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Study on Multi-water Sources Allocation Based on Multi-scenario potential tapping under Extreme Drought: An Example from the Yellow River Water Supply Area in Henan

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Abstract: The water supply of water resources allocation under extreme drought is insufficient, and the limited available water resources make it urgent to tap the potential of water supply. In this paper, the Yellow River water supply area in Henan Province is taken as an example to study the multi-water source allocation under extreme drought. According to the Palmer Drought Severity Index (PDSI), the extreme drought years are selected, and the water supply and demand balance in the extreme drought years is analyzed, and the water shortage degree of each water supply area is obtained. In this paper, unconventional water, flood resource utilization and elastic exploitation of

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groundwater are used as potential water sources. Different water supply scenarios are set up according to different potential tapping measures, and multi-scenario supply increase under extreme drought is explored. A multi-water source allocation model with the goal of minimizing water shortage is constructed, and a multi-scenario supply increase allocation scheme is proposed, which provides a basis for the study of water supply increase allocation to alleviate the drought degree of the the Yellow River Water Supply Area in Henan. Through the Multi-scenario potential tapping of multiple water sources, the existing potential water volume can be maximized, which is conducive to reducing the water supply pressure and water use restrictions of conventional water sources, improving the support capacity and guarantee capacity of water resources, and reducing the economic and social development bottlenecks caused by extreme drought.

Keywords: Multi-water sources allocation; Multi-scenario potential tapping; Palmer Drought Severity Index; the Yellow River Water Supply Area in Henan

Introduction

Drought is a common and complex natural disaster. In the past 50 years, 34% of the people affected by natural disasters in the world have been affected by drought (WMO, 2021). The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2021) pointed out: Climate change is exacerbating the uneven water cycle. High temperatures and multiple types of drought events are frequent in parallel, causing varying degrees of drought in many regions. In recent years, the dry and wet imbalance in the Yellow River Water Supply Area in Henan with monsoon climate characteristics. According to the “China Drought Disaster Data Set” (Zhu et al, 2018), the Yellow River Basin has staged 5~6 extreme droughts in the past 50 years. The extreme drought events in the Yellow River Basin are staged every 10 years (Zhu et

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al,2018; Zheng et al, 2022), which limits the development of industrial and agricultural production, life development, ecological environment and other aspects. With the development of social economy, the allocation of conventional water resources has been unable to meet the expected demand. The Ministry of Water Resources "Guidance on the Integration of Unconventional Water Resources into the Unified Allocation of Water Resources" (Zhou, 2017) emphasizes the importance of the potential research of unconventional water resources, so that it can play a guarantee role in the water resources allocation system, and requires the use of various means to expand the scope of allocation and increase the proportion of water distribution. Therefore, on the basis of the existing conventional water resources, it will be an important measure to alleviate the drought in the Yellow River Water Supply Area in Henan by tapping the potential and increasing the supply, and integrating unconventional water, flood resources and elastic exploitation of groundwater into the water source system of water resources allocation.

In recent years, the theory and technology of conventional water resources allocation have become more mature, and the research on optimal allocation of water resources has attracted attention at home and abroad. Wang Yu et al. (2021) scientifically set the water diversion index in the river according to the incoming water situation, and at the same time consider fairness and efficiency, and increase the saved water supply to the provinces along the Yellow River; Yang Mingzhi et al. (2022) regarded social water use and natural hydrology as the research object, studied the feedback between the two processes, and developed a distributed allocation model based on the water cycle; Tan et al. (2018) took the unilateral water benefit as the objective function, considered the fractional programming and robust optimization at the same time, and established the water resources optimization model, which improved the utilization efficiency of

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agricultural water; Ren et al. (2017) gave full play to the advantages of multi-objective fuzzy programming, constructed a multi-objective model of multiple benefits, rationally planned land use and irrigation water, and obtained an effective and fair irrigation plan; Aiming at the prediction of water supply and demand and its comprehensive value, Zhang et al. (2023) used the WRA model to study the coordination and stable development of each system, used the emergy analysis method to carry out quantitative analysis, reasonably calculated the base year and the planning year, and proposed a sustainable water distribution plan; Sperotto A et al. (2019) discussed the application of multi-scenario analysis method based on Bayesian network in water quality sustainability assessment under uncertain conditions. Razavi S et al. (2014) used a multi-scenario, multi-reservoir optimization method to evaluate these new control structures, and proposed an optimization model based on dynamic programming; Marques J et al. (2015) proposed a new ROs method to deal with the uncertainty and two conflicting objectives throughout the planning scope, and defined some new possible expansion areas for different scenarios; Banadkooki F B et al. (2022) discussed the optimal allocation of water resources in arid basins, analyzed 13 scenarios, and determined the optimal solution by comparing the results of GA and NSGA-II optimization techniques; Balla K M et al. (2020) established a multi-scenario MPC (MS-MPC) method to deal with the uncertainties of the expected inflow of urban drainage network (UDN). Most of the above studies use conventional water as the configuration water source. The water source configuration is relatively simple, and the scenario selection lacks consideration of multiple water sources. The optimization of the model and the improvement of the configuration method are limited. At present, the utilization of rainwater and other unconventional water sources in the Yellow River Water Supply Area in Henan is only 465 million m3 (2021 Annual “China Water

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Resources Bulletin" released, 2018). Therefore, this paper will start from the perspective of tapping potential and increasing supply, and take unconventional water, flood resources and elastic exploitation of groundwater as new water sources to study the allocation of water resources in the Yellow River Water Supply Area in Henan under extreme drought.

