Comprehensive application mode of flood and waterlogging control as well as water resources regulation in coal mining subsidence area of Nansihu basin, China

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Abstract. The basin of Nansihu lake is dominated by alluvial plain landform in Shandong Province, China. The region is rich in coal resources and coal mining has formed a large number of subsidence areas. In view of the difficulty of surface water regulation and storage in plain area and the fact that coal mining subsidence area can provide effective storage capacity. The mode of combination of flood, waterlogging control and water resources regulation by using coal mining subsidence area in the basin is put forward. The advantages and disadvantages compared constructing plain reservoirs with using coal mining subsidence area as reservoirs is recognized. The effects of flood control and waterlogging control in coal mining subsidence areas from the scale of watershed and specific cases are analysed. From the perspective of flood and waterlogging control effect, in 2025 and 2035, coal mining subsidence area can reduce the flood of 5% frequency by 12.43% and 34.22% respectively. By 2025, urban waterlogging at 20% frequency will be reduced by 56.19%. In 2035, the ability of coal mining subsidence area to resist urban waterlogging at the same frequency can reach 100%. The coal subsidence area in Longguhu can reduce the flooding at 10%, 5% and 2% frequencies by 15.8%, 12.1% and 9.2%, respectively. It can completely resist the one-day waterlogging in the city at 20% frequency and reduce the waterlogging in the city for three-days by 70.8%. The reconstruction of plain reservoir using the coal mining subsidence area is feasible in technology and engineering construction. But it is still faced with the problem to be solved of the guarantee rate of water supply, water quality etc...

1. Introduction
Coal mining subsidence area is an unavoidable problem in coal mining process. In the Nansihu basin of Shandong Province, China, the alluvial plain is the main type, the coal resources are abundant and the quality is good, which is convenient for large-scale mining. Coal mining will lead to land subsidence and agricultural production reduction. The impact on the environment and residents' lives is long-term with continuous coal mining. Therefore, the governance and utilization of subsidence areas should be considered as a strategic issue in long-term planning. At the same time, there is little surface water storage space in the plain area, so the coal mining subsidence area can increase the storage capacity of rain flood, reclaimed water and mine water in the plain area.

Scholars at home and abroad have actively explored the restoration and treatment of coal mining subsidence area. The treatment methods of coal mining subsidence areas include land reclamation, ecological restoration and comprehensive treatment. Land reclamation is to restore the land use state by backfilling the deep pit formed by collapse with fly ash and coal gangue[1-3]. The land can be used...
by using the methods of thinning, leveling on the spot, digging deep and shallow[4-5]. The ecological restoration of coal mining subsidence area is to improve the damaged soil structure and restore the ecological environment of the subsidence area through biotechnology. Comprehensive management technology is a comprehensive and coordinated development of ecological, economic and social benefits through the innovation of resource utilization mode combined with the natural, economic and social conditions of the collapsed land. At present, the comprehensive utilization ways of coal mining subsidence areas include forestry, agricultural planting, fishery breeding and other ways[6]. Based on the research at home and abroad, this paper puts forward a new idea of controlling coal mining subsidence area: using the reservoir capacity formed by the subsidence land to participate in flood control, waterlogging control and water resources regulation and storage in the basin.

2. Study area

2.1. Present situation of coal mining subsidence area
According to the Special Plan for Comprehensive Control of Coal Subsidence areas in Shandong Province, the cumulative area of coal subsidence areas in the Nansihu Basin will be 52,560.24 hm² and 65,180.21 hm² respectively in 2018 and 2025. Combined with the development trend of coal mining subsidence land, it is estimated that the accumulative area of coal mining subsidence area is 86546.64 hm² in 2035. Considering the situation of coal mining, the steady settlement, the degree of collapse and the treatment of coal mining subsidence area, the effective storage capacity of coal mining subsidence area in 2025 and 2035 is estimated to be 310 million m³ and 512 million m³, respectively.

