Urban water dissipation calculation based on the improved water balance models

Ke Zhou

ABSTRACT

The urban water dissipation models are developed based on observation and different urban construction patterns. The regional water dissipation is selected in Zhengzhou, the capital city of Henan Province, China. According to model calculation results, the annual water dissipation was obtained (820.0 mm), which is significantly higher than that compared with the traditional methods (494. 4 mm). The results show that the water dissipation contribution rate of green space, inside building, hardened ground and pavement, and water surface are 40.58, 38.70, 18.32, and 2.40%, respectively. The water dissipation of hardened ground and pavement, green space, and water surface is greatly influenced by hydrological and meteorological factors. The water dissipation inside a building is proportional to the number of building layers and residents. The results show that water dissipation inside a building cannot be ignored and it is the main component of artificial water dissipation. Under the same rainfall conditions, the water dissipation of the hardened ground and pavement is inversely proportion to the runoff coefficient.

Key words | binary water cycle, mathematical models, mechanism, urban hydrology, water dissipation

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HIGHLIGHTS

- Urban water dissipation was classified according to different urban facilities.
- Water dissipation models were proposed based on different urban water dissipation sectors.
- The water dissipation contribution rate of different urban facilities was calculated.
- The results will be an important technical support for urban water planning and utilization.

GRAPHICAL ABSTRACT

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INTRODUCTION

Under the influence of global climate change and rapid urbanization, urban water-logging disasters occur frequently. Urban water environment, water resources, and water ecological problems are becoming more and more serious. As a result, urban water cycle mechanisms and water flux variation have become hot issues in urban hydrological science research (Zhang *et al.* 2014). Climate change and human activities have become two major driving factors affecting the hydrological cycle (Song *et al.* 2013). At the 7th International Congress of Hydrology Science, scholars pointed out that the impact of urbanization on the hydrological process is the focus of urban hydrology and water resource research (Xia & Zuo 2006). Urban hydrology is facing many important challenges (Fletcher *et al.* 2013). For instance, the proportion of urban population in China was 10.64% in 1949. The proportion of urban population exceeded 50% in 2011. In 2019, the proportion of urban population reached 60.77. The urban water issues are becoming more prominent owing to the increase of urban population, urban area, and the total amount of water consumption. In the north regions of China, variation of underlying land surface due to human activities reduces the runoff in many rivers (Zhang *et al.* 2013), increases the frequency of short duration heavy rainfall, intensifies rainfall events, and heightens the cumulative rainfall in the areas affected by urbanization (Reng *et al.* 2016). In Zhengzhou, the capital city of Henan Province, the average precipitation in 2018 was 640.0 mm, and the total water supply was 20.23×10^8 m^3. The urbanization area reached 1,100 km^2, but the water dissipation mechanism is vague and different dissipation components are unclear (Zhang *et al.* 2012).

Urban water dissipation is an important component in the hydrological process, and the magnitude of water dissipation directly affects the size of water flux in the circulation process. The urban hydrological process includes both the 'natural' cycle that occurs on the complex underlying ground surface and the 'social' cycle that concentrates on the urban water supply process (Liu *et al.* 2014).

In the aspect of urban 'natural' water dissipation, the soil–plant–atmosphere system model (SPAC) (Zhang *et al.* 2011) and remote sensing are widely used in the calculation of ground surface evapotranspiration. Experimental and analytical methods are used in plant water evapotranspiration research. There are relatively few studies on water dissipation in the urban 'society' sector (Di *et al.* 2011; Livesley *et al.* 2016). The current research is mainly focused on urban water demand prediction and water requirement management (Li *et al.* 2012; Ni 2013; Giacomoni & Berglund 2015; Loubet *et al.* 2015; Muhammad *et al.* 2015). Where the existing research findings are concerned (Minhua *et al.* 2021), the urban water consumption study is mainly focused on the 'natural' side (Ouyang *et al.* 2021), such as transpiration and dissipation characteristics of urban trees, lawns, and water surfaces. There are few studies on evaporation and dissipation of urban buildings, hardened ground, and pavement.

The water consumption research on the 'social' side is mainly focused on the sector of water resource allocation, and there are few studies on the mechanism of water dissipation, especially inside buildings, which is closely related to the residents' daily life and production. This is the reason why the current theories and models cannot solve the problems of urban high-intensity water consumption.