In this paper, the water resources allocation under different potential tapping scenarios under extreme drought is taken as the research focus, and the Palmer Drought Severity Index(PDSI) is taken as the research index to study the drought structure distribution and water shortage in extreme drought years. Based on the multi-scenario mining potential of multi-water sources, a water resources allocation model with the goal of minimizing water shortage is constructed. According to the water demand level and allocation principle, a multi-scenario allocation scheme is proposed to provide a strong basis for future research on drought control measures.

1 Overview of the study area

1.1 Watershed generalization

The Yellow River Water Supply Area in Henan is located along the Yellow River, located in the northern part of Henan Province (Figure 1), accounting for nearly half of the area of Henan Province, the specific regional reference Table 1. The Yellow River Water Supply Area in Henan contains 14 cities, some of which are not fully covered. At present, the total population of the Yellow River water supply area is about 69.8 million, and the urbanization rate is 54% (Du, Liu, and Hao, 2020). The effective irrigation area in the water supply area is 53.6 million mu, and the actual irrigation area is 47.8 million mu (Du, Liu, and Hao, 2020). The total amount of water supply in the cities of the Yellow River water supply area is reduced, and the unbalanced spatial and temporal precipitation leads to a large water gap in the southwest region (Yao et al, 2018). The

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gap between flood season and non-flood season is prominent, and the proportion of flood season inflow is relatively large (about 60%~70%) (Fang et al, 2019), and the runoff is mostly distributed in mountainous areas(Sun, 2021). In recent years, the total amount of water used in the Yellow River water supply area has been increasing, domestic water and ecological water use have increased, industrial water and agricultural water use have generally declined, and the overall drought situation in the region has continued (Sun, 2021).

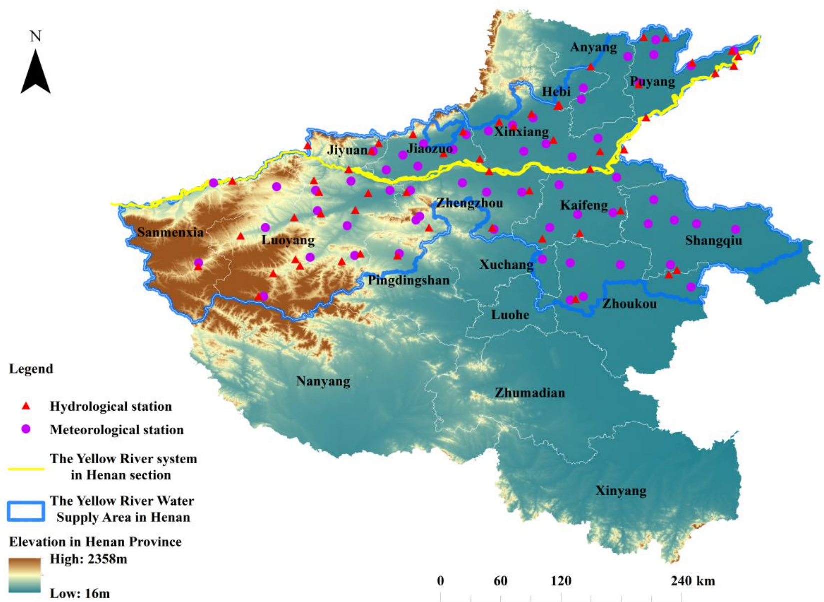

Figure 1 The administrative division of the Yellow River Water Supply Area in Henan and the map of meteorological and hydrological stations

Table 1 The specific division scope of the Yellow River Water Supply Area in Henan

Partition of water supply area	Specific scope	Partition	Specific scope
Zhengzhou division	Municipal district,Gongyi City,Xingyang City,Zhongmu County,Xinzheng City,Dengfeng City	Jiaozuo division	Qinyang City, Mengzhou City, Boai County, Wuzhi County, Wen County, Xiuwu County

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Kaifeng division	Municipal districts, Qixian County, Weishi County, Lankao County, Tongxu County	Puyang division	municipal distric, Fan County, Taiqian County, Puyang County, Qingfeng County, Nanle County
Luoyang division	Municipal district, Yanshi City, Mengjin County, Yiyang County, Luoning County, Yichuan County, Xin 'an County, Luanchuan County, Song County, Ruyang County	Xuchang division	Yanling County
Pingdingshan division	Ruzhou City	Sanmenxia division	Municipal districts, Yima City, Mianchi County, Lushi County, Lingbao City
Anyang division	Hua County, Neihuang County	Shangqiu division	Municipal districts, Yucheng County, Zhecheng County, Xiayi County, Minquan County, Ningling County, Sui County
Hebi division	Xun County	Zhoukou division	Luyi County, Fugou County, Xihua County, Taikang County
Xinxiang division	Municipal distric, Weihui City, Yanjin County, Fengqiu County, Changyuan County, Xinxiang County, Huojia County, Yuanyang County	Jiyuan division	Jiyuan demonstration area
Total	63 counties (cities, districts)		

1.2 Basic information

The data come from the Resource and Environmental Science and Data Center and the Henan Provincial Water Resources Bulletin. The data of 59 meteorological stations in the Yellow River Water Supply Area in Henan were collected. The data of precipitation, temperature and soil were based on 58 years (1961-2018) monthly data.

2 Selection of extreme drought years and setting of potential tapping scenarios

2.1 Selection of extreme drought years

In this paper, the extreme drought years the Yellow River Water Supply Area in Henan are selected according to the Palmer Drought Severity Index (PDSI). Figure 2 is the PDSI histogram from 1961 to 2018, which reflects the drought change of the PDSI annual sequence in the Yellow River Water Supply Area in Henan. According to the size of the PDSI value, the drought grade is

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divided (Lu et al, 2022), as shown in Table 2.

