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Study on the Model of Soil Water Resources Quantity in Baoding Plain

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Abstract: The soil water resources has special properties, independent of surface water resources and groundwater resources. The relationship between soil water resources and soil water, the concept and characteristics of soil water resources have been analyzed and the model calculating the soil water resources quantity under the natural condition has been put forward based on the principle of water balance principle in this study. The model parameters have been focused on. Firstly, the daily precipitation has been determined based on typical year. Secondly, the surface runoff has been applied on the basis of the hydrological model of runoff yield in excess of infiltration. Thirdly, canopy interception rainfall has been concluded according to canopy interception model. Fourthly, the water quantity of infiltrated out of the assessment layer has been calculated based on the hydrological model of runoff yield at natural storage. The model has been applied to the work of soil water resources assessment of Qingyuan county in Baoding plain and the result has showed that the soil water resources quantity in mean precipitation year is 301.1485 million m^3 and its temporal distribution is consistent with the distribution of rainfall of the year.

Keywords: Baoding plain, calculation model of soil water resources, Qingyuan county, soil water resources

INTRODUCTION

For a region, the surface water, groundwater and soil water constitute the main water body for industrial and domestic, ecological and environmental water demand. For a long time, the surface water and groundwater were paid enough attention to as a result of their characteristics of pumping, conveyance and diversion, but the soil water was ignored because the soil moisture only can be used by plants (or crops) on-site, without the feature of the surface water and groundwater. Since 1970's, the concept of soil water resources was put forward by the pre-Sovietunion geographic hydrologists, research work on the concept and calculation model of soil water resources in China have carried out in different views (Shi and Su, 1984; Feng and Wang, 1990; Jin and Zhang, 1999; Wang *et al*., 2006; You and Wang, 1996; Jin and Fang, 2006). About the concept of soil water resources, typical view of representatives were as follows: one was soil water stored in the vadose zone called soil water resources, which could be direct and indirect use for human production and life (Wang *et al*., 2006), the other was soil water resources was defined soil water, used by agriculture production and utilization of ecological environment and recharged by precipitation and evaparation of shallow groundwater (Shen, 2008). About the computing model of soil water resources mainly had two methods: one was water balance method (You and Wang, 1996; Jin and Fang, 2006), the other was the combining of water balance method and numerical method (Shen, 2008). The above literatures showed that the conception of soil water resources paid no attention to the recharge sources, which could not be separated by the traditional water resources (the surface water resources and the groundwater resources), so the concept of soil water resources should be further defined and the calculating model of soil water resources should be put forward based on the redefined conception. Taking into account the available data and convenient calculation, study on the model of soil water resources quantity in Baoding plain will be made in the study, including conceptual characteristics and soil water calculation model.

Study area: The Baoding area is situated in the middle of Hebei pronvince and borders shanxi province on the west, Zhangjiakou city and Beijing on the north, Langfang and Cangzhou on the east, Hengshui and Shijiazhuang on the south (Fig. 1). The whole area covers 22103 km^2, 47% of which is plain area, called Baoding plain, shown in Fig. 1.

Because of a monsoon influence, precipitation is highly variable; mean annual rainfall in Baoding plain is 576 mm, 80% of which is concentrated between June and September. There are five Soil types in Baoding plain, which are sand, sandy loam, loam, clay loam and clay, the ratio is shown in Fig. 2. The main crops are winter wheat and summer corn in the area.