Therefore, the main purposes of this paper include studying the comprehensive calculation methods by conjunctive use of experiment, investigation and statistical data; carrying out water dissipation mechanism analysis on each water component; constructing water dissipation models through analysis of different urban construction components, and selecting a typical example to carry out urban water dissipation calculation.

MATERIALS AND METHODS

Framework of the urban water dissipation model

In this paper, the urban water dissipation pattern is classified based on urban water requirement, land surface features, and urban hydrological circulation routes. In order to explore the urban water dissipation mechanism,

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the corresponding mathematical calculation model and water dissipation system model are established. In the models, the urban space is classified as four types, i.e., buildings, hardened ground and pavement, green space, and water surface. Figure 1 is a framework of urban water dissipation. The water dissipation in the model is the mean annual water dissipation per unit area, in units of mm.

Dissipation models for hardened ground, pavement, and roof

Hardened ground and pavement could be classified as impervious (such as concrete, cement, and asphalt road) and permeable pavement. The building roof, as an impervious ground, cannot be penetrated, and the source of water dissipation is only from natural precipitation. It could be considered that the retained precipitation on building roofs could be totally dissipated after a short period of rainfall. For permeable pavement, the intercepted precipitation could be simultaneously dissipated both in evaporation and infiltration. The infiltrated water could be evaporated again. For the annual scale, usually, it is considered that the rain water intercepted by permeable ground surface and building roofs could be evaporated completely (Daba & You 2020). The dissipation module consists of effective rainfall, as follows:

$$W_Y = P_2 + (1 - \psi)(P - P_2) \quad (1)$$

in which, W_Y is dissipation from hardened ground, pavement surface, and building roof, mm; P_2 is the accumulated precipitation volume (daily rainfall less than 2, mm); ψ is the annual runoff coefficient, ≤ 1; and P is the annual precipitation, mm.

For urban sprinkling roads, the sources of water dissipation are from both artificial sprinkle and natural precipitation. The water dissipation from natural precipitation could be calculated with Equation (1). This model assumes that all artificial sprinkles on roads are evaporated and dissipated without surface runoff and infiltration. Therefore, for water dissipation on the sprinkle road, artificial sprinkle water volume W_A should be added.

Dissipation model of urban river and lake surface

Considering the meteorological factors affecting rivers and lakes (Doulgeris *et al.* 2020), we can develop the dissipation model for urban river and lake surfaces as follows:

$$W_W = \frac{\Delta}{\Delta + \gamma}(R_n + A_h) + \frac{\gamma}{\Delta + \gamma}\frac{6.43(1 + 0.536U_2)D}{\lambda} \quad (2)$$

in which W_W is the dissipation capacity of urban river and lake surface; A_h is the energy transported to the water body in the form of advection, MJ/(m^2·d); R_n is the net radiation, MJ/(m^2·d); U_2 is the wind speed at the height of 2 m, m/s; D is the saturated vapor pressure difference, kP$_a$; Δ is the slope of temperature and the saturated vapor pressure curve, kP$_a$/$^\circ$C; γ is a constant in wet and dry meters, kPa/$^\circ$C; λ is the latent heat of dissipation, MJ/kg, $\lambda = 2.50$.

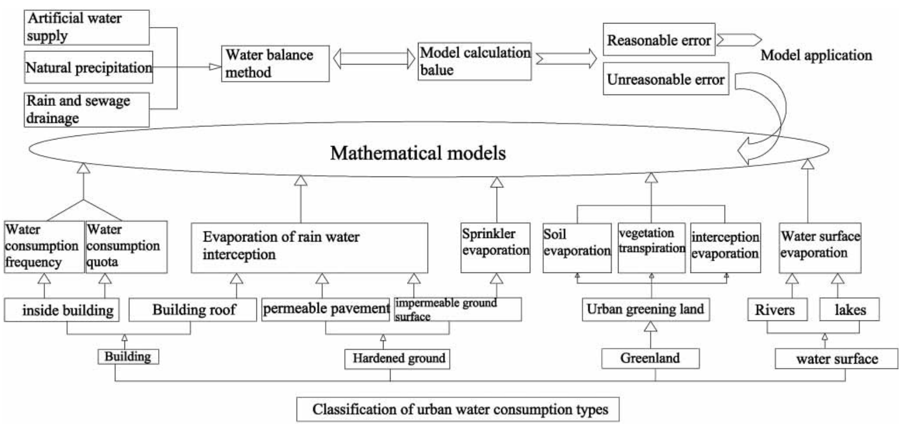

Figure 1 | Framework of the urban water dissipation model.