Table 2 PDSI drought classification standard table

PDSI	Drought level	PDSI	Drought level
(-1, 1)	Normal	(-4, -3]	Serious drought
(-2, -1]	Light drought	(-∞, -4]	Extreme drought
(-3, -2]	Moderate drought		

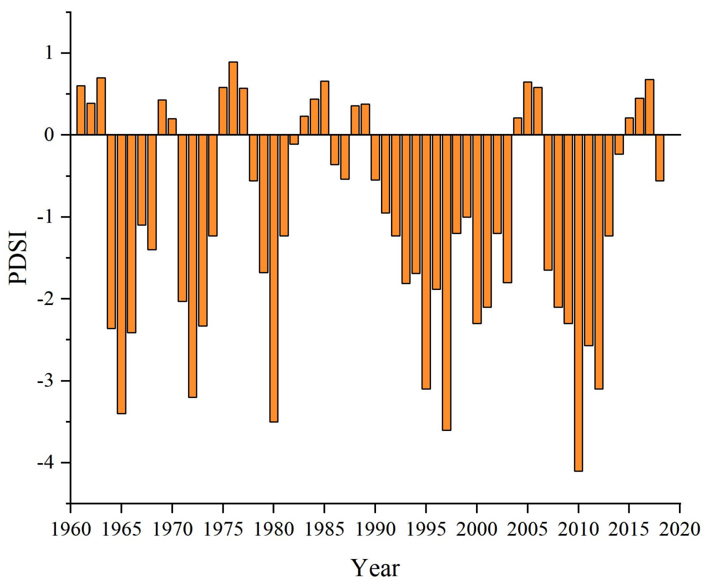

Figure 2 The overall PDSI annual sequence histogram of the Yellow River Water Supply Area in Henan

From the above Figure 2, it can be seen that from 1961 to 2018, there were many frequent drought years in the Yellow River Water Supply Area in Henan as a whole. Among them, serious droughts occurred in 1965, 1972, 1980, 1995, 1997, 2010 and 2012, and serious droughts were staged every 10 or so. The degree of drought in 2010 reached the level of extreme drought, and the other years were mild drought or normal. Therefore, 2010 was selected as the extreme drought

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year. The distribution of drought grade in each district of the Yellow River Water Supply Area in Henan in 2010 is shown in Figure 3.

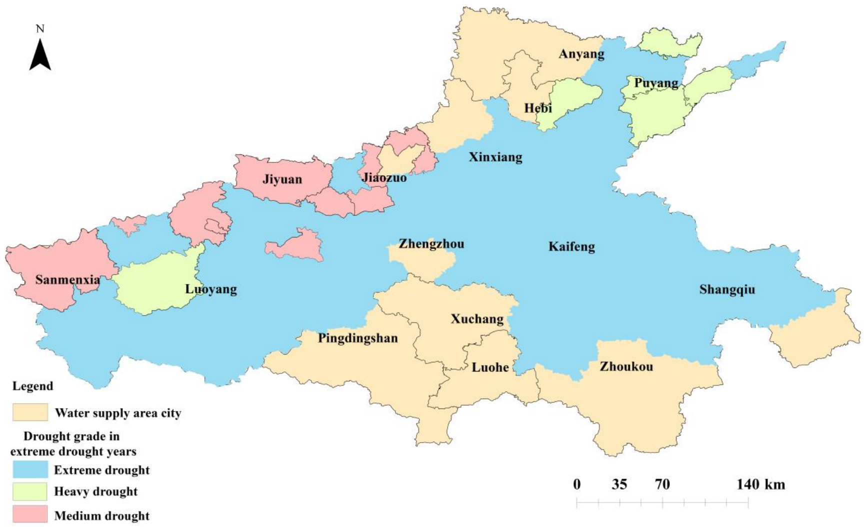

Figure 3 Distribution of drought grade in the Yellow River Water Supply Area in Henan in 2010

It can be seen from Figure3 that, on the whole, the drought degree of the Yellow River Water Supply Area in Henan reached the level of extreme drought in 2010.Extreme drought occurred in 48 of the 63 districts and counties, and severe drought or moderate drought occurred in the remaining districts and counties (some districts and counties in Sanmenxia City, Jiyuan City, Jiaozuo City, Luoyang City, Puyang City and Hebi City).

According to the water resources bulletin of Henan Province in 2010 and the "Water Quota" (Qian, 2019), the supply and demand balance of the Yellow River Water Supply Area in Henan in 2010 was analyzed, as shown in Table 3.

Table 3 The Yellow River Water Supply Area in Henan in 2010 supply and demand balance analysis table Unit: hundred million m^3