2.2. Necessity of development and utilization of coal mining subsidence areas
Coal mining subsidence area can optimize the water supply structure in the region. The amount of water resources per capita is low in the basin, which belongs to the area of water shortage. The water supply and water use structure in the region are unreasonable, excessively depend on groundwater, and the utilization rate of surface water and reclaimed water is low. After the reconstruction of coal mining subsidence area, it can participate in the retention of rain and flood and improve the utilization rate of rain and flood resources. At the same time, the coal mining subsided area is transformed into wetland, which can purify the water quality of reclaimed water and increase the water supply of water resources in the region.

Coal mining subsidence area can improve the regional flood control and waterlogging situation. The eastern part of the basin is a shallow hilly area, the western part is a yellow river flood plain, and the middle part is a low-lying area. Due to the influence of geographical factors, the eastern river of the lake have short river distance and fast flow rate, and the western river in the lake have larger area and lower flow rate. Floods and waterlogging occur frequently in the river basin. At present, the basin can resist 2%-5% frequency standard flood and 20% frequency standard urban waterlogging. Coal mining subsidence area can be used as a place to stay and store floods. The direction of urban waterlogging is mainly river. Coal mining subsidence area can share part of urban waterlogging.

Coal mining subsidence area can improve the ecological environment in the region. Water table in the basin is falling and wetlands are drying up because of the overexploitation of groundwater. Urban sewage and agricultural drainage lead to ecological pollution. Coal mining subsidence area can be converted into constructed wetland, which is beneficial to the improvement of water quality and local climate, and promotes the development of landscape tourism. At the same time for the good hydrogeological conditions of coal mining subsidence area to be transformed into groundwater recharge site.
3. Advantages and disadvantages of rebuilding reservoir and building plain reservoir in coal mining subsidence area

3.1. Advantage Analysis
Shandong Province is short of water resources, relying on the Yellow River water, plain reservoir has been rapid development. As of June 2013, 806 plain reservoirs have been built, with a total design capacity of more than 2 billion m³, with a total investment of about 8 billion yuan. As a kind of abandoned land resource, the coal mining subsidence area is used to rebuild the reservoir, which is smaller than the normal reservoir in engineering investment, land requisition and compensation investment. Therefore, the unit price of water source for rebuilding reservoir in coal mining subsidence area is cheaper than that of normal reservoir. Taking the water price of coal mining subsidence area of Longguhu as an example, the full cost water price of unilateral water is 1.80 yuan. From the statistical data, the single water investment of plain reservoir is about 4 yuan, and the cost price of single water in collapse area is far lower than that of plain reservoir.

Technically speaking, the reconstruction of plain reservoir in coal mining subsidence area is a subsidence basin after coal mining, so as to achieve the purpose of water accumulation, water storage and water transfer. Therefore, it is very important to carry out dynamic subsidence simulation planning in advance by analyzing the comprehensive conditions of ground and underground and mining plan before ground subsidence. The simulation technology of land dynamic evolution under the influence of coal mining and other related technologies have been formed, which can be scientific and intuitive. Through the relevant case analysis, the accuracy of dynamic subsidence can reach more than 90%. Thus, from the technical point of view, the dynamic construction goal of building plain reservoir by subsidence area can be achieved.

In terms of engineering construction economy, the main problems in the construction of the existing plain reservoir are the difficulty of land requisition, the huge investment and the long return period. Coal mining subsidence inevitably leads to ground subsidence and stagnant water, which can solve the problem of partial land requisition. And in the production process, the coal enterprises have set aside related funds for village relocation, land compensation and compensation. Therefore, combining with plain reservoir construction can greatly save funds and avoid repeated investment.

3.2. Disadvantage Analysis
The water sources of coal mining subsidence area are mainly rain and flood, mine drainage and reclaimed water, and the water supply guarantee rate and water quality cannot meet the requirements. Therefore, it can only be used as a supplement or auxiliary water supply for conventional water supply projects. The water quality of rain flood, mine pit drainage and reclaimed water in coal mining subsidence area is unstable and can only be supplied to different water departments according to different water quality. If as domestic water supply, water quality treatment has higher requirements, water supply efficiency is difficult to be guaranteed. Although the project investment of plain reservoir rebuilt in coal mining subsidence area is small, the reservoir scale is mostly medium and small. The reservoir capacity of coal mining subsidence area is small and the water quality is poor. The attitude of water use department to select water supply in coal mining subsidence area is unknown. After rebuilding the reservoir in the coal mining subsidence area, it will raise water table, which will easily cause secondary salinization of soil with uncertain influence on the surrounding agriculture is unknown. In summary, the comprehensive benefit of rebuilding plain reservoir in coal mining subsidence area is uncertain.