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Dissipation model of urban green space

The water dissipation sources of urban green space are from artificial water supply and natural precipitation. Natural precipitation could be intercepted, evaporated, and infiltrated by plants and soil in the urban green space. A dissipation model for urban green space is as follows:

$$W_G = W_{EI} + W_{ET} + W_{EO} \tag{3}$$

in which, W_G is dissipation from green space; W_{EI} is vegetation rainfall interception dissipation; W_{ET} is vegetation transpiration; W_{EO} is soil dissipation in planting area, mm.

The model is built according to the existing mathematical model. The vegetation rainfall interception dissipation W_{EI} could be calculated with the Noilhan–Planton equation.

$$W_{EI} = V_{EG}\delta W_W \tag{4}$$

where V_{EG} is the crop coverage area, m^2 and δ is the area ratio of wet leaf surface.

$$W_{ET} = K_{cb}E_p \tag{5}$$

$$W_{EO} = K_e E_p \tag{6}$$

where K_{cb} is basic crop coefficient; K_e is the soil water evaporation coefficient, which could be selected according to FAO Irrigation and Drainage Paper No. 56 (Allan *et al.* 1998). E_p is the potential evapotranspiration capacity of vegetation (calculated by the Penman–Monteith method).

$$E_p = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{(T_{mean} + 273)}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{7}$$

where G the is net land surface radiation, MJ/(m^2·d); T_{mean} is the daily mean temperature, °C; e_s is the saturated vapor pressure, kP_a; e_a is the actual vapor pressure, kP_a.

Water dissipation model inside buildings

The dissipation inside buildings is an important component in urban water dissipation. In this study, the principle of bionics was adopted to simulate the different buildings as 'the concrete forest' with 'different height and physiological pattern'. The living buildings are simulated as 'life trees', the office buildings are simulated as 'office trees', and the production buildings are simulated as 'production trees'. Different kinds of trees are composed of their own cells. Each cell has its own water dissipation cycle and behavior. For example, the 'cell' of 'life trees' is a 'family', corresponding to a house; its water dissipation behavior includes laundry, cooking, floor cleaning, window cleaning, wiping tables, bathing, and so on.

According to different functions and mechanisms, urban buildings could be classified as residential buildings, office buildings, commercial buildings, hotels, restaurants, hospitals, teaching buildings, public service buildings (libraries, theatres, and museums), and production workshops. The relevant water dissipation is simulated as a real tree. According to the formula of vegetation transpiration, a general equation for calculating water dissipation inside buildings is established as follows:

$$W_i = C_i N_i A_i W_{DI}\delta_I \tag{8}$$

in which W_i is the total water dissipation inside the ith building, mm; C_i is the dissipation ratio of the ith building to the total buildings, %; N_i is the total number of the ith building layers; A_i is the land area occupied by the ith building, m^2; W_{DI} is the potential water dissipation inside the ith building, mm; and δ_i is the area ratio of wet floor inside the ith building, %.

The parameters in the model are determined according to the building purposes and framework. The area ratio of wet floor is the ratio of wet area to the total area of each building. The area occupied by the building refers to the horizontal area. Potential water dissipation refers to the daily water dissipation capacity per unit area of the building, which depends on the building purpose and water consumption types inside the building. Water dissipation frequency is determined through the questionnaire survey. The water dissipation quota is determined through the quantitative experiment.

Water balance model (Nunes *et al.* 2020)

The urban water use comes from artificial water supply (W_S) and natural precipitation (P). Urban water dissipation can

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be classified as two parts: outdoor water dissipation (W_{OUT}) and dissipation inside buildings (W_{IN}).