Partition of	Water demand in 2010	Water supply in 2010	Differentials	Water

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water supply area	Agric ulture	Industry	Life	Ecology	Subtotal	Surfac e water	Ground water	Other water	Subtotal		shortage rate (%)
Zhengzhou division	3.49	4.78	4.69	4.12	17.07	4.72	6.92	0.24	11.88	-5.19	30.40
Kaifeng division	10.28	2.45	1.77	3.25	17.74	3.03	8.56	0	11.59	-6.15	34.67
Luoyang division	4.29	5.84	2.61	1.84	14.58	6.19	5.53	0	11.72	-2.86	19.61
Pingdingshan division	1.18	1.55	0.39	0.10	3.22	0.83	1.22	0	2.04	-1.18	36.66
Anyang division	7.10	1.21	0.87	1.39	10.56	1.75	4.65	0	6.40	-4.16	39.38
Hebi division	1.50	0.35	0.40	0.35	2.61	0.48	1.35	0	1.83	-0.78	29.87
Puyang division	11.94	3.06	1.28	1.05	17.33	7.54	4.95	0.30	12.79	-4.54	26.18
Xuchang division	1.04	0.49	0.28	0.22	2.03	0.37	0.65	0	1.02	-1.01	49.81
Sanmenxia division	1.31	1.50	0.86	0.56	4.23	2.17	1.37	0.03	3.58	-0.65	15.33
Shangqiu division	10.55	1.67	1.96	0.65	14.83	1.41	7.41	0	8.82	-6.01	40.52
Zhoukou division	8.11	1.52	1.65	0.42	11.71	0.45	7.61	0	8.06	-3.65	31.18
Jiyuan division	0.99	0.77	0.22	0.46	2.44	1.09	0.80	0.09	1.99	-0.45	18.34
Jiaozuo division	6.54	3.02	1.00	0.50	11.07	3.71	5.17	0	8.89	-2.18	19.66
Xinxiang division	12.25	2.04	1.77	1.16	17.21	4.85	5.61	0	10.46	-6.75	39.24
Total	80.56	30.24	19.74	16.08	146.62	38.60	61.81	0.66	101.07	-45.55	31.07

It can be seen from Table 3 that the total water demand the Yellow River Water Supply Area in Henan is 14.662 billion m^3, the total water supply is 10.107 billion m^3, the total water shortage is 4.555 billion m^3, and the water shortage rate is 31.07%. In general, the supply and demand of the Yellow River Water Supply Area in Henan is unbalanced in extreme drought years, and the water shortage rate of 8 water supply areas exceeds 30%. In order to ensure the normal needs of residents and the good ecological environment, it is urgent to tap the water supply potential of unconventional water sources, flood water sources and elastic exploitation of groundwater.

2.2 Potential tapping scenario setting

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On the basis of the structure of the original water supply source, the water source system is expanded and managed according to local conditions to maximize the supply capacity of water resources, such as expanding the construction of reclaimed water and rainwater harvesting projects, the appropriate adjustment of the flood limit water level of the reservoir, and improving the utilization rate of reclaimed water and sewage. The Multi-water sources allocation of different potential tapping scenarios is to study the potential of unconventional water sources, flood water resources and elastic exploitation of groundwater under extreme drought. According to different supply increase measures, it is divided into three water supply scenarios to study the multi-scenario supply increase under extreme drought, so as to realize the sustainability of water resources supply and the maintenance of ecological environment. The development potential of unconventional water sources is great. At present, the utilization form of unconventional water sources in the Yellow River Water Supply Area in Henan is mainly rainwater harvesting. Under extreme drought conditions, it is necessary to increase the scale of rainwater harvesting facilities, improve the utilization efficiency of reclaimed water and sewage, and increase the utilization of mine water; In order to improve the accuracy of flood forecasting, it is necessary to increase the dam gate, make full use of natural depressions and artificial lakes, improve the water storage capacity of the water storage project, speed up the storage and set the scheduling rules scientifically, which is suitable for improving the normal water level of the reservoir, and the potential of increasing the supply of flood resources will be greatly improved; The elastic mining of groundwater is based on the unit water yield of the water source well and the spring flow to carry out water-rich zoning(Zhao and Zhao, 2014).As shown in Table 4, according to the strength of water-richness, different scenarios are tapped. According to the potential of supply increase

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from small to large, it is divided into supply increase scenario 1, supply increase scenario 2 and supply increase scenario 3 in turn. Different supply increase scenarios correspond to different supply increase measures, as shown in Table 5.

Table 4 Division table of groundwater water abundance in the Yellow River Water Supply Area in Henan

Regionalization basis	Partition			
	Weak water-rich area	Medium water-rich area	Strong water-rich area	Extremely strong water-rich area
Unit output of water source well(m³/h·m)	q<1	1 ≤ q<5	5 ≤ q<10	q>10
Flow capacity of spring (L/s)	Q<1	1 ≤ Q<10	10 ≤ Q<50	Q<50

Table 5 Measures for increasing supply of different potential water sources under different supply scenarios

Additional supply scenario	Unconventional Water Tapping	Flood resource utilization	Elastic groundwater exploitation
Scenario 1	Increase the scale of rainwater harvesting facilities by 5%	Increase the scale of water storage project by 5%	Mining 15% of water source in strong water-rich area and extremely strong water-rich area
Scenario 2	Expand the scale of 5% rainwater harvesting facilities; reclaimed water and sewage utilization efficiency increased by 10%	Increase the scale of water storage project by 5%; reasonable setting to speed up the recovery scheduling rules	Mining 15% of the water source in the strong and extremely rich water area; mining and excavating 10% of the water source in the medium water-rich area
Scenario 3	Expand the scale of rainwater harvesting facilities by 5%;the utilization efficiency of reclaimed water and sewage is increased by 10%;increase the utilization ratio of mine water by 20%	Increase the scale of water storage project by 5%; reasonably set up the scheduling rules for accelerating the recovery of savings; dynamic adjustment of reservoir flood control level	Mining 15% of the water source in the strong and extremely rich water area; mining and excavating 10% of the water source in the medium-rich water area; mining 5% water source in weak water-rich area

3 Study on Multi-water sources allocation of Multi-scenario potential tapping

3.1 Water source analysis of Multi-scenario potential tapping

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Based on the potential unconventional water volume, flood resource water volume and groundwater volume, Multi-scenario potential tapping is carried out, In 2010, the potential water volume of unconventional water in the Yellow River Water Supply Area in Henan was 5.045 billion m^3, the potential water volume of flood resources was 10.223 billion m^3, and the potential water volume of groundwater elastic exploitation was 9.660 billion m^3.According to the proportion of different potential water volume and potential total water volume, it is divided into three different potential water source scenarios. The potential water volume and the comparison before and after potential tapping are shown in Table 6.

