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# Adaptability between agricultural water use and water resource characteristics

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## ABSTRACT

Based on analysis of characteristic of agricultural water, water requirement characteristic of main water-intensive crops and effective precipitation throughout each city in Henan Province, agricultural water deficit and crop irrigation water productivity under the condition of natural precipitation and manual irrigation are calculated and the adaptability between agricultural water and water resources characteristic are revealed. The results show that under the condition of natural precipitation, water deficit in Henan Province is 240.5mm and falls to 76.3 mm after manual irrigation. The deficit period is concentrated mostly in March ~ June, accounting for more than 65% of annual water deficit. Spatially water deficit is gradually decreasing from north to south, and agricultural irrigation water productivity is relatively high in central China and relatively low in the south and north. Thereby, the region with full irrigation (the south) and the region with large crop water deficit (the north) have a relatively low irrigation water productivity; a certain degree of water deficit (in central China) is conductive to improvement of crop irrigation water productivity. And then the adaptability between regional agricultural water and water resource characteristic shall not be balanced simply based on the degree of crop water deficit, instead, it shall be closely combined with irrigation water productivity.

## KEYWORDS

Agricultural water use; Effective precipitation; Water resource characteristic; Irrigation water productivity; Adaptability.

Water resources is really short in Henan Province and the water resource of per capita is 441m³, accounting for 1/5 of national average; water consumption per mu (a unit of area (=0.0667 hectares)) is 403m³, accounting for 1/6 of national average [1]. As a big agricultural and grain province, Henan Province's grain yield accounts for 10% of national yield, but stable and high grain yield is premised on sufficiency of agricultural water resources [2]. In water consumption in Henan Province, agricultural water consumption accounts for more than 55% and consumes the most water resources. Therefore, it is really important for Henan Province to study the adaptability between agricultural water use and water resource characteristic. Also it is importation to analyzeits spatial distribution of water deficit and irrigation water productivity in order to develop water-saving high-efficiency agriculture and relieve the crisis of water resources [3].

## AGRICULTURAL WATER CHARACTERISTICS IN HENAN PROVINCE

Henan Province is located in east central China, in the middle and lower reaches of the Yellow River, including 18 cities such as Zhengzhou, Luoyang, Puyang, Kaifeng and Luoyang, etc, with coverage of 167,000km$^2$ and a population of 95.291 million. Its northern part enjoys warm temperate climate and its south part enjoys subtropical climate, with four distinctive seasons and precipitation concentrated in the period from June to September.

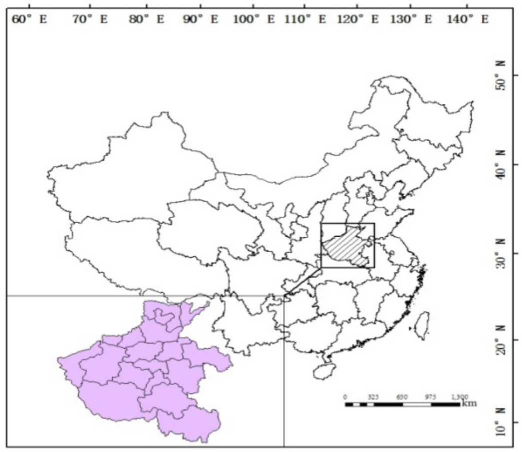



Fig.1 Location of Henan Province

In 21st century, though agricultural water consumption in Henan Province shows a trend of fluctuation decrease, it has always been kept above 11.00 billion m$^3$/a, with an average of 13.44 billion m$^3$/a. During the period, agricultural waterconsumption was the highest in 2001, being 15.96 billion m³/a and the lowest in 2003, being 113.4 m$^3$/a, as shown in Fig.2. Agricultural water proportion was kept at higher than 55.0%, with average of 61.5%. In 2005, agricultural water consumption was the largest share in total water consumption, up to 73.1%; in 2008, it was the smallest, being 55.4%. Agricultural water consumption is relatively high in Henan Province and takes a relatively large share in total water consumption, which decides that agricultural water consumption in Henan Province will directly affect sustainable development of agricultural safety and water resources.

