the piedmont region makes the water supply scarcer and more competitive in the plain region (Yang et al., 2010; Yang et al., 2014). The inbound water diversion project plays an essential role in maintaining the ecosystem and sustainability of surface water resources, which took over 61% of the total surface water supply in 2019 from 43% in 2010 (BWCB, 2022; BWRER, 2006). In Hebei province, agricultural irrigation primarily depends on groundwater extraction, and the groundwater consumption in Baoding exceeds the provincial and national averages, which are 84.8% and 30.1%, respectively (GMIA, 2013). Despite the fact that the government has emphasized the severity of groundwater overexploitation and implemented strict regulations to supervise the groundwater resources, groundwater still has been persistently overexploited, resulting in a consecutively deteriorated average buried depth of 26.41m (BWRER, 2006).

The crop pattern refers to the spatial distribution of various crops during a year, and agricultural production is generally categorized as grains and cash crops in Baoding (BMPGO, 2022). Grains, including maize and wheat, take up the majority of total agricultural production, followed by vegetables, oil plants, and fruits. The rest cultivars(others) consisting of a fraction of millets from grains and cotton from cash crops are considered within the estimation of CWR.

The total cultivated area and the area equipped for irrigation have simultaneously shrunk due to urbanization and industrial development over the past decades (BWCB, 2022; BWRER, 2006). It is expected to decrease further when the local authority continues promoting the “Returning Farmland to Forests” strategy and sustainable ecological development. Moreover, the available water resources supplied to irrigation were gradually reduced mainly due to the water competition between different industries. As a result, the corresponding consequence was reflected in the proportion of the area actually irrigated reduced from 95.4% to 85.6% in Baoding, which was close to the national average of 85.2% in 2020 (GMIA, 2013).

CROPWAT 8.0 is a computer-based program developed by FAO, which calculates CWR, develops irrigation schedules for individual conditions, and optimizes water supply schemes according to various crop patterns. Moreover, irrigation practices and crop performance can be evaluated through the program (FAO, 2022). This study adopted the data collected from the Agricultural Machinery Bureau and climate data used in CLIMWAT 2.0 to analyze the climate condition in Baoding. Both sources captured a series of monthly data with more than 15 years of observation. The reference evapotranspiration and effective rainfall used for estimations were obtained from Agricultural Machinery Bureau. It consists of a series of data provided by 17 meteorological and hydrological stations distributed over the entire Baoding. The reference evapotranspiration was collected through the φ20 type pan, which was used at most meteorological and hydrological stations in China over the last century (Yu et al., 2017). Subsequently, it converted to the values of E-601 type pan with a coefficient of 0.65 for computations in CROPWAT 8.0 (BWRER, 2006). Values of the E-601 type pan show a relatively stable and acceptable systematic deviation from the Penman-monteith method estimate, compared to the φ20 type pan (Chen et al., 2005).

The precipitation distributes unevenly during a year from the perspective of spatial-temporal distribution. Its piedmont region has higher precipitation than the plain region, which creates a significant uneven spatial distribution of precipitation (BWCB, 2022). The precipitation intensifies between June and September (flood season) with a monthly average of 97mm, and lessens from December to March of the following year with an average slight amount of 5 mm monthly. Effective rainfall is primarily affected by the climate, soil texture, structure, and root zone depth (Brouwer et al., 1986). The FAO/AGLW formula below (1) and (2) was used to determine the effective rainfall:

$Peff = 0.6 * P - 10$ for $Pmonth <= 70$ mm (1)

$Peff = 0.8 * P - 24$ for $Pmonth > 70$ mm (2)

In Baoding, agricultural production, especially irrigation projects, mainly occurs in the plain region. The plain region is combined with alluvial fan plains and flood plains, where the brown earth and the fluvo-aquic soil are formed (DARA, 2022). The soil texture in most areas is classified as loam, consisting of very deep, well-drained, and moderately permeable soils on alluvial fans. Loam accounts for 51% of the entire plain region in Hebei Plain (Zhang et al., 2017). CROPWAT 8.0 soil file has stored default values on heavy (clay), light (sand) and medium (loam) soil in the model, and medium (loam) soil was applied to this study.