The outdoor water dissipation source comes from two parts: artificial water supply and natural precipitation, while artificial water supply is the only source of water dissipation inside buildings. The natural dissipation from precipitation could be classified as vegetation rainfall interception evaporation, vegetation transpiration, soil evaporation, water surface evaporation, hardened ground, and pavement rain water evaporation and building roof rainfall interception evaporation. Artificial outdoor water supply is mainly used for garden and green space irrigation, road sprinkling, and guardrail cleaning. It is believed that except for a small amount of seepage on the green space irrigation, the majority of outdoor water supply is totally dissipated without ground surface runoff and infiltration. Water consumption in an urban building mainly includes drinking water, face washing, bathing, cooking, washing clothes, flushing toilets, floor wetting, and humidifier. Different building types have different water consumption components and different water consumption quotas.

Based on the circulation process of urban water systems, the water balance model is established as follows:

$$W_S + P = W_{IN} + W_{OUT} + D + W_{SUR} + \Delta W_{GRO} \quad (9)$$

in which W_S is the total amount of annual artificial water supply for a city.

$$W_S = W_{SI} + W_{SO} \quad (10)$$

where W_{SI} is the annual total water supply for urban buildings and is equal to the sum of water supply for each building. W_{SO} is the annual outdoor water supply, mainly including municipal water use (road sprinkling, guardrail cleaning, green space water use, and water recharge to urban rivers and lakes); P is annual precipitation; W_{IN} is the total amount of annual water consumption inside buildings.

$$W_{IN} = \sum_{i=1}^{n} W_i \quad (11)$$

W_{OUT} is the total annual outdoor water consumption.

$$W_{OUT} = W_Y + W_A + W_G + W_W \quad (12)$$

D is the water drainage; W_{SUR} is the annual precipitation surface runoff; and ΔW_{GRO} is the annual underground water storage variation. The unit in the water balance model is m^3.

CASE STUDY

The basic quota of urban water dissipation is obtained by means of case observation, including 'natural' (such as meteorological data and hydrological data) and 'society' sides (such as per quota of water consumption). The frequency of water consumption per person per day is analyzed by a questionnaire survey. The urban underlying ground surface could be classified according to water consumption features. According to the features of different water consumption, the corresponding dissipation model is established. The calculation is made for different water dissipation components using different models. The integrated dissipation is achieved by using the area weighted method. Finally, verification is made with the water balance method.

We selected a region of Zhengzhou city in Henan Province, China, to carry out a water dissipation case study. The region selected covers 352 hm^2 with 60,000 residents and low buildings. Each building generally has 13 layers. The green rate in the region is 54.8%. The annual mean precipitation is 640.5 mm. All data come from the authority department, Henan Province Hydrology and Water Resources Bureau.

Water dissipation patterns

There are many water dissipation components in the urban area. In order to make reasonable water dissipation calculation and according to the model requirement and the water balance model proposed above, water dissipation could be classified as four different components, i.e., water dissipation inside buildings, on the pavement, in green space, and on the water surface (Table 1).

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Table 1 | Area ratio of different water dissipation in the study region

Surface type	Area (m^2)	Ratio (%)
Building body	1,137,031	32.31
Pavement	1,796,180	51.04
Green space	517,268	14.70
Water surface	68,421	1.95
Total	3,518,900	100.0

According to the real situation, the hardened pavement includes impervious pavement (such as asphalt road) and permeable pavement (such as pedestrian).

There is no artificial sprinkler on roads in the study area. Hence, the only source of water dissipation comes from rainwater interception.

Investigation on the frequency of living water consumption

Based on the water dissipation model inside buildings (Equation (8)), the frequency of living water consumption was investigated by the questionnaire. Three hundred questionnaires were distributed, and 272 questionnaires were effectively collected, covering the residents and staff of the main buildings in the area. The proportion of male-to-female respondents to the questionnaire is nearly 1:2, ranging in age from 18 to over 60, covering different age groups.

Seven questions were asked about the different frequencies of water consumption in daily life. Statistics were made in m^3 per day per capita. Table 2 shows the content of the questionnaire, and Table 3 shows the daily average water consumption.

Experimental measurement of water dissipation quota

Temperature, humidity, wind speed, precipitation, radiation, and other meteorological data were collected from the meteorological stations. The period of meteorological data is from January 1 to December 31. The 'natural' water consumption was calculated based on the collected meteorological data, including vegetation transpiration, vegetation intercepted water evaporation, soil water evaporation, water surface evaporation, hardened ground, and pavement precipitation interception evaporation.