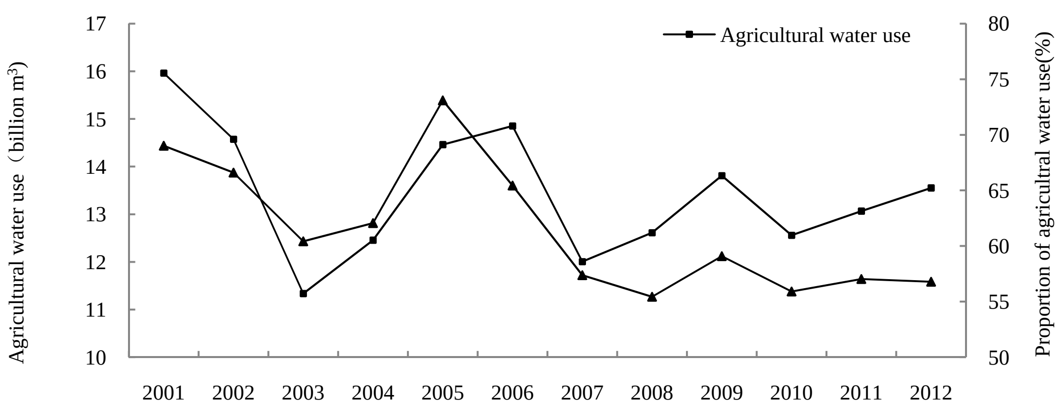



Fig. 2 Agricultural Water in Henan Province during 2001~2012

## ADAPTABILITY BETWEEN CROP WATER REQUIREMENT AND PRECIPITATION CHARACTERISTIC

### Characteristics of crop water requirement

Henan Province (except Xinyang) takes winter wheat and summer maize as main food crops, according to 2001~2012 *Statistical Yearbook of Henan Province*, double cropping system of winter wheat and summer maize accounts for about 57% of total planting area. However, winter wheat an summer maize are all water-intensive crops and consume water of about 800~900 mm each year[4], multi-year average precipitation of 782.2mm cannot meet crop requirement and irrigation must be supplemented. Though Xinyang gives priority to rice growing, it also grows winter wheat and summer maize. Here double cropping system of winter wheat and summer maize is studied.

In Henan Province, growth period of winter wheat is mainly concentrated in the period from the first ten days of October to the first ten days of June next year, about 240d generally, and can be divided into the growth stages including seeding, wintering, revival, jointing, blooming and maturation, etc. A large amount of water is needed in the period from seeding to jointing, accounting for about 30%~40% of total water requirement in the whole growth period, then the water amount needed in the period from grain filling to maturation accounts for about 20~30% of total water requirement in the whole growth period, the water amount needed in the period from jointing to heading is close to that needed in the period from heading to grain filling, accounting for 10%~20% of total water requirement in the whole growth period[5].

Summer maize will be planted in the middle tens of June and harvested in the last ten days of October, with a whole growth period of 91d, including the stage of sprouting, jointing, heading, grain filling, ripening and reaping. Daily water requirement is small in seeding stage, then it will increase significantly after jointing stage and reach a peak in heading and blooming stage, and still keep at a relatively high level in grain filling stage and then significantly decrease after maturation stage[6,7].

Monthly water requirement in winter wheat-summer maize planting mode [5,6] is as shown in Fig.1.