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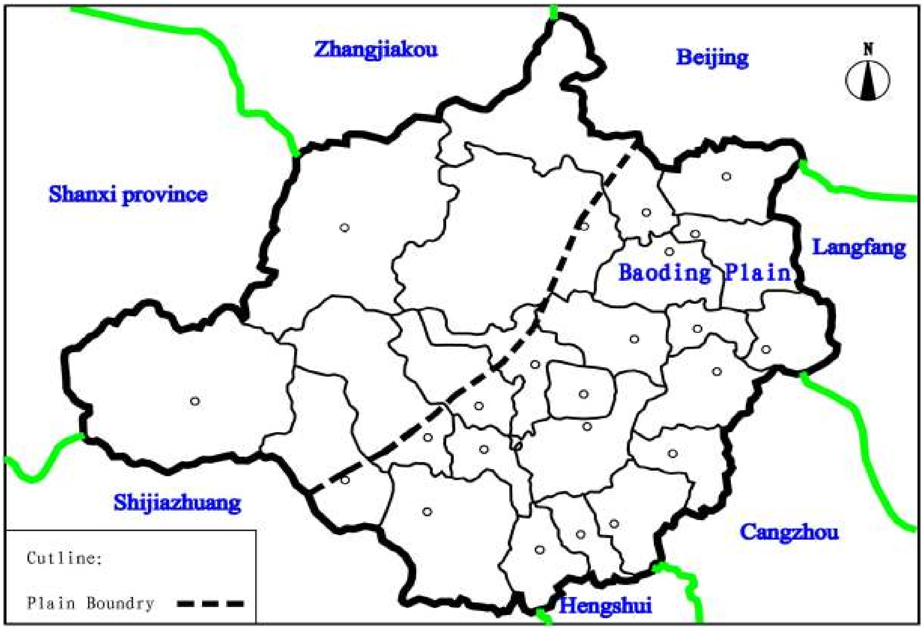

Fig. 1: The geographic position of Baoding area

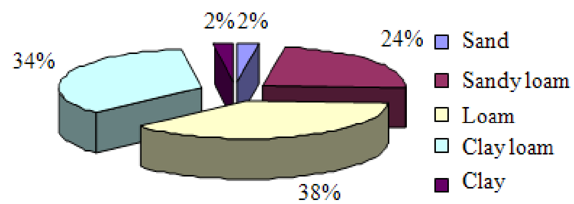

Fig. 2: Ratio of five types soil in Baoding plain

METHODOLOGY

Concept and characteristics of soil water resources:
Concept of soil water resources: There are closely relationships between soil water and soil water resources. Soil water refers to water stored in unsaturated layers by molecular forces, capillary force and with no movement under the action of gravity. People often care no about the total number of soil water and source of soil water (rainfall or irrigation) and often focus on stored soil water status and migration law. On soil water resources, people often ignore the specific state of migration and focus on its quantity and quantity change. Not all of soil water compose soil water resources, on the one hand, the requirement is to meet water requirement absorbed by crops or plants, on the other hand, the requirement is to facilitate the verification and coordination between traditional water resources evaluation results and soil water resources evalution results, so soil water resources should add at least three limitations to the soil water (Cheng and Sheng, 2008).

Storage space: Confined to the root active layer, rather than the entire unsaturated layer.

Storage status: Soil moisture for use only between field capacity and wilting coefficient.

Water source: Limited to precipitation.

Soil water resources is the soil water stored in the evaluation layer, between the wilting coefficient and field capacity to crop or plant roots uptake and recharged from precipitation. The quantity of soil water resources is called soil water resources amount.

Characteristics of soil water resources: Compared with surface water and groundwater, soil water resources has three important properties.

Computational complexity: On the one hand, influence factors of the soil water resources have a lot and its size depends on the characteristics of successive precipitation, soil texture and structure, crop type and production status. On the other hand, the amount of soil water resources have related to irrigation and groundwater recharge. Because soil moisture recharged by Irrigation and groundwater will occupy storage space of soil water resources, but not directly from atmospheric precipitation, which can't be counted soil water resources quantity.

Dynamic changes: Varies of soil water resources depends on the change between precipitation and evapotranspiration. Because precipitation is discrete variables, evapotranspiration is continuous variables and soil water resources evaluation layer has dynamic variability. From the recharge perspective, the root zone soil moisture is often affected by precipitation and irrigation water supplies. Precipitation and irrigation water supply of soil water are different: precipitation plays a positive impact on the soil water resources, but irrigation water plays a negative impact. From the perspective of excretion, soil water resources cannot be mined as groundwater and surface water, only be used in place of crops and varied with crop type and tillage practices.