According to the water balance model (Equations (9)–(11)), five typical families were selected to carry out an experimental investigation. The weighing method was adopted for water dissipation measurement. For instance, through comparing towels weight before (dry) and after (wet) washing face, hands, and bath, the water dissipation of washing face was measured. The water amount consumed in washing clothes is equal to the weight of wet clothes minus the weight of dry clothes. Cooking water consumption refers to the water amount used in cooking, including dissipation during the cooking process and water converted into cooked food. The scale accuracy in the experiment is 1 g. For the wetting floor, humidifier and other water consumption, the calculation is based on the unit area. Table 3 shows the average water dissipation per household.

Table 2 | Contents of the questionnaire

No.	Content	Item selection
1	Gender	A; male; B female
2	Age	A under 18; B 18–25; C 26–60; D over 60.
3	Daily face washing times	A 1; B 2; C 3; D 4; F -
4	Toilet frequency daily	A 1(4); B 2(5); C 1(6); D 1(7); F -
5	Number of washing clothes daily	A 1; B 2; C 3; D 4; E 5; F -
6	Daily bathing times	A 1; B 2; C 1/2; D 1/3; E 1/4; F –
7	Daily cooking times	A 1; B 2; C 3; D 4; F -

Table 3 | Frequency and average living water dissipation

Items	Daily frequency (average)	Mean (L/times)
Flower irrigation	1	0.40
Washing (face, hands)	2	1.00
Humidifiers	1	2.00
Toilet	5	0.25
Washing clothes	2	0.85
Bath	1/2	4.00
Cooking	3	2.20

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DISCUSSIONS

Calculation results for different kinds of water dissipation

Using the relevant methods and the equations, water dissipation patterns were classified first in the region. Then, different kinds of water dissipation were calculated.

Hardened ground, pavement, and roof water dissipation

Due to flat building roofs in the experimental area, the roof precipitation–runoff coefficient ψb is 0.90. According to the Urban Drainage Engineering Planning Code (The Ministry Housing and Construction China 2017) and the Outdoor Drainage Design Code (The Ministry of Housing and Construction China 2016), the runoff coefficient ψp of impermeable ground or pavement is 0.90. The runoff coefficient of permeable ground or pavement ψs is 0.55. Based on Equation (1), the daily precipitation greater than 2.0 mm was considered as the effective precipitation. According to calculated results using Equation (1), the runoff coefficient of roof water dissipation and impermeable ground and pavement interception dissipation is 189.9 mm. The runoff coefficient of water dissipation of permeable ground or pavement is 320.70 mm.

Water surface evaporation (dissipation)

The lake surface dominates the water surface in the study area. The calculation of water surface evaporation assumes that the water surface is still. Assuming that the study area's water body is enough for evaporation, according to calculation results using Equation (2), the annual water dissipation per unit water surface area is 1,010.7 mm.

Green space water dissipation

Grassland, shrubs, and trees are the main vegetation in the study area. The water dissipation includes three parts: soil evaporation, vegetation transpiration, and plant rainwater interception evaporation. Soil evaporation and vegetation transpiration can be calculated based on plant potential evaporation, and crop potential evaporation can be calculated according to Equation (7). Plant interception rain water evaporation can be calculated according to water surface evaporation. The total area of evapotranspiration equals the total area of the region multiplied by the vegetation coverage rate (i.e., $V_{eg} = 0.55$). The area of soil evaporation equals the green land area. The final calculated soil evaporation of green space is 258.80 mm. Vegetation transpiration dissipation is 488.80 mm, and the evapotranspiration of vegetation rain water interception is 48.90 mm.

Water dissipation inside a building

Water dissipation inside a building is the largest component in urban water dissipation, closely related to residential life and work. The water source inside the building comes from an artificial water supply through pipelines. Omitting the lost water transfer process, the water dissipation calculation can be classified into two parts, i.e., daily life and floor wetting. The calculation unit of water dissipation in life and work is in per capita. The dissipation calculation of the wetting floor is in the unit area (m^2). According to calculation results, water dissipation inside the building per unit area is 260.6 mm, in which water dissipation of daily life by residents is 151.7 mm, and water dissipation by floor wetting is 108.9 mm.