Crop factors (Kc) values provided by FAO were adopted for CWR estimation. When dealing with comprehensive irrigation planning and management on a city-level scale, a constant and averaged coefficient can be applied, which is more flexible than capturing Kc daily by selecting various crops and soil coefficients. When summarizing various crops in specific fields for a period of time, a combination of transpiration and evaporation coefficients should be considered (Allen, Richard G. et al., 2000). The crop factor mainly depends on the crop type, the growth stage of the crop, and the climate. It may vary during different growth stages of a single crop (Brisson, Nadine, et al., 1998). The total growing period covers the days from sowing to the last day of harvesting. In other words, the growing period primarily depends on local circumstances (Ko, Jonghan, et al., 2009). The total growing period can be divided into four growth stages: the initial stage, the crop development stage, the mid-season stage, and the late-season stage. In general, crops require less water during the initial and late stages. The water demand will continuously increase during the crop development stage until it reaches its peak point, which roughly uses three times the water than the initial stage (Cakir, 2004; Allen, Richard G., et al., 2000). Overall, if effective rainfall is inadequate to cover the water demand of the crops during any growth stage, irrigation is inevitable under such circumstances.

RESULT AND DISCUSSION

CWR, irrigation requirements, and irrigation schemes are computed according to climate, soil, and crop data on a monthly basis from 2015 to 2019 in Baoding. CWR of each crop was calculated based on four growth stages of crops. The CWR was obtained by subtracting the effective rainfall amount from ETc.

Table 1. Estimated Annual CWR, ETc, Effective Rainfall (ER) Based on the Crop Pattern in Baoding

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Wheat	Stage	Int	Dev	Dev	Dev	Dev	Mid	Lat	Lat	Lat				
	ETc	45	31.2	24.7	30	50	108.4	163	117.1	6.4				575.8
	ER	3.7	0.1	0	0	0	0.1	5	9.8	2.5				21.2
	CWR	41.7	31	24.7	30	50	108.2	157.9	107.3	3.2				554
Maize	Stage									It&Dv	Mid	Lat	Lat	
	ETc									27.8	161.4	124.8	48.5	362.5
	ER									21.4	103.5	59.2	22.5	206.6
	CWR									7.1	58.1	65.6	24.3	155.1
Others	Stage								Int	Dv&Md	Mid	Mid	Lat	
	ETc								50	136.2	154.6	127.3	77.7	559
	ER								9.8	30.8	103.5	59.2	24.1	230.9
	CWR								40.2	105.3	51.3	68.1	53.4	328.2
Vegetables	Stage					Int	Dev	Mid	Lat					
	ETc					31.4	89.9	145.6	29.9					296.8
	ER					0	0.1	5	1.3					6.4
	CWR					31.4	89.8	140.6	28.8					290.6
Oil Plants	Stage								Int	Dev	Mid	Md&Lt	Lat	
	ETc								65.6	145.8	159	118.3	15.6	504.3
	ER								9.8	30.8	103.5	59.2	8	211.3
	CWR								55.8	114.9	55.5	59.1	4.2	289.5
Fruits	Stage								Int	Dev	Mid	Lat		
	ETc								80.7	142.3	145.8	98.4		467.2
	ER								9.8	30.8	103.5	55		199.1
	CWR								70.9	111.4	42.3	39.2		263.8

The results in table 1 showed that the highest CWR was estimated for growing wheat, followed by others (small grains), vegetables and oil plants, and growing maize has the least irrigation requirement. However, the total amount of irrigation applied to crops primarily depends on the estimated cultivated areas of individual crops. From the perspective of monthly CWR, the highest requirement occurred during the intensified crop production period from April to June. There were no production activities from November to January except for wheat production in Baoding.

The irrigation scheme can be calculated after importing data of the crop pattern into CROPWAT 8.0, as shown in Table 2.