Regulatability: Control measures make efficient use of soil water resources according to the character of using by plant at places. On one hand, adjusting and selecting spatial and temporal distribution of crops suitable to local soil water resources situation; on the other hand, regulating soil water input and output interface, increasing the effective supply of soil water and reducing soil water invalid loss adapt to the crop water requirements as much as possible.

COMPUTATONAL MODEL OF SOIL WATER RESOURCES OF FARMLAND

Natural field hydrological cycle: Field hydrological cycle involves four water, precipitation, surface water, soil water and groundwater to meet crop water requirement law. Soil water is the core part of the field water cycle. The sources of field hydrological cycle usually include precipitation and irrigation water. First, precipitation recharges soil and becomes soil water uptaken by the crop root, only when soil water in root zone does not meet the water requirements of crop, traditional water resources (surface water resources or groundwater resources) should be irrigated into the field and form the soil water to supply the crop absorption and utilization. If precipitation is the only sources of field water cycle without the irrigation water, the water cycle is called natural field hydrological cycle. The natural water cycle is shown in Fig. 3. Where P is the daily precipitation (mm), P_w is canopy rainfall interception, ET is evapotranspiration, P_{rd} is the water quantity of infiltrated out of the evaluation layer, R_s is surface runoff, E_g is the recharge quantity by shallow groundwater. First, there are three losses from to soil water resources in the evaluation layer as follows:

- Canopy rainfall interception P_w, which evaporate to the atmosphere.
- Surface runoff R_s, which form surface water resources.
- Water quantity of infiltrated out of the evaluation layer P_{rd}, which store the evaluation layer below or develop the groundwater resources; Second, the soil water may be recharged by shallow groundwater evaporation; Third, the soil water in the evaluation layer evaporate and transipirate into the atmosphere.

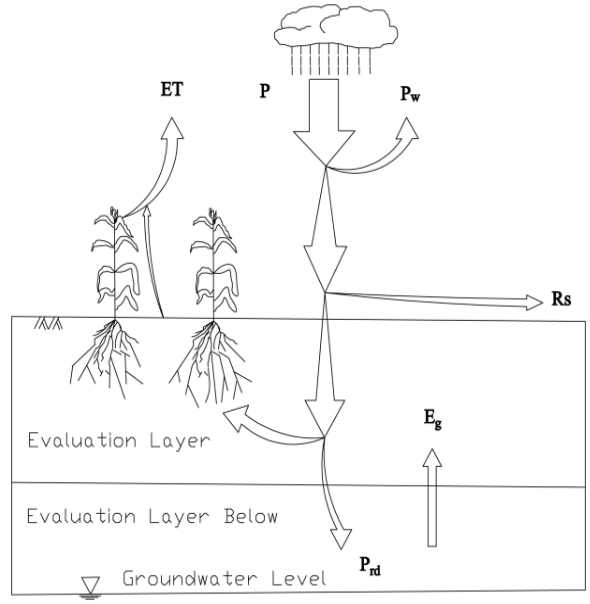

Fig. 3: Natural field hydrological cycle

Calculation model of soil water resources: In order to facilitate the calculation, calculation time taken for the day, surface precipitation in different day of the year is calculated and its invalid precipitation, surface runoff, recharge water leakage below evaluation layer is decided. Field hydrological cycle is the theoretical basis of the model calculation of Soil water resources and soil water balance is the basic principles of calculation model of soil water resources. Field hydrological cycle shows that the three loss amount from precipitation to soil water resources of evaluation layer includes plant canopy interception, surface runoff and below infiltration from evaluation layer. Seen from the water balance, soil water resources of evaluation layer is calculated by the difference between the amount of annual precipitation and loss of annual precipitation and the Eq. (1) is as follows:

$$W = \sum P - \sum P_w - \sum R_s - \sum P_{rd} \tag{1}$$

W = The soil water resources quantity of evalution layer (mm)
P = The daily precipitation (mm)
P_w = Canopy rainfall interception, which cannot be used by crop root (mm)
R_s = Daily surface runoff (mm)
P_{rd} = Daily water quantity of infiltrated out of the evaluation layer (mm)

Calculation method of model parameters: In order to get the soil water resources amount of evaluation layer, the parameters should be calculated separately. To determine the surface runoff Rs and water quantity of infiltrated out of the evaluation layer Prd, two basic assumptions will be introduced: surface runoff follow runoff yield in excess of infiltration and water quantity of infiltrated out of the evaluation layer abide by runoff yield at natural storage.