Table 6 The amount of potential tapping water in different scenarios and the comparison table before and after potential tapping Unit: hundred million m^3

Water supply scenario		Unconventional water		Flood resource utilization		Elastic groundwater exploitation		Total
		Quantity of water	Percentage of total potential unconventional water	Quantity of water	Percentage of total potential unconventional water	Quantity of water	Percentage of total potential unconventional water	
Before digging potential		0.39	0.01%	0	0	0	0	0.39
After digging potential	Scenario 1	5.05	10%	5.11	5%	4.83	5%	14.99
	Scenario 1	7.57	15%	10.22	10%	9.66	10%	27.45
	Scenario 1	10.09	20%	15.33	15%	14.49	15%	39.91

According to the Table 6, there is a great potential for the development of unconventional water and flood water resources. The potential water of unconventional water sources in scenarios 1, 2 and 3 is 505 million m^3, 757 million m^3 and 109 million m^3; The amount of potential water in flood resource tapping scenarios 1, 2 and 3 is 511 million m^3, 1022 million m^3, and 1.533 billion m^3. With the increase of excavation potential, the total water volume of water supply scenarios 1, 2 and 3 is 1.499 billion m^3, 2.745 billion m^3 and 3.991 billion m^3. Compared with before tapping the potential, the available water supply has been greatly improved. The rational development and

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utilization of unconventional water sources and flood water sources plays an important role in the sustainable development of water resources in the future.

3.2 Water demand level division and configuration principle

Western sociologist Maslow's hierarchy of needs theory believes that human needs are divided into five levels like a ladder, namely: physiological needs, security needs, social needs, respect needs, and self-realization needs. The more these needs are met, the stronger the sense of well-being will be. Specific to the river basin, combined with the water demand characteristics of various departments and development conditions in different regions, the life, industry, agriculture, and ecological water demand processes are divided into three levels, namely rigid demand, rigid elastic demand, and elastic demand, as shown in Figure 4.

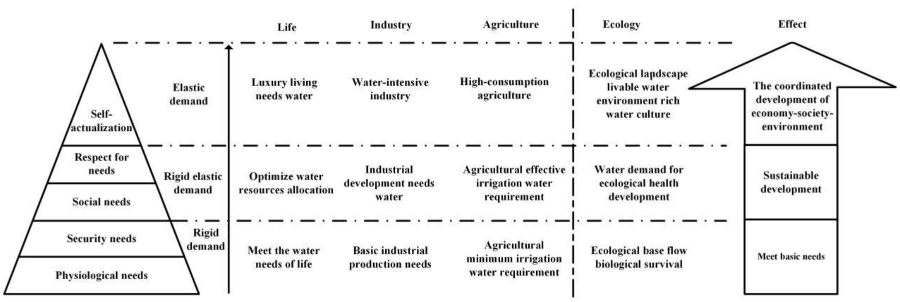

Figure 4 Water demand level division diagram

The satisfaction of each water sector is the relationship between water users according to their water demand status and water distribution. It is generally a subjective evaluation. It is the happiness of water users after their needs are met. When the water demand of the water sector is met. The more, the higher the satisfaction. The runoff volume and wet and dry years are different, and the water demand level is different. The rigid water demand is the first priority in the distribution water, and it will be difficult to recover the loss once it is destroyed. The rigid elastic water demand is in the second priority in the water distribution, and the loss caused by water shortage is recoverable; elastic water demand is the last consideration in water resources allocation. When the water distribution amount obtained by the water use department is at different water demand levels, the level of satisfaction is related to different water use departments. For example, in dry years and when the runoff is small, the water use department meets the basic needs. At this time, the satisfaction of the agricultural department is higher than that of the domestic, industrial and ecological water use departments.

The configuration of Multi-water sources allocation it he Yellow River Water Supply Area in Henan should follow the following principles:

(1) The principle of matching the type of potential water sources with the water use department. Under extreme drought conditions, groundwater sources are flexibly exploited for domestic water and some industrial water; unconventional water sources are mainly used for industrial water and landscape greening water; flood water resources are used for agricultural irrigation and ecological water use.

(2) Priority principle. Priority should be given to the protection of basic domestic water. Because the drought in the study area is mainly reflected in agriculture, agricultural water is put in the second place, and on this basis, industrial water and ecological water are considered in turn. At the same time, give priority to meet the rigid demand, and then ensure the rigid elastic water, and finally meet the elastic demand.

(3) The principle of fairness. Equal distribution is needed between individual water users and water users, and between partitions and regions in the Yellow River Water Supply Area in Henan. Each district cooperates with each other and cooperates with the overall situation, and objectively has the same status to allocate water sources.

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(4) The principle of total control. The development of groundwater elastic mining, unconventional water and flood water resources in the Yellow River Water Supply Area in Henan should be matched with the carrying capacity of local water resources, reasonably control the polluting environmental industries and high-intensity water consumption industries, and strengthen the supervision of their total amount.

(5) The principle of sustainable use. In the case of widespread drought and complex water shortage structure in the Yellow River Water Supply Area in Henan, a fair, effective, reasonable and scientific setting of the water distribution ratio between life, agriculture, industry and ecology is conducive to the benign maintenance of water resources regeneration mechanism and sustainability.

3.3 Model construction

(1) Taking the minimum water shortage as the objective function:

$$\min Z_p = \sum_{c}^{h}\sum_{d}^{l}(W_{c,p} - W_{d,p}) \tag{1}$$

Where Z_p is the total water deficit in the scenario of enemy p , hundred million m^3, p = （1， 2， 3）; W_c is the water supply of type i users in scenario p , hundred million m^3, c = （1,2,3… h ）; W_j is the water demand of type d user in type p scenario, hundred million m^3, d = （1,2,3… l ）.