Table 1 Monthly Water Requirement in Double Cropping System of Winter Wheat-Summer Maize (mm)

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water requiremen t | 22.3 | 26.2 | 49.0 | 115.8 | 141.7 | 89.5 | 119.9 | 112.3 | 77.5 | 32.0 | 38.4 | 25.7 | 850.3 |

### Effective precipitation characteristic of crops

The main effect of precipitation on crops is to supplement plowing-layer soil moisture necessary to crop growth; the effect of precipitation on the crops mainly depends on whether it can supplement the rainfall to effective roots of the crops, which is a mark to balance effective precipitation of farmland [8]. Therefore, effective precipitation refers to the part of precipitation necessary to crop evapotranspiration in crop cultivation condition, excluding surface runoff and those seeped to crop roots and also excluding those deep seepage of precipitation necessary to salt leaching, because this part of water is not used for crop evapotranspiration[9]. Effective precipitation may be affected by many complex factors, different crop strains, growth stage, water consumption characteristics, precipitation characteristics, soil characteristics, groundwater depth, farming management measures and other factors may directly or indirectly affect its amount[10]. Calculation methods for effect precipitation include field instrument measurement method, experience formula method and water balance method [11-13]. In this paper, experience formula method is used to calculate effective precipitation:

$$P_e = \alpha P_t$$

Table 2 Monthly Average Effective Precipitation under Different Precipitation Frequencies (mm)

| Month | Wet year (p=25%) | Normal year (p=50%) | Dry year (p=75%) |
|---|---|---|---|
| 1 | 9.0 | 8.0 | 6.6 |
| 2 | 12.2 | 13.1 | 9.5 |
| 3 | 26.5 | 21.2 | 21.7 |
| 4 | 42.4 | 36.6 | 23.4 |
| 5 | 63.8 | 49.6 | 37.6 |
| 6 | 70.4 | 65.8 | 37.5 |
| 7 | 162.2 | 125.6 | 129.3 |
| 8 | 151.0 | 99.1 | 61.0 |
| 9 | 93.3 | 64.8 | 39.9 |
| 10 | 45.3 | 34.7 | 29.5 |
| 11 | 22.4 | 22.9 | 16.7 |
| 12 | 7.3 | 8.5 | 7.4 |
| 合 ▪ | 706.0 | 549.8 | 419.1 |

Where, $P_t$ is quantity of precipitation (mm); $P_e$ is effective precipitation (mm); $\alpha$ is effective utilization coefficient of precipitation, which is related to quantity of precipitation, precipitation intensity, precipitation duration, soil nature, ground cover, terrain and other factors. It is generally held that when quantity of precipitation is less than 5mm, $\alpha$ =1.0; when quantity of precipitation is 5~50mm, range of $\alpha$ is 0.8~1.0, when quantity of precipitation is larger than 50mm, range of $\alpha$ is 0.7~0.8[14]。

The results of monthly effective precipitation at different frequencies calculated according to 53 years of data and materials of Henan Province from 1961 to 2013 are as shown in Table 2 below.

From Table 2 it can be drawn that annual distribution of effective precipitation in Henan Province is relatively concentrated. Effective precipitation is 476.9mm in the period from June to September in a wet year, 355.3mm in a normal year and 267.7mm in a dry year, respectively accounting for 68%, 66% and 63% of total effective precipitation of the corresponding year.

### Adaptability between crop water requirement and effective precipitation

Effective precipitation in a wet year in Henan Province is 706.0mm;it can meet the crop water requirement in the period from July to October while it cannot meet the requirement in other months, with water deficit of 254.6mm, as shown in Fig.3. Effective precipitation in a normal year is 549.8mm, it can meet the crop water requirement in July and October and is in short in other months with different degrees, with total water deficit of 308.8mm. Effective precipitation is 419.1mm in a dry year, it is not in short only in July and cannot meet crop water requirement in other months, with total water deficit of 439.6mm.