Water dissipation mechanism analysis

Table 4 shows the different water dissipation items in the study area, in which the water dissipation inside a building

Table 4 | Different water dissipation intensities

Items	Volume (mm)
Inside building	260.6
On roof	189.9
On impermeable pavement	189.9
On permeable pavement	320.7
River, lake surface	1,010.7
Vegetation transpiration	488.8
Interception evaporation	48.9
Soil water evaporation	258.8

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is representative of the 'social' sector. The amount of water dissipation is determined by the residents' living and working habits, and the water dissipation varies from person to person and is less affected by meteorological factors. The water dissipation outside the building is greatly affected by meteorological factors.

The building roof water dissipation is the same as impermeable ground or pavement because of the same runoff coefficient. Due to different runoff coefficient, water dissipation on roof is different from that on permeable pavement. The runoff coefficient determines rain water interception evaporation intensity on hardened ground and pavement.

The calculation of green space water dissipation is divided into three parts, in which vegetation interception evaporation depends on the shape of vegetation leaves and the characteristics of precipitation. Vegetation transpiration and soil evaporation represent water dissipation in the urban 'natural' sector, which depends mainly on factors such as temperature and precipitation, sunshine and solar radiation, and other meteorological factors. The amount of water surface evaporation is mainly determined by meteorological factors such as temperature, relative humidity, and solar radiation.

Contribution rate of different water dissipation

The contribution rate of each water dissipation is equal to the water dissipation ratio to the total water dissipation in the study area. Table 5 indicates the different water dissipation rates.

It can be seen from Table 5 that the green space water dissipation rate (40.58%) ranks first. The reason is that water dissipation of green space happens at three layers in vertical direction, i.e., soil evaporation, vegetation transpiration, and intercepted rain water evaporation on plant leaves, and the latter two is much larger than the area of green space.

Table 5 | Different water dissipation contribution rates

Surface types	Inside building	Pavement	Green space	Water surface	Total
Rate (%)	38.70	18.32	40.58	2.40	100.00

This is due to the plantation of trees and shrubs on both sides of the road, the calculated area of which depends on the degree of vegetation coverage. The ratio of calculation area equals to the green space rate, which is 14.70%.

The area ratio occupied by buildings in the region is 32.31%. However, because the water dissipation of the building is distributed at multi-layers in the vertical direction, which is proportional to the number of the building layers, and considering the intercepted rainwater evaporation on roofs, it is concluded that the contribution rate of the total water dissipation of the building is 38.70%, which can be divided into two parts, i.e., water dissipation inside buildings and rain water interception evaporation on building roofs, the former is 31.22%, and the latter is 7.48%.

For the hardened ground or pavement, the area ratio is 51.04%, in which the permeable surface accounts for 40.73%, and the impermeable ground accounts for 10.31%. However, water dissipation occurs only in the surface layer, which is closely related to rainfall characteristics, and the final calculated contribution rate is 18.32%.

The water surface's dissipation contribution rate is 2.40% because of the small proportion of water surface area in the study region.

Water balance verification

Figure 2 shows the total water dissipation and water supply in the region. Assuming that there is no change of surface water volume in the experimental area, the drainage capacity is calculated according to the drainage coefficient, and the groundwater recharge is equal to the leakage of the pipeline, according to the calculation with Equation (9), the relative error accounts for 4.25% in the total water supply. The reason is that there is an error in measuring the variation of groundwater volume, and only the leakage loss of the pipeline is considered in the study.

Comparison analysis on the studied results

The calculation of urban water dissipation is mostly limited to the natural water consumption, and the binary attribute of natural and social sectors is ignored. The urban water dissipation process has obvious dual attributes (natural–social).