Daily precipitation: First the typical rainfall stations should be choice in the region and precipitation data should be collected and checked, then the surface area of annual precipitation data will be calculated from rainfall of the point based on Thiessen polygon method and finally typical annual rainfall can be calculated using frequency analysis methods and daily precipitation data corresponding to the different typical year can be concluded.

Canopy interception rainfall: Canopy interception is the storage phenomenon of rain water in plant leaves and it is the first interception and distribution of rainfall from precipitation to the ground in the field and it is an important part of the hydrological cycle (Rui, 2004; Wang and Zhang, 2009). Canopy interception is affected by the crop characteristics and meteorological factors. Canopy interception capacity is the maximum canopy rainfall interception. LAI is the characterization of the canopy rainfall interception capacity index (Yu *et al*., 2011), which is used to measure the impact of crop species and growth stage of the crop to the canopy interception. The actual interception mainly is affected by rainfall and rainfall intensity. For the first rains, the crop canopy interception was increased with a non-linear relationship between rainfall and canopy interception. Canopy interception model is divided into empirical, conceptual and physical models (Liu *et al*., 2012). In comparison, from the statistical model, conceptual model to the physical model, canopy interception mechanism needs for more in-depth consideration of the input data and model parameters and the difficult is also growing. According to information available, the statistical model is selected in this study to determine canopy interception, that is the equation, based on observational data of rainfall and leaf area index for the impact factor, the plant interception formulas (2) is as follows (Liu, 2004):

$$P_w = \begin{cases} 0.092LAI \cdot P^{[0.53-0.0085(p-5.0)]} & (P \le 17\,mm/d) \\ 0.225LAI & (P > 17\,mm/d) \end{cases} \tag{2}$$

P_w = Interception plant of daily average precipitation
LAI = Leaf Area Index
P = Daily average rainfall

Surface runoff: Daily infiltration capacity of different soil types should be determined based on surface runoff obtained from typical year. Evaluation layer depth should be identified based on agriculture root zone method. The surface runoff Eq. (3) is shown as follows. If (P-P_w) is greater than F_M, surface runoff will be produced, otherwise, surface runoff will not be produced:

$$R_s = \begin{cases} 0 & P - P_w \le F_M \\ P - P_w - F_M & P - P_w > F_M \end{cases} \tag{3}$$

R_s = Daily surface runoff (mm)
P_w = Canopy rainfall interception (mm)
F_M = Daily infiltration capacity (mm/day)

Water quantity of infiltrated out of the evaluation layer: According to the principle of runoff yield at natural storage, the water quantity of infiltration out of the evaluation layer will be calculated. That is when precipitation deducting invalid precipitation and surface runoff rainfall recharge of evaluation layer exceeds field capacity, the excess will be the water quantity of infiltrated out of evaluation layer. Of course evaluation layer soil water recharge also includes recharge phreatic evaporation. In addition, soil water supply of evaluation layer also includes artificial irrigation water and phreatic evaporation. Phreatic evaporation in deep groundwater area is negligible. Artificial irrigation water in natural condition is zero.

Daily soil water of evaluation layer is calculated be the following Eq. (4):

$$w_{n+1} = w_n + P_n - P_{wn} - R_{sn} + E_{gn} - ET_n - P_{rd} \tag{4}$$

w_{n+1} = The soil moisture content of the n+1 day
w_n = The soil moisture content of the n day
P_n = The precipitation of the n day
P_{wn} = The canopy interception precipitation of the n day
R_{sn} = The surface runoff of the n day
E_{gn} = The recharge of shallow groundwater of the n day, its value equal zero under deep groundwater zone (groundwater depth greater than 4 m)
ET_n = Evapotranspiration of plant in the n day, which can be obtained in accordance with the relationship of potential crop evapotranspiration and crop coefficient
P_{rd} = Water quantity of infiltrated out of the evaluation layer