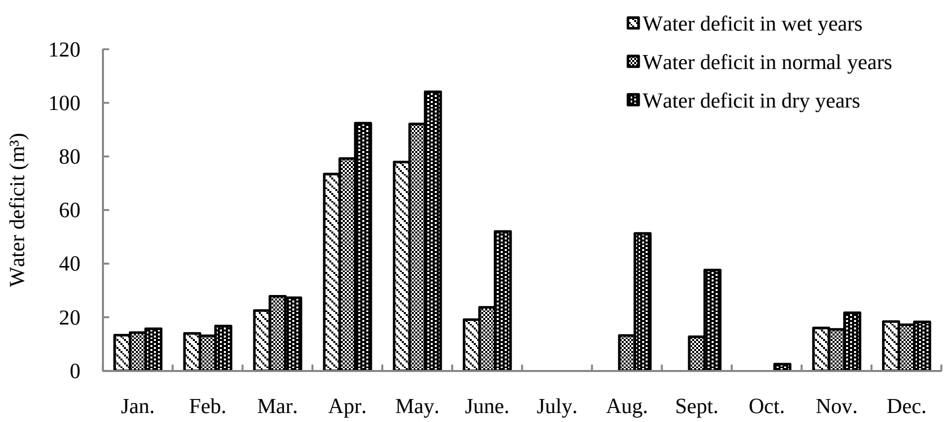



Fig.3 Water Deficit in Winter Wheat-Summer Maize Planting Mode under Different Frequencies

The difference of the effect of wet year, normal year and dry year on crop water deficit is mainly reflected in two aspects. Firstly, crop water deficit will gradually increase along with decrease of effective precipitation. For example, in May, effective precipitations in a wet year, normal year and dry year are respectively 63.8mm, 49.6mm and 37.6mm, with a decrease trend,while water deficits are respectively77.9mm, 92.1mm and 104.1mm, with an increase trend.Secondly, deficit duration is gradually prolonged along with decrease of effective precipitation. Water deficit may not occur in the period from July to Octoberin a wet year, not occur in July and October in a normal year and not occur only in July in a dry year.

The period from March to June is the main water deficit period, water deficit in the period respectively accounts for 75.8%, 72.2% and 62.7% in a wet year, normal year and dry year. Water deficit in the period from March to June happens because precipitation in the period is relatively small, less than 20% of annual precipitation, and spring drought has become an outstanding disastrous weather. On the other hand, the period from March to June is the key growth period of winter wheat, needing relatively large amount of water. Under the combined action of small precipitation and high-quantity water requirement, crop growth and precipitation in the period from March to June come up withinsufficient adaptation, which is also a real reflect of “Rain in spring is as precious as oil.”In addition, water deficit is also relatively serious in the period from August to September, mainly because this period is the water-intensive growth stage of summer maize, needing large amount of water. Furthermore, due to “summer drought”, precipitation is also relatively small.

## DISTRIBUTION CHARACTERISTICS OF REGIONS WITH AGRICULTURAL WATER DEFICIT

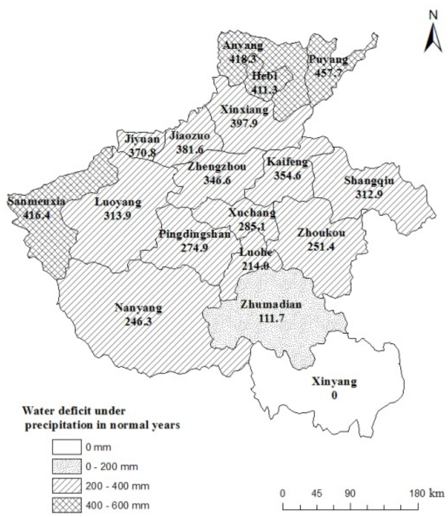
### Distribution characteristics of water-deficit regions under natural precipitation condition

Under natural precipitation condition, distribution characteristics of water deficit of each city in Henan Province are as shown in Fig.4. As a whole, natural precipitation of each city in Henan Province cannot meet crop water requirement, thenorthern region has a relatively large water deficit while the southern region has a relatively small water deficit, which is mainly inseparable from the distribution characteristics of Henan Province’s precipitation, on a diminishing scale from south to north.