Table 2. Estimation of Irrigation Scheme and Total Irrigation Requirements Based on the Crop Pattern and Irrigated Areas in Baoding

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation Deficit												
Wheat	30	50	108.3	157.9	107.3	3.2	0	0	0	41.7	31.1	24.7
Maize	0	0	0	0	0	7.1	58	65.6	24.3	0	0	0
Others	0	0	0	0	40.2	105.3	51.2	68.1	53.4	9.9	0	0
Vegetables	0	31.4	89.8	140.6	28.8	0	0	0	0	0	0	0
Oil Plants	0	0	0	0	55.8	115	55.5	59.1	4.2	0	0	0
Fruits	0	0	0	0	70.9	111.4	42.3	39.2	0	0	0	0

Total	30	81.4	198.1	298.5	303	342	207	232	81.9	51.6	31.1	24.7
Net scheme irr. req. in												
mm/day	0.3	0.7	1.4	2.1	1.3	0.5	1.1	1.2	0.4	0.4	0.3	0.2
mm/month	9.3	18.6	42.5	63	41	14.7	33.8	38.1	13.5	13.1	9.6	7.6
l/s/h	0.03	0.08	0.16	0.24	0.15	0.06	0.13	0.14	0.05	0.05	0.04	0.03
Irrigated area (% of total area)	31	41	41	41	50	90	59	59	58	33	31	31
Irr.req. for actual area (l/s/h)	0.11	0.19	0.39	0.59	0.31	0.06	0.21	0.24	0.09	0.15	0.12	0.09
million m^3	44.09	100.72	206.74	312.76	200.41	69.82	160.20	183.08	67.49	64.00	48.10	36.07
Total												1493.48
Average Annual Actual Supply												1374.33
Irrigation Deficit in million^3												-119.15

Table 2 indicates that the irrigation requirements reached the highest amount in March, April. and May. In June, the total irrigated area reached the maximum during a year, which covered 90% of the total area equipped for irrigation in Baoding. The total irrigation requirements can be obtained by multiplying the irrigation requirements with the irrigated area of each month. The result showed that the maximum amount of irrigation was required in April, while the minimum amount of irrigation was required in December. Given the fact that the average annual actual water supply was 1374.33 million m^3, which resulted in an annual irrigation average deficit of 119.15 million m^3 in Baoding.

Similarly, estimations of irrigation requirements were repeated based on a regional scale, including all counties and districts in Baoding from 2015 to 2019 (Table 3).

Table 3. Supply and Demand Balance in All Counties and Districts in Baoding

	2015			**2016**			**2017**			**2018**			**2019**		
	Irr. Req.	**Actual Supply**	+/-	**Irr. Req.**	**Actual Supply**	+/-	**Irr. Req.**	**Actual Supply**	+/-	**Irr. Req.**	**Actual Supply**	+/-	**Irr. Req.**	**Actual Supply**	+/-
Urban	367	391	24	371	371	0	380	345	35	380	304	76	373	273	100
Laishui	28	73	46	26	68	43	25	68	42	24	43	19	23	34	11
Fuping	25	15	10	26	15	11	24	15	9	24	24	0	24	21	3
Dingxing	154	162	9	154	154	0	154	143	10	154	126	28	154	90	64
Tang	65	57	8	65	52	13	58	38	19	60	92	33	60	59	1
Gaoyang	89	64	25	89	64	25	91	64	27	81	56	25	81	43	38
Laiyuan	10	9	1	10	9	2	9	8	1	9	7	2	9	11	1
Wangdu	79	82	3	81	78	3	81	73	8	80	64	16	80	64	16
Yi	67	54	13	63	48	15	64	47	17	61	42	20	61	57	5
Quyang	51	73	23	51	69	19	49	64	16	47	57	10	48	56	8
Li	118	72	46	118	68	50	103	63	40	113	56	57	114	56	58
Shunping	64	107	44	63	102	38	66	95	28	66	83	17	65	67	1
Boye	76	54	22	76	55	21	78	55	23	78	41	37	78	37	41
Zhuozhou	97	137	40	100	130	31	101	121	20	101	107	6	99	90	9
Anguo	112	119	7	113	113	0	112	105	7	112	92	20	112	82	30
Gaobeidian	95	113	18	97	104	6	99	86	13	99	83	16	100	81	19
Total	1496	1583	87	1503	1501	2	1493	1391	103	1489	1277	212	1481	1120	361