If w_{n+1} is greater than the storage capacity (I_{max}), the P_{rd} can be calculated by the following Eq. (5) and the P_{rd} will be zero under other situations:

Table 1: The soil water resources amount items of different type soil in mean precipitation year unit: mm

Soil type	P	P_w	R_s	P_{rd}	W
Sand	494.49	44.13	0	0	450.36
Sand loam	494.49	44.13	0	0	450.36
Loam	494.49	44.13	0	0	450.36
Clay loam	494.49	44.13	0	0	450.36
Loam	494.49	44.13	3.67	0	446.69

Table 2: The soil water resources amount of different type soil in mean precipitation year in Baoding Qingyuan county unit: 10,000 m^3

County	Soil type	W
Qingyuan	Sand	15.31
	Sand loam	8119.99
	Loam	7813.75
	Clay loam	12213.76
	Loam	1952.04

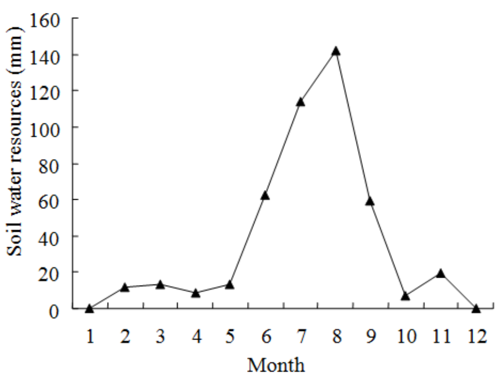

Fig. 4: Monthly change process of soil water resources of clay loam in mean precipitation year

$$P_{rd} = \begin{cases} 0 & w_{n+1} \le I_{\max} \\ w_{n+1} - I_{\max} & w_{n+1} > I_{\max} \end{cases} \quad (5)$$

I_{max} is the storage capacity of the soil. According to the above method, daily rainfall, ineffective rainfall, surface runoff and water quantity of infiltrated out of the evaluation layer are calculated in the year and put into formula (1), and the results of the total soil water resources will be gotten. In this way the dynamics of soil water resources of the year will be found.

A case study of soil water resources quantity: Baoding plain belongs to deep underground water area, farmland soil water resources under natural conditions can be calculated by the proposed mathematical model. The soil water resources in the region has been calculated, taking Qingyuan County in Baoding plain as an example. The results are as follows: Table 1 is different parameters calculated result in five soil texture during the mean hydrological year and Table 2 is soil water resources quantities of 5 soil textures of Qingyuan county in Baoding plain. Figure 4 is the change process of soil water resources in clay loam during the mean hydrological year.

Table 1 shows that precipitation, canopy interception rainfall and water quantity of infiltrated out of the evaluation layer in five soil texture are the same and only the surface runoff in five soil texture is different. The surface runoff of clay soil is distinctive, larger than that of other four soil texture, indicating that the amount of soil water greatly influenced by soil daily infiltration capacity of evaluation layer. Table 2 shows that the amount of soil water resources of five soil type in Qingyuan County and the sum amount is 301,148,500 m^3.

Figure 4 shows that the distribution of soil water resources amount in mean precipitation year is consistent with of rainfall distribution during the year. The precipitation in January is little and soil water resources amount is small. If the monthly precipitation is big and soil water resources amount is big, for example, soil water resources in 6-8 months is 318.43 mm, accounting for 70.71% of the amount of soil water resources in the year.

CONCLUSION

Calculating model of soil water resource in natural field hydrological cycle is established in this study, which can not only obtain the soil water resources amount of different frequency in the region, but also can clear dynamic change of the soil water resources during the year in the area. The model has been applied to the work of soil water resources assessment of Qingyuan county in Baoding plain and the result has shown that the soil water resources quantity in mean precipitation year is 301.1485 million m^3 and its temporal distribution is consistent with the distribution of rainfall of the year, which can be used to calculate the main crop's soil water resources in different period. The size of soil water resources in the region can provide macro support data for the adjustment of planting structure on the basis of available soil water resources to achieve the sustainable develop in agriculture.

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