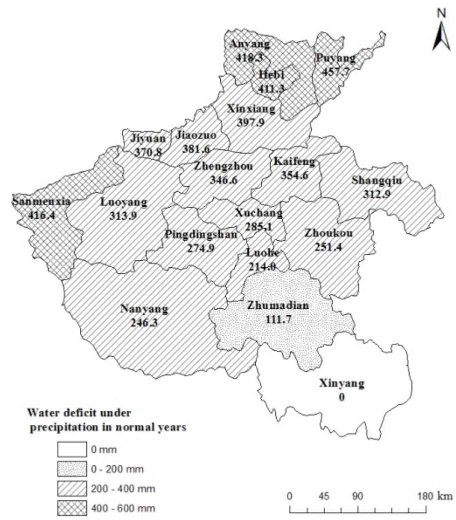
In a wet year, Xinyang, Nanyang and Zhumadian in the southern region in Henan Province are not in short of water while Anyang, Puyang, Hebi, Xinxiang, Jiaozuo, Jiyuanin the northern regionand Sanmenxia in the western region are in short of water of 200~400mm, and other cities are in short of water of an amount less than 200mm.

In a normal year, only the natural precipitation of Xinyang can meet the crop water requirement while other cities endure water deficit of different degrees. Among them, Zhumadianendures a relatively small water deficit, about 111.7mm; Anyang, Puyang, Hebi in the northern region and Sanmenxia in the western region endure a relatively large water deficit, more than 400mm; other cities endure water deficit of 200~400mm.

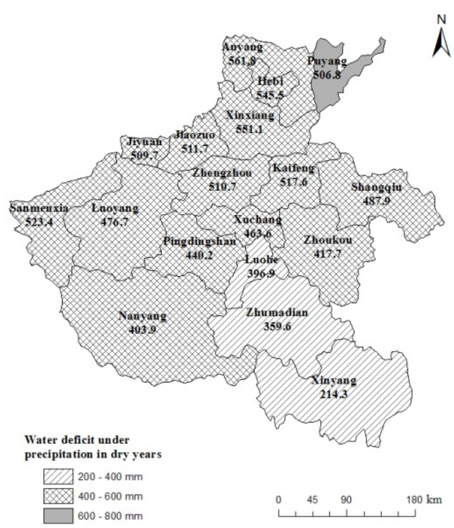
In a dry year, all cities in Henan Province endure water deficit of an amount more than 200mm, except Xinyang, Zhumadian and Luohethatendure water deficit of 200~400mm, the other 15 cities endure water deficit of an amount more than 400mm. Among them, Puyanghas the largest water deficit, up to 606.8mm.




(a) Spatial Distribution of Water Deficit in a Wet Year




(b) Spatial Distribution of Water Deficit in a Normal Year




(c) Spatial Distribution of Water Deficit in a Dry Year

Fig.4 Spatial Distribution of Water Deficit under Natural Precipitation in a Wet Year, Normal Year and Dry Year

**Distribution characteristics of regions with water deficit under manual irrigation condition**

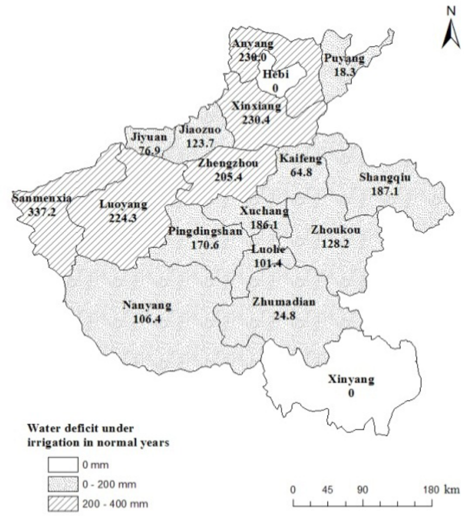
After the intervention with manual irrigation, distribution of regions with agricultural water deficit of each city in Henan Province is as shown in Fig.5.

In a wet year, Anyang, Xinxiang and Zhengzhou in Henan Province are in short of water, but less than 60mm; Sanmenxia has a relatively large water deficit, being 182.8mm, and other regions can meet crop water requirement for growth after manual irrigation.