The result in Table 3 shows a decreasing trend in overall irrigation requirements, mainly due to the shrinkage of irrigated areas and the variation of the crop pattern in Baoding. Meanwhile, the intensive competition between agriculture, domestic needs, and industry, as well as the ecological restoration urgently needed in Xiongan New District, significantly reduced the annual actual water supply. The greater cutdown on annual water supply than irrigation requirements resulted in annual irrigation deficits since 2016, and the deficit rapidly increased to 361 million m^3 in 2019. The continuous increase in irrigation deficits led to 75% of the counties suffering from irrigation deficits in Baoding. In 2015, there were nine over-irrigated counties, resulting in a total amount of 87.22 million m^3 irrigation surplus, which covered more than 50% of administrative regions in BC. The irrigation requirements and actual annual supply tended to balance with only 2 million m^3 irrigation deficits in 2016. The continuous increase in irrigation deficits led to 75% of the counties suffering from irrigation deficits except for Laishui, Laiyuan, Quyang, and Shunping in 2019.

Under the pressure of water resources scarcity, the actual irrigation supply was insufficient to maintain the overall irrigation requirements. CWR and irrigation requirements maintain intense while conditions remain unchanged within crop pattern, irrigation performance and water resource management. The source of water supply predominantly relies on water diversion projects, while the inbound water resources are far insufficient for local development. Urbanization and industrial transformation have intensified the water competition when an increasing number of counties have become irrigation deficient since 2015. As the role player in the grain supply within the synergetic strategy, the irrigation deficit cannot be solved by simply reducing the total cultivation areas and shrinking the production in agriculture. The CWR differences among each month during cultivation and uneven supply distribution between each county have emphasized the importance of integrality and comprehensiveness in water resources management. Meanwhile, the situation will worsen because 1) groundwater resources covered nearly 89.7% of the total irrigation supply, and the number needs to be cut down to at least 30.1% in the future for the purpose of ecological restoration; 2) the reduced amount of water can not be obtained from surface water resources since it is already insufficient for agricultural production; 3) urbanization and industrial development will intensify the water resources competition. Therefore, the situation of irrigation must be urgently improved to solve water scarcity.

The improvement can be implemented through physical and political measures. From physical perspectives, 1) the inbound water diversion project, as the most reliable inbound surface runoff, has to ensure a sufficient amount of water resources continuously flow into Baoding; 2) the scale of the area equipped for irrigation can be reduced, which a limited amount of irrigation water can be rationally distributed to maintain the irrigation requirements for a reduced area, which will increase the production per ha; 3) the water-saving irrigation technology has to be extensively adopted to enhance the irrigation efficiency. From political perspectives, 1) the crop pattern should be adjusted at the municipal or county level to reduce the irrigation requirements; 2) a sound dispatching regime for irrigation water resources coordination among each county should be established to balance the supply and demand; 3) a critical standard that aims for water-saving in Baoding should be established for irrigation management; 4) awareness of saving water has to be improved on both management and operational levels.

CONCLUSIONS

Under the water scarcity conditions in Baoding, this study aims to obtain the irrigation requirements on both municipal and county levels via CROPWAT 8.0. An average annual irrigation deficit of 119.15 million m^3 was estimated. The greater cutdown on annual water supply compared to irrigation requirements led to a consecutive exacerbation of the annual irrigation deficit since 2016. Despite counties including Laishui, Laiyuan, Quyang, and Shunping showing a surplus in irrigation supply, the rest of the counties had a shortage of irrigation supply in 2019. To improve the current situation, securing inbound water diversion projects, reducing the area equipped for irrigation corresponded to the limited water resources, and promoting water-saving technology should be urgently implemented in the short term. In the meantime, adjusting the crop pattern, improving the dispatching regime among individual counties, creating critical standards on management, and strengthening the awareness of saving water should also be considered in the long term.

