Effect of Digital Elevation Model Spatial Resolution on Depression Storage

Short running title: Effect of DEM Spatial Resolution on Depression Storage

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Abstract

Surface water storage—including wetlands and other small waterbodies—has largely been disregarded in traditional hydrological models. In thi paper, the grid resampling method is adopted to study the influence of the digital elevation model (DEM) grid resolution on depression storage (DS) considering different rainfall return periods. It is observed that the DEM grid size highly affects DS, and the higher the grid resolution t larger the DS value. However, when the grid resolution reaches a certain value, the maximum DS value decreases. This suggests that a critical grid resolution value exists at which the water storage capacity of depressions is maximized, namely, 20 m in this work. This phenomenon is furt verified in two test cases with and without the infiltration process, i.e.,

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calculations of the local area and without infiltration area, respectively. This research may facilitate the accurate computation of the DS process, which is greatly affected by the grid resolution, thereby improving th reliability of hydrological models.

Keywords digital elevation model; depression storage; grid resampling; hydrological models; grid resolution; infiltration

1. Introduction

The effects of microtopography on hydrological have r become an important topic to further improve the accuracy of terrain calculations. As one of the most common microtopographic structures depressions are widely distributed across all types of soils, vege types, and rocks, and even in the form of gullies, these structures notably affect the runoff yield and concentration (Ha depressions in the landscape vary in size, including relatively small, unmanaged water storage systems to large, regularly m bodies, such as lakes and reservoirs, small surface depressions, such as wetlands embedded in highlands or river corridors, ponds similar small water bodies (Rajib, Golden, Lane, & Wu, 2020). Lakes and reservoirs, as the main aquatic systems considered in the quantification of the availability of water resources, exhibit higher storage capacity. In previous studies (Dang, Chowdhury, & Galelli, 2020; Liu et al., 2018), small surface depressions have not been included in traditional watershed-scale hydrological dynamic models, and surface depress have thus been ignored on a large scale. However, the impact of thes small depressions on the hydrological system has in acknowledged (Cohenet et al., 2015; Yu & Harbor, 2019).

It is necessary to quantitatively describe surface depression storage (DS) at the watershed scale. The following fundamental question occurs: What are the roles of surface depressions in a given hydrologic system?

Studies have demonstrated the notable influences of [cut off] hydrologic processes. It has been found that surface DS is a component of the rainfall-runoff process. In this process, rainfall reaches the Ear[th's] surface in amounts that vary spatially and temporally. Some rainfall [is] intercepted and retained by the vegetation cover, and the remainder reaches the ground and infiltrates at a rate dependent on soil conditions. When the rainfall intensity exceeds the soil infiltration [cut off] depressions are filled, and the water stored in these depressions is denoted as **DS**. Surface runoff is initiated when surface depressions are completely filled and overflow occurs. Surface runoff continues to r[cut off] elevation watershed elements depending on the rainfall, infiltration and microrelief conditions of the relief created by human cultural practices or nature (Mitchell & Jones, 1976).

A **digital elevation model (DEM)** contains abundant landfo[rm] information (Yu, Chen, & Ai, 2007) and is one of the methods to represent the elevation of the Earth surface. It has been applied in various fields, such as modeling (Steinhy, 1998), morphology (Le, Delclaux, Genthon, & Favre, 2009), quality assessment (Cassel-Demargne & Puech, 2000), topographic features (Liu, Zhu, Wu, Zhu, & Tang, 2006; Tang, Ge, Li, & Zhou, 2005), geological hazard monitoring (Zhao, Li, Feng, Wang, & Hu, 2016) and natural hazard mapping (Li, Solana, Canters, & M Kervyn, 2017). Since the DEM directly reproduces the spatial characte[cut off] its accuracy exerts an important influence on numerica[l] [cut off] Therefore, DEM-based methods have received increasing attention (Loye, Jaboyedoff, & Pedrazzini, 2009). The change of DS value can be caused by different DEM resolutions; unfortunately, the main data acquisitio[n] [cut off] techniques and processing methods are related to specific terrain and land cover types, and DEMs contain inherent errors, while the accuracy of each data set is often unknown and inconsistent (Mukherjee et al., 2013). At present, the app accuracies has been studied in soil erosion (Hou et al., 2020), digital soil mapping (DSM)-based prediction models (Sena, Veloso, Fernandes-Filho, Francelino, & Schaefer, 2020) and quantitative water surface stora reduction (Amoah, Amatya, & Nnaji, 2012; Abedini, Dickinson, & Rudra, 2006). In related research, Abedini et al (2006) found that digital mapping allowed visualization of the location and topology of poten surfaces and the manner in which water likely flows from one depression to another. Based on pond analysis and associated spatial mapping, it was observed that most geometric characteristics relating to DS size and spatial location, including the area, volume dependent. In their research, the relationship between the contribut area of each depression and its surface area at various depths was established, and the mechanism underlying this relationship was examined (Abedini, Dickinson, & Rudra, 2006). However, relatively littleis known regarding the influence of the DEM spatial resolution on depression water storage.

Therefore, it is necessary to study the influence of the DEM accuracy on DS. In this paper, through terrain resampling, the influence of the DEM accuracy on DS within the same area is studied, local research area and without infiltration area are selected to verify the obtained determine the optimal DEM grid resolution. The answers to our research questions may pave the way for a new comprehensive assessment method of surface DS and provide important insights for those who study, manage and simulate surface water resources worldwide.