4. Estimation of flood control and waterlogging and water resources storage capacity in coal mining subsidence area of Nansihu Basin under design conditions
The flood control and waterlogging capacity of coal mining subsidence area is analyzed from watershed scale. In view of the hydrogeological conditions and technical limitations of the subsidence area in the basin, the utilization rate of the collapse area is less than 100%. However, with the
development of technology, the settling rate and technology of subsidence area are increasing year by year. Therefore, the utilization ratio of reservoir capacity in the subsidence area in 2025 and 2035 is 30% and 50%, which are 93 million m³ and 256 million m³, respectively.

By estimating the flood control and waterlogging capacity of the subsidence area in the basin, it can be seen that in 2025, the coal mining subsidence area should deal with the flood with 5% flood frequency, reduce the flood volume by 12.43% and store flood volume of 93 million m³. Coal mining subsidence area in 2035 to deal with the same standard flood, can reduce the flood volume of 34.22%, flood storage 256 million m³.

Coal mining subsidence area in 2025 should be 20% frequency of urban waterlogging, can reduce the amount of waterlogging 56.19% and accept 93 million m³ of waterlogging. Coal mining subsidence area in 2035 should be under the same standard urban waterlogging, can fully reduce waterlogging and storage 165 million m³ of water.

5. Case Analysis

5.1. Case background
Longguhu mining subsidence area is located in the Zhuzhaoxin River basin. The water source of the subsidence is the rain flood of Zhuzhaoxin River and the diversion water of Nansihu lake. The storage capacity of the second phase of the project is 80 million m³. The annual water diversion volume of Nansihu Lake is less than 45 million m³. The construction of Longguhu wetland is to make use of the rain-flood and Nansihu water resources and improve the local water supply security capacity.

5.2. Analysis of flood control and waterlogging effect
In this paper, a long series of analysis is carried out on the maximum flood peak discharge in the month of 1974-2015 in Weilou Sluice, and formula (1)-(2) is used to calculate the flood control calculus. The results are shown in Table 1.

\[
\frac{Q_1 + Q_2}{2} \Delta t - \frac{q_1 + q_2}{2} \Delta t = V_2 - V_1
\]
\[
q = f(V)
\]

Table 1. Calculation of Flood in Longguhu Collapse.

| Typical frequency | Numerical value (m³/s) | Flood detention (10⁴ m³) | Reduction rate (%) |
|-------------------|------------------------|--------------------------|--------------------|
| P=10%             | 191.36                 | 259.2                    | 15.8               |
| P=5%              | 248.24                 | 259.2                    | 12.1               |
| P=2%              | 324.94                 | 259.2                    | 9.2                |

The Longguhu wetland has a certain effect on flood regulation at 10% and 5% frequencies, and is deficient for flood regulation at 2% frequencies. In response to the one-day urban waterlogging at 20% frequency, it can be fully accepted, and in response to the three-day urban waterlogging, it can be reduced by 70.87%. The flood control and waterlogging effect of Longguhu wetland can be improved greatly, the design standard of lake entry gate can be improved, and part of the delayed flood resources can be reserved as the backup water source in non-flood season.