(2) Constraint conditions

Constraints of available water supply and water demand:

$$\sum_{i}^{m} W_i \le W_G \tag{2}$$

$$\sum_{j}^{n} W_j \le W_X \tag{3}$$

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$$W_G = W_B + W_D + W_C + W_H \tag{4}$$

$$W_X = W_S + W_Y + W_N + W_T \tag{5}$$

In the formula, W_G is the total amount of water available, billion m^3; W_B is the available water supply of surface water, billion m^3; W_D is the available water supply of groundwater, billion m^3; W_X is the total water demand, billion m^3; W_S is the total amount of domestic water demand, billion m^3; W_Y is the total amount of industrial water demand, billion m^3; W_N is the total amount of agricultural water demand, billion m^3; W_T is the total ecological water demand, billion m^3.

Unconventional water and flood water resources constraints:

$$\sum_r^a W_{C_{p,r}} \le W_{C_0} \tag{6}$$

$$\sum_k^b W_{H_{p,k}} \le W_{H_0} \tag{7}$$

$$\frac{\sum_r^a W_{C_{p,r}} + \sum_k^b W_{H_{p,k}}}{W_G} \ge \alpha \tag{8}$$

In the formula, $W_{C_{p,r}}$ is the unconventional water supply of type r users in scenario p, billion m^3, r =(1,2,3... a); W_{C_0} is the original unconventional water supply, billion m^3 ; $W_{H_{p,k}}$ is the amount of water supply for flood water resources of the type k user in the p th scenario, 100 million m^3, k =(1,2,3... b); W_{H_0} for the original flood water resources, water supply, billion m^3 ; α is the reasonable proportion coefficient of unconventional water and flood water resources.

Priority constraint. The order of water supply is as follows:

$$W_1 > W_2 > W_3 > W_4 \tag{9}$$

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$$W_{\mathrm{I}} > W_{\mathrm{II}} > W_{\mathrm{III}} \tag{10}$$

W_1 is the order of domestic water supply; W_2 the order of supply for agriculture; W_3 is the order of industrial water supply; W_4 is the order of ecological water supply; W_{I} is the order of rigid water demand; W_{II} is the order of rigid elastic water demand; W_{III} is the order of elastic water demand.

Groundwater depth constraint:

$$D_e \geq D_f \tag{11}$$

In the formula, D_0 is the average groundwater depth of the e region, m; D_f is the maximum allowable groundwater depth in zone f, m.

The minimum ecological flow constraint is:

$$E_{g,t} < H_{g,t} \tag{12}$$

In the formula, $E_{g,t}$ and $H_{g,t}$ are the minimum ecological flow and the actual flow in the t period of the g ecological control section, m^3/s.

Non-negative constraints: All variables are greater than or equal to 0.

4 Scenario configuration scheme analysis

4.1 Scheme calculation

According to the distribution of water shortage and drought grade in each area of the Yellow River Water Supply Area in Henan in extreme drought years, the model is solved according to the configuration principle and water use constraint conditions. The solution process is based on three different water supply scenarios to obtain three schemes for increasing supply. The configuration results are shown in Table 7

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Table 7 Results table of water resources allocation in the Yellow River Water Supply Area in Henan Unit: hundred million m^3

Type of water supply	Life			Industry			Ecology		
Partition of water supply area	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Zhengzhou division	4.69	4.69	4.69	3.34	3.88	4.45	2.56	3.11	3.61
Kaifeng division	1.77	1.77	1.77	1.71	1.99	2.28	2.02	2.45	2.85
Luoyang division	2.61	2.61	2.61	4.08	4.74	5.43	1.14	1.39	1.62
Pingdingshan division	0.39	0.39	0.39	1.08	1.26	1.44	0.06	0.08	0.09
Anyang division	0.87	0.87	0.87	0.84	0.98	1.12	0.86	1.05	1.22
Hebi division	0.4	0.4	0.4	0.25	0.29	0.33	0.22	0.27	0.31
Puyang division	1.28	1.28	1.28	2.14	2.48	2.84	0.65	0.79	0.92
Xuchang division	0.28	0.28	0.28	0.34	0.4	0.46	0.14	0.17	0.2
Sanmenxia division	0.86	0.86	0.86	1.05	1.22	1.39	0.35	0.42	0.49
Shangqiu division	1.96	1.96	1.96	1.17	1.36	1.55	0.41	0.49	0.57
Zhoukou division	1.65	1.65	1.65	1.07	1.24	1.42	0.26	0.32	0.37
Jiyuan division	0.22	0.22	0.22	0.54	0.62	0.71	0.28	0.34	0.4
Jiaozuo division	1	1	1	2.11	2.45	2.81	0.31	0.38	0.44
Xinxiang division	1.77	1.77	1.77	1.43	1.66	1.9	0.72	0.88	1.02
Total	19.74	19.74	19.74	21.14	24.56	28.14	9.99	12.13	14.11