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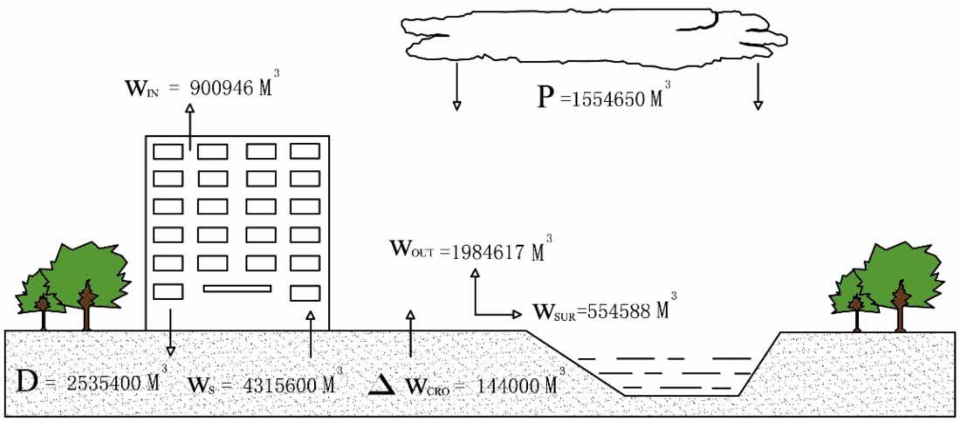

Figure 2 | Schematic of water components in the water balance system.

To accurately calculate urban water dissipation and water circulation, this paper classifies urban water dissipation into five types based on different land use, i.e., green space, water surface, soil surface, buildings, and hardened ground. The analysis framework of urban natural–social dual water dissipation is put forward, and the urban dual water dissipation calculation model is constructed.

Based on the proposed methods, the annual water dissipation in Zhengzhou is obtained (820.0 mm), which is significantly higher than that compared with the traditional methods (494.4 mm). The results show that the water dissipation contribution rate of green space, inside the building, hardened ground and pavement, and water surface are 40.58, 38.70, 18.32 and 2.40%, respectively. It is shown that water dissipation inside the building cannot be ignored, and it is the main component of artificial water dissipation.

The study results show that with the increasing urbanization level, the comprehensive water dissipation intensity increases in urban areas, and the water dissipation proportion of the social sector increases. Population density and building density are the main factors affecting the water dissipation intensity of the urban social side. The increase of urbanization level would reduce the seasonal difference of urban water dissipation.

CONCLUSIONS

In this paper, the water dissipation models were set up based on urban construction patterns and the data from authority departments, which are used to quantitatively calculate water dissipation for different types of urban facilities. The calculated rain water dissipation on roof and impermeable ground is 189.9 mm. Rain water dissipation on permeable ground or pavement is 320.70 mm. The annual water evaporation of water surface is 1,010.7 mm. The vegetation transpiration dissipation is 488.80 mm, and the transpiration from rain water intercepted by vegetation is 48.90 mm. Water dissipation inside buildings per unit area is 260.6 mm, in which water dissipation of daily life by residents is 151.7 mm, and water dissipation by floor wetting is 108.9 mm.

Compared with traditional hydrological models that can only consider the evaporation caused by precipitation and neglect artificial dissipation, more detailed information on water circulation could be obtained using the models proposed in this paper and will play an essential role in urban construction.

The results show that the water dissipation inside buildings cannot be ignored in urban water planning and allocation. This kind of water dissipation is proportional to the number of building layers, and its potential water dissipation is mainly determined by human activities, and is less influenced by hydrological and meteorological factors.

Under the same rainfall conditions, the water dissipation of the hardened ground and pavement is inversely proportional to the runoff coefficient. The water dissipation of hardened ground, pavement, green space, and water surface is greatly influenced by hydrological and meteorological factors.

According to the calculated contribution rate of different water dissipation components to the total water

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dissipation, the green space water dissipation rate is 40.58%, ranking the first. The building water dissipation contribution rate is 38.70%, which ranks second. For the hardened ground or pavement, the final calculated water dissipation contribution rate is 18.32%. The water dissipation contribution rate of different construction patterns to the total water dissipation is determined by the area ratio of different construction patterns to the total area. The larger the water dissipation, the larger the area, the greater the water dissipation contribution rate would be.

It is sure that the present findings should be helpful to scientifically measure the dissipative flux of urban hydrological cycle, provide theoretical and technical support for urban water planning, and lay a scientific basis for urban water demand management and water saving.

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DECLARATION OF COMPETING INTEREST

The author declares that there should be no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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