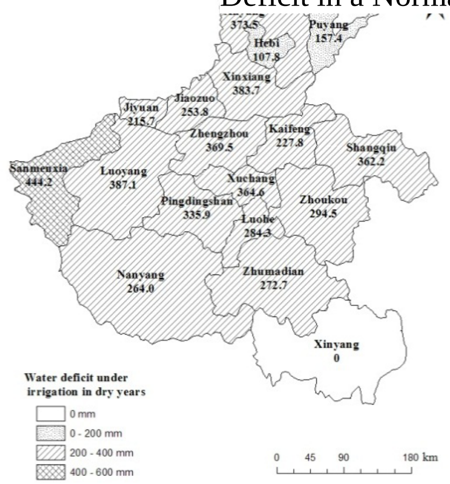
In a normal year, after manual irrigation, Xinyang and Hebi are not in short of water anymore. Cities such as Anyang, Xinxiang, Zhengzhou, Luoyang and Sanmenxia in the western region endure relatively serious agricultural water deficit, being more than 200mm. Other cities endure agricultural water deficit of 0~200mm.

In a dry year, after manual irrigation, only Xinyang is not in short of water. Sanmenxia endures water deficit of more than 400mm, and except Puyang and Hebithat endure water deficit of an amount less than 200mm, all other cities endure relatively serious water deficit of an amount of more than 400mm.


(a) Spatial Distribution of Water Deficit in a Wet Year




(b) Spatial Distribution of Water Deficit in a Normal Year




(c) Spatial Distribution of Water Deficit in a Dry Year

Fig.5 Spatial Distribution of Water Deficit in a Wet Year, Normal Year and Dry Year under Manual Irrigation Condition

Relative to natural precipitation condition, after manual irrigation, the number of water-deficient regions and water deficit decrease significantly, and water-deficient regions and water deficit are mainly concentrated in northern region and western region in Henan Province after irrigation. Water deficit in the northern region mainly results from low precipitation, while water deficit in the western region results from hilly mountain terrain, weak agricultural infrastructures, insufficient irrigation and other factors, in addition to low precipitation.

**Region distribution of agricultural irrigation water productivity**

Irrigation water productivity refers to the number of agricultural products produced by unit irrigation water. Irrigation water productivity can not only directlyreflect the crop output effect of unit irrigation water input into the region, but also comprehensively reflect agricultural production level, irrigation engineering state and irrigation management level of a region[15-18]. Calculation formula of irrigation water productivity is as shown below.

$$WP_i = Y/W_i$$

Where, $WP_i$ is irrigation water productivity (kg/m$^3$); Y is total crop output of the irrigation region (kg) or the production of unit area (kg/hm$^2$); $W_i$ is total irrigation water consumption of the irrigation region (m$^3$) or irrigation water consumption of unit area (m$^3$/hm$^2$).

Calculation results and region distribution of irrigation water productivity of Henan Province in 2011 are as shown in Fig.6. The central region enjoys relatively high irrigation water productivity, Sanmenxia, Luoyang, Nanyang, Pingdingshan, Xuchang, Luohe, Zhoukou, Shangqiu and Zhumadian enjoy an irrigation water productivity of more than 4.0kg/m³. Among them, Xuchagn and Zhumadian enjoy the highest productivity, up to 7.3kg/m$^3$ and 7.2kg/m$^3$ respectively. In the northern region, Anyang, Xinxiang, Jiaozuo, Zhengzhou and Kaifeng take second place in irrigation water productivity, ranging 2.0~4.0 kg/m$^3$. Puyang, Hebi, Jiyuan in the northern region and Nanyang in the southern region enjoy the lowest irrigation water productivity, lower than 2 kg/m$^3$. Among them, Xinyang enjoys irrigation water productivity as low as 1.1kg/m³.

Xinyang enjoys the lowest irrigation water productivity mainly because of high precipitation, abundant water resources, low irrigation efficiency and waste of agricultural water resources in this region, while Puyang, Hebi and Jiyuan in the northern region enjoy lower water deficit and more abundant irrigation than other regions in a wet year, normal year and dry year, but crop output effect of irrigation water is relatively low mainly because that a certain amount of water deficit (insufficient irrigation) is conductive to increase of crop production.