Table 7 Schedule

Type of water supply	Agriculture			Subtotal			Water deficit		
Partition of water supply area	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Zhengzhou division	2.82	3.12	3.42	13.41	14.8	16.17	3.66	2.27	0.9
Kaifeng division	8.32	9.2	10.08	13.82	15.41	16.98	3.92	2.33	0.76
Luoyang division	3.47	3.84	4.21	11.31	12.58	13.87	3.27	2	0.71
Pingdingshan division	0.95	1.06	1.16	2.49	2.78	3.08	0.73	0.44	0.14
Anyang division	5.74	6.35	6.96	8.32	9.25	10.17	2.24	1.31	0.39
Hebi division	1.21	1.34	1.47	2.08	2.29	2.51	0.53	0.32	0.1
Puyang division	9.66	10.68	11.71	13.73	15.24	16.75	3.6	2.09	0.57
Xuchang division	0.84	0.93	1.02	1.61	1.78	1.96	0.43	0.25	0.08
Sanmenxia division	1.06	1.17	1.28	3.31	3.67	4.03	0.91	0.56	0.2
Shangqiu division	8.54	9.44	10.35	12.07	13.25	14.43	2.76	1.58	0.39
Zhoukou division	6.57	7.26	7.96	9.54	10.47	11.39	2.17	1.24	0.32
Jiyuan division	0.8	0.89	0.97	1.84	2.07	2.3	0.6	0.36	0.13
Jiaozuo division	5.3	5.86	6.42	8.72	9.69	10.67	2.34	1.38	0.4
Xinxiang division	9.91	10.96	12.01	13.83	15.27	16.7	3.38	1.95	0.52
Total	65.21	72.11	79.01	116.08	128.54	141	30.53	18.07	5.61

According to Table 7, based on different potential tapping levels, the configuration schemes of different scenarios are obtained. With the increase of the proportion of water supply in the potential tapping water, the water shortage in each partition is significantly reduced, and the water supply and demand are close to balance. Under different water supply scenarios, the total water supply in the Yellow River Water Supply Area in Henan increased from 11.07 billion m^3 to 11.608 billion m^3, 12.854 billion m^3, and 14.100 billion m^3, respectively, and the total water shortage decreased from 4.555 billion m^3 to 3.053 billion m^3, 18.07 billion m^3, and 5.61 billion m^3.

4.2 Discussion of the scheme

(1) Comparative analysis of tapping potential water

According to the water resources bulletin of Henan Province in 2010, in addition to conventional water, the water supply volume of unconventional water in Henan Province in 2010 was 39 million m^3. In this paper, through the excavation of the potential water volume of unconventional water, the potential water volume of flood resources and the elastic exploitation of groundwater in 2010, the total water volume of potential exploitation based on different potential exploitation scenarios was 1.499 billion m^3, 2.745 billion m^3 and 3.991 billion m^3, respectively. Therefore, the effect of tapping potential and increasing supply in the Yellow River Water Supply Area in Henan is obvious.

(2) Comparative analysis of department water supply

The water supply data of the water resources bulletin department of Henan Province in 2010 are compared with the results of the three scenarios after tapping the potential, as shown in Table 8. After the allocation, compared with the water resources bulletin of Henan Province in 2010, the water supply under different scenarios increased, which alleviated the water pressure of various departments and realized the improvement of social and economic benefits and the benign development of ecological environment.

Table 8 Comparative analysis table of department water supply after tapping potential

Unit: hundred million m^3

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Department		Life	Industry	Zoology	Agriculture	Total water supply quantity	Total water requirement
Henan Water Resources Bulletin 2010		19.74	19.38	8.98	52.97	101.07	
After digging potential	Scenario 1	19.74	21.14	9.99	65.21	116.08	146.62
	Scenario 2	19.74	24.56	12.13	72.11	128.54	146.62
	Scenario 3	19.74	28.14	14.11	79.01	141.00	146.62

(3) Mitigation analysis of water shortage

The comparative analysis of the water shortage results of each water supply scenario is shown in Table 9. On the whole, the water shortage situation in the Yellow River Water Supply Area in Henan has been significantly improved compared with that before tapping the potential. Under different supply scenarios, the average water shortage in the water supply area decreased from 325 million m^3 to 218 million m^3, 129 million m^3 and 40 million m^3 respectively. The overall water shortage rate decreased from 31.07% to 20.83%, 12.33% and 3.83%, respectively. Among them, there is no water shortage in domestic water. Through the potential tapping of multiple scenarios, the water shortage rate of industrial water decreased from 35.90% to 30.09%, 18.78% and 6.94% respectively. The water shortage rate of ecological water decreased from 44.12% to 37.87%, 24.56% and 12.25%, respectively; The water shortage rate of agricultural water decreased from 34.25% to 19.05%, 10.49% and 1.92% respectively. After Multi-scenario potential tapping, the water shortage rate of each department (except domestic water) has been greatly reduced, but there is still a shortage of water in industrial water, ecological water and agricultural water. In the future, it is urgent to deepen the excavation of unconventional water sources and flood water sources, so that the Yellow River Water Supply Area in Henan has sustainable water resources support.

Table 9 Comparison table of water shortage results before and after tapping the potential of the Yellow River Water Supply Area in Henan Unit: hundred million m^3

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Analysis index		Domestic water shortage rate (%)	Industrial water shortage rate (%)	Ecological water shortage rate (%)	Agricultural water shortage rate (%)	Mean value of water shortage in each district	Water shortage rate (%)
Before digging potential		0	35.90	44.12	34.25	3.25	31.07
After digging potential	Scenario 1	0	30.09	37.87	19.05	2.18	20.83
	Scenario 2	0	18.78	24.56	10.49	1.29	12.33
	Scenario 3	0	6.94	12.25	1.92	0.40	3.83