5.3. Effect analysis of water resource regulation and storage
Longguhu Wetland is mainly responsible for the surrounding industrial, agricultural and ecological water, with a water demand of 14,500 million m³/a. Scheme one is the result of supply and demand balance when the rain flood is only introduced from Zhuzhaoxinhe river. The second scheme is the
result of supply and demand balance of Zhuzhaoxinhe river rain flood and Nansihu water at the same time.

| Typical year | Water demand ($10^4$ m$^3$) | Water supply ($10^4$ m$^3$) | Proportion (%) | Surplus water ($10^4$ m$^3$) |
|--------------|-------------------------------|-----------------------------|---------------|-------------------------------|
| Annual average | 14500 | 6930.6 | 47.8 | 2580.89 |
| P=25% | 14500 | 9121.16 | 62.9 | 5261.18 |
| P=50% | 14500 | 9228.30 | 63.64 | 0 |
| P=75% | 14500 | 6316.87 | 43.56 | 695.96 |

Table 3. Analysis of supply and demand balance in scheme 2.

| Typical year | Water demand ($10^4$ m$^3$) | Water supply ($10^4$ m$^3$) | Proportion (%) | Surplus water ($10^4$ m$^3$) |
|--------------|-------------------------------|-----------------------------|---------------|-------------------------------|
| Annual average | 14500 | 10943.66 | 75.47 | 3556.34 |
| P=25% | 14500 | 12665.72 | 87.35 | 5897.57 |
| P=50% | 14500 | 12772.85 | 88.09 | 0 |
| P=75% | 14500 | 9861.43 | 68.01 | 972.86 |

By comparing scheme one with scheme two, it can be seen that there is contingency between abundant and dry in a single water source, and there are some limitations in water supply and water supply guarantee rate. The limitation of single water source in water supply can be made up to a certain extent by simultaneously introducing the rain and flood of Zhuzhaoxinhe River and the water of Nansihu.

6. Conclusions
Based on the present situation and the necessity of utilization of coal mining subsidence area in Nansihu Basin, this paper analyzes the advantages and disadvantages of rebuilding plain reservoir in coal mining subsidence area, meanwhile analyzes the effects of flood control, waterlogging removal, water resource regulation and storage in different scales of coal mining subsidence area in Nansihu Basin and specific cases. The conclusions are as follows:

The coal subsidence area of Nansihu Basin can reduce the flood volume by 12.43% and store 93 million m$^3$ of flood in 2025, aiming at 5% frequency of flood. By 2035, it can reduce 34.22% and store 256 million m$^3$ of flood. In 2025, for urban waterlogging at 20% frequency, coal mining subsidence area can reduce 56.19% and store 93 million m$^3$ of water. In 2035, it can fully reduce urban waterlogging under the same standard, storing 165 million m$^3$ of water.

Floods at 10%, 5% and 2% frequencies can be reduced by 15.8%, 12.1% and 9.2% in Longguhu wetland. The effect is remarkable in removing waterlogging.

The advantages and disadvantages of rebuilding plain reservoir in coal mining subsidence area are analyzed. It is economically feasible for technical and engineering construction. However, it is faced with the problems of water supply guarantee rate, water quality and water supply benefit after completion. The impact on the ecological environment can not be ignored.

References
[1] Nadja Zier, Rainer Schiene, Helmut Koch. (1999) Agricultural Reclamation of Disturbed Soils in a Lignite Mining Area using Municipal and Coal Wastes: the Humus Situation at the Beginning of Reclamation. J. Plant and Soil., (1): 241-250.
[2] Jiao, H.F., Lu, L. (1999) Study on the reclamation of coal-mining subsidence land- a case study of huaibei city in Anhui province. J. Economic geograph., (04): 90-94.

[3] Zhao, G.X., Wang, K.H., Shi, Y.X. (2000) Study on Reclamation Mode and Comprehensive Development Technology of Coal Mine Collapse Land. J. China Land Science., (05): 44-46.

[4] Wu, Y.Z., Xing, Z.L. (2007) Study on Comprehensive Utilization of Land Reclamation in Coal Mining Collapse Area. J. Agriculture & Technology., 03: 75-76.

[5] Zhou, X.D., Gao, W.D. Yin, W.Z. (2003) Methods and experiences of reclamation and comprehensive treatment of coal mining subsidence areas in Pei County, Xuzhou. J. Coal Engineering., (10): 38-41.

[6] Mao, H.Y., Fang, C.L., (1998) Cave-in land types by coal mining and their comprehensive utilization ecological model. J. Acta Ecologica Sinica., (05): 3-8.