The central region in Henan Province enjoys the highest irrigation water productivity, because water deficit existing after manual irrigation is suitable for crop growth and production increase.

Anyang, Xinxiang, Jiaozuo, Zhengzhou and Kaifeng in thenorthern region enjoy moderate irrigation water productivity, because water deficit is still relatively high after irrigation, which restrains crop production and increase of production.

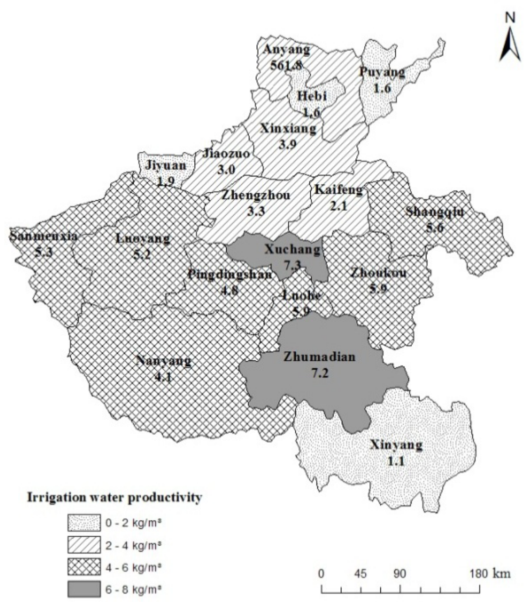



Fig.6 Spatial Distribution of Irrigation Water Productivity

Based on contrastive analysis of distribution characteristics (Fig.6) of regions of agricultural irrigation water productivity in Henan Province and distribution characteristics of regions of crop growth-related water deficit under manual irrigation condition (Fig.5), it can be drawn that the regions without water deficit (Xinyang in the southern region of Henan Province) or with high water deficit (the northern region of Henan Province) after manual irrigation enjoy relatively low irrigation water productivity, however, a certain degree of water deficit is conductive to increase of crop irrigation water productivity (the central region of Henan Province). It shows that irrigation water productivity will be not only affected by total production of irrigated crops and irrigation water in the irrigation region, but also be closely related to water deficit after manual irrigation and other factors.

A certain degree of water deficit is conductive to increase of irrigation water productivity of crops, therefore, the adaptability between regional agricultural water and characteristics of water resources cannot be simply balanced depending on water deficit of crops, instead, it shall be closely combined with irrigation water productivity. That is, a proper water deficit can enable limited water resources to produce higher agricultural production effectiveness and prompt the adaptability between the agricultural water and water resources.

## CONCLUSION

(1) In a wet year, normal year and dry year, along with decrease of effective precipitation, crop water deficit in Henan Province gradually increases and water deficit duration is gradually prolonged. Water deficit period is mainly dominated by the period from March to June, and obvious inadaptability occurs between crop growth and precipitation characteristics.

(2) Natural precipitation in all cities in Henan Province cannot meet crop water requirement, the northern region endures a relatively high water deficit while the southern region endures a relatively low water deficit, which is inseparable from the diminishing precipitation distribution characteristics from south to north in Henan Province. After manual irrigation, the number of water-deficient regions in Henan Province and water deficit decrease significantly, and the water-deficient regions are mainly concentrated in the northern and western regions.

(3) The overall trend in irrigation water productivity in Henan Province is high in central region and relatively low in the southern and northern regions, showing the regions with full irrigation (the southern region) and high crop water deficit (the northern region) enjoy a relatively low irrigation water productivity, however, a certain degree of water deficit (the central region) is conductive to increase of crop irrigation water productivity.

(4) The adaptability between regional agricultural water and characteristics of water resources cannot be simply balanceddepending on crop water deficit, instead, it shall be closely combined with irrigation water productivity. Proper water deficit is conductive to promoting the adaptability between agricultural water and water resources.

## CONFLICT OF INTEREST

This article content has no conflict of interest.

## ACKNOWLEDGEMENT

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