(4) Configuration effect of multi-level water demand

Based on three water demand levels (rigid demand, rigid elastic demand and elastic demand), this paper explores the potential of multiple water sources. Different water supply scenarios correspond to different water demand levels. Water supply scenarios 1, 2 and 3 correspond to rigid demand, rigid elastic demand and elastic demand respectively, and a multi-level water demand configuration scheme is obtained. Table 10 shows the water demand satisfaction under different water demand conditions. Through the increase of different potential tapping scenarios, the overall satisfaction rates of rigid demand, rigid elastic demand and elastic demand have reached 79.17, 87.67 and 96.17 respectively. Specifically, under the condition of rigid water demand, the satisfaction rates of domestic water demand, industrial water demand, ecological water demand and agricultural water demand are 100%, 69.91%, 62.13% and 80.95% respectively. Under the condition of rigid elastic demand, the satisfaction rates of domestic water demand, industrial water demand, ecological water demand and agricultural water demand are 100%, 81.22%, 75.44% and 89.51% respectively. Under the condition of elastic demand, the satisfaction rates of domestic water demand, industrial water demand, ecological water demand and agricultural water demand are 100%, 93.06%, 87.75% and 98.08% respectively.Based on different potential tapping scenarios corresponding to different water demand levels, in the future, water demand can be considered to be hierarchical to achieve precise potential tapping and supply increase and

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scientific configuration.

Table 10 is the unit of water demand satisfaction under different water demand conditions: %

Analysis index		Domestic water demand satisfaction rate	Industrial water demand satisfaction rate	Ecological water demand satisfaction rate	Agricultural water demand satisfaction rate	The average water demand satisfaction rate of each district
Water requirement levels	Rigid demand	100	69.91	62.13	80.95	79.17
	Rigid elastic demand	100	81.22	75.44	89.51	87.67
	Elastic demand	100	93.06	87.75	98.08	96.17

4.3 Discussion

In terms of research results, the total water demand in extreme drought years in this paper is 146.62 billion m3, and the total water supply in water supply scenarios 1,2 and 3 is 116.08 billion m3,128.54 billion m3 and 141.00 billion m3, respectively. Similar to the research results of other scholars,(Sun X, 2021: Wang X, 2024) due to the different spatial scales, water supply structures and methods of research, the results are different.

In terms of research methods, this paper constructs a model with the minimum water shortage as the goal, and uses genetic algorithm and dynamic programming to calculate the configuration model. The limited objective function and constraint conditions in the multi-water source configuration model are difficult to fully consider the current situation and development requirements of the water supply area. In the future, it is necessary to improve the applicability of multi-water source users and configuration models, and at the same time, it is necessary to comprehensively consider high-quality development goals such as economic growth, water supply safety, and ecological health.

In terms of research perspective, this paper takes the multi-water source potential tapping and multi-scenario supply increase configuration in extreme drought years as the research highlights. The water supply sources mainly include unconventional water, flood resource water source and groundwater elastic mining water source. Through the potential tapping of different measures, the drought situation in the water supply area has been greatly alleviated. However, there are water supply safety problems in the exploitation of flood resource water and groundwater, especially the realization of flood resource through the regulation of reservoir flood limit water level, which makes the contradiction between benefit and flood control safety. In the future, we can consider vigorously exploiting unconventional water sources to achieve the reduction of water supply risk and the benign maintenance of ecological environment.

5 Conclusion

Aiming at the problem of multi-resource allocation under extreme drought the Yellow River Water Supply Area in Henan, this paper sets different water supply scenarios through different potential tapping measures, constructs a Multi-water sources allocation model based on multiple scenarios, and proposes three schemes for increasing supply. The main conclusions of this paper are as follows: (1) Under extreme drought, the amount of potential tapping water has been significantly improved through different scenarios of potential tapping measures. The amount of potential tapping water in the three scenarios is 1.499 billion m^3, 2.745 billion m^3 and 3.991 billion m^3, respectively. The potential of unconventional water and flood resources the Yellow River Water Supply Area in Henan is great. The results of potential tapping provide practical value for the study of reasonable potential tapping of unconventional water sources. (2) After the

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allocation, the overall water shortage degree of the Yellow River Water Supply Area in Henan has been significantly alleviated. Under different water supply scenarios, the total water shortage has been reduced from 4.555 billion m^3 to 3.054 billion m^3,1.808 billion m^3 and 5.62 billion m^3, respectively. The overall water shortage rate decreased from 31.07% to 20.83%, 12.33% and 3.83%. (3) At present, the potential of groundwater is very limited, and the potential space of unconventional water source and flood resource water source is very large. Under different scenarios, the sum of the potential water volume of unconventional water source and flood resource water source and the total water supply before the potential is more than 10%. Under extreme drought conditions, this paper studies the water resources allocation of Multi-scenario potential tapping and increasing supply. In the actual water distribution, the water quality of the water distribution is subject to various complex requirements and restrictions, such as different water users have different water quality requirements. In the future research, the joint allocation of water quantity and water quality can be further considered.

Declarations： We declare that we have no conflict of interest or the authors do not have any possible conflicts of interest, the authors are not affiliated with or involved with any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this paper.

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Ethics Approval: Not applicable.

Consent to Publish: Not applicable.

Authors Contributions: Conceptualization, F.W. and S.P.; Methodology, X.Z.; Supervision, F.Z.; Formal analysis, F.W.; Investigation, Y.W. and X.Z.; Writing original draft, W.W. and H.S. And all authors read and approved the manuscript.

Consent to Participate: Not applicable.

Open Research: The data come from the Resource and Environmental Science and Data Center and the Henan Provincial Water Resources Bulletin. The data of 59 meteorological stations in the Yellow River Water Supply Area in Henan were collected. The data of precipitation, temperature and soil were based on 58 years (1961-2018) monthly data.

The datasets come from the following:

China Soil Analysis Dataset; PerMonthy and China natural Runoff

These data are ArcGIS data, is the original data, need to be processed to use.

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Our data is non-public and private.

Our data is currently being archived and the planned database is Mendeley Date.

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