REFERENCE

Allen, Richard G., et al. (2000). "Revised FAO procedures for calculating evapotranspiration: irrigation and drainage paper no. 56 with testing in Idaho." Watershed Management and Operations Management: 1-10.

Baoding Municipal People’s Government Office(BMPGO). (2022/03/28). Available online http://www.baoding.gov.cn/mlbd-1472-316387.html

Baoding Water Conservancy Bureau(BWCB). (2022/03/28). Available online: http://slj.baoding.gov.cn/ejzwgk-17-91-list.html

Baoding Water Resources Evaluation Report, 2rd ed(BWRER). (2006); Baoding Water Conservancy Bureau: Baoding Hebei, China,

Brisson, Nadine, et al. (1998). "STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn." Agronomie 18.5-6: 311-346.

Brouwer, C. and Heibloem, M., (1986). Irrigation water management: irrigation water needs. Training manual, 3.

Cakir, Recep. (2004). "Effect of water stress at different development stages on vegetative and reproductive growth of corn." Field Crops Research 89.1: 1-16.

Chen, Deliang, et al. (2005)."Comparison of the Thornthwaite method and pan data with the standard Penman-Monteith estimates of reference evapotranspiration in China." Climate research 28.2: 123-132.

Chu, Zhaopeng, et al. (2018). "Sustainable development of the economic circle around Beijing: A view of regional economic disparity." Sustainability 10.10: 3691.

Department of Agriculture and Rural Affairs of Hebei Province(DARA). (2022/03/28). Available online: http://nync.hebei.gov.cn/article/gdbhjc/tzgg/202008/20200800017204.shtml

Fang, Chuanglin, et al. (2018). "Evaluating performance and elucidating the mechanisms of collaborative development within the Beijing–Tianjin–Hebei region, China." Sustainability 10.2: 471.

FAO (Food and Agriculture Organization), CROPWAT software. (2022/03/28). Available online: http://www.fao.org/land-water/databases-and-software/cropwat/en/

Feng, Zhiming, Dengwei Liu, and Yuehong Zhang. (2007). "Water requirements and irrigation scheduling of spring maize using GIS and CropWat model in Beijing-Tianjin-Hebei region." Chinese Geographical Science 17.1: 56-63.

Global Map of Irrigation Areas(GMIA). (2013). China; FAO: China; pp. 1-44.

Ko, Jonghan, et al. (2009). "Determination of growth-stage-specific crop coefficients (Kc) of cotton and wheat." Agricultural Water Management 96.12: 1691-1697.

Liu, Zhaowen, et al. (2020). "Towards developing a new model for inclusive cities in China—the case of Xiong’an New Area." Sustainability 12.15: 6195.

Wang, Xue, Xiubin Li, and Liangjie Xin. (2014)."Impact of the shrinking winter wheat sown area on agricultural water consumption in the Hebei Plain." Journal of Geographical Sciences 24.2: 313-330.

Xiongan, China. (2022/03/28). Available online: http://english.xiongan.gov.cn/index.html

Yang, Yanmin, et al. (2010). "Estimation of irrigation requirement for sustainable water resources reallocation in North China." Agricultural water management 97.11: 1711-1721.

Yang, Yanmin, et al. (2014). "Regional water balance based on remotely sensed evapotranspiration and irrigation: An assessment of the Haihe Plain, China." Remote Sensing 6.3: 2514-2533.

Yu, Teng-Fei, et al. (2017). "Simulation of pan evaporation and application to estimate the evaporation of Juyan Lake, Northwest China under a hyper-arid climate." Water 9.12: 952.

Zhang, Xiuzhi, et al. (2017). "The classifying of soil texture types based on the regional soil geochemical elements in Hebei Plain." Quaternary Sciences 37.1: 25-35.