2. Materials and methods

2.1 Study area of rainfall-runoff simulation

The model is applied in the Wangmaogou catchment, which is a small semiarid loessal catchment (37°36′03″N) located in Suide County, Shanxi Provin 1a). It covers an area of approximately 5.9 km^2, with an altitude ranging from 934.55 to 1187.75 m. The main ditch is 3.75 km long, the average ditch bottom drops to 2.7%, the gully density is 4.31 km/km^2, the ground slope ranges from 0°~15° accounting for 8.6% of all slopes, 16°~25° accounting for 20.1% of all slopes, 26°~35° accounting for 40.9% of all slopes, and >35° accounting for 30.4% of all slopes. The land surface is fractured, and the landform is complex, which of the first sub-region within the loess hilly gully region. A water collecting tank is placed at the channel outlet to collect basin water (Fig. 1b). DEM and land use/land cover (LULC) maps are employed to simulate rainfall-runoff processes in the considered catchment areas. A DEM of the study area is obtained at a 1:1000 topographic map and then resized to different resolutions, i.e., 2 m, 4 m, 10 m, 20 m and 40 m. P=1, P=2, P=10 and P=50 are selected as rainfall return periods, and the rainfall duration is set to 2 h (Fig. 2). It is assumed that the soil is saturated due previous rainfall, so a constant infiltration rate i The Manning coefficient (Fig. 1c) and soil infiltration rate (Fig. 1d) and are related to the land use type (Table 1).

Fig. 1 Location and basic characteristics of Wangmaogou

Fig. 2 Rainfall at the different frequencies

Table 1 Infiltration rate (mm/h) and Manning coefficient (s/m$^{1/3}$) considering the different land uses

Land use	Farmland	Orchard	Forest	Grass land	Transportation land	Rural land	Terrace	Terraced orchard	Water
Infiltration rate	2.48-4.5	3.12-3.5	4.12-6.5	3.25-5	0	0.5-0.6	2.6-5.5	3.5-7	0
Manning coefficient	0.044-0.07	0.15-0.2	0.2-0.3	0.059-0.15	0.01-0.013	0.01-0.03	0.18-0.34	0.15-0.20	0.033

2.2 Governing equation

The **shallow water equations** (**SWEs**) are derived from the conservation of mass and momentum by assuming a hydrostatic pressure distribution. In vector form, two-dimensional **SWEs** can be written in conservative form as follows:

$$\frac{\partial q}{\partial t}+\frac{\partial f}{\partial x}+\frac{\partial g}{\partial y}=S \quad (1)$$

$$q=\begin{bmatrix} h \\ q_x \\ q_y \end{bmatrix},\quad f=\begin{bmatrix} q_x \\ q_x^2/h+gh^2/2 \\ q_x q_y/h \end{bmatrix},\quad g=\begin{bmatrix} q_y \\ q_x q_y/h \\ q_y^2/h+gh^2/2 \end{bmatrix}$$

$$S=S_b+S_f=\begin{bmatrix} i \\ -gh\partial z_b/\partial x \\ -gh\partial z_b/\partial y \end{bmatrix}+\begin{bmatrix} i \\ -C_f q_x\sqrt{q_x^2+q_y^2}/h^2 \\ -C_f q_y\sqrt{q_x^2+q_y^2}/h^2 \end{bmatrix} \quad (2)$$

where t is the time, x and y are two-dimensional Cartesian coordinates, q is a vector of the flow variables h, q_x and q_y, which denote the water depth and unit-width discharge along the x and y directions, respectively, f and g are flux vectors along the x and y directions, respectively, S is a source vector consisting of the slope source S_b and friction source S_f, z_b is the bed elevation, and C_f is the bed roughness coefficient computed as $C_f = gn^2/h^{1/3}$, with n and g denoting the Manning coefficient an

respectively. In addition, the water level η, defined as $\eta = h + z_b$, is introduced in this work and implemented when appropriate (Hou, Liang, Simons, & Hinkelmann, 2013).

The graphics processing unit (GPU)-accelerated surface water flow and associated transport model (GAST) uses the dynamic wave method to simulate the rainfall process. The Godunov scheme f volume method is applied to discr To address the problems of abrupt flow and discontinuity, the mass and momentum fluxes at the interface of a given cell are calculat the Harten-Lax-van Leer contact wave (HLLC) approximate Riemann solver. The code is written in C++ and CUDA, which is run on GPUs to substantially accelerate the computation process (Liang, & Smith, 2015).

2.3 Depression storage (DS) model

The rainfall distribution on the ground is divided i runoff, **DS**, infiltration and evaporation, and the changes observed in the overland flow area and subsurface soil-water conte modeled with a physics-based continuity model comprisi nonlinear ordinary differential and continuity equations (Rossi, & Ares, 2012):

$$\frac{dQ_0}{dt} = W = IN(t) - O(t) \quad (3)$$

$$\frac{dQ_V}{dt} = IN(t) \qquad (4)$$

$$CW = Q_0 + Q_V \qquad (5)$$

Where Q_0 is the water stored in the overland plume (mm^3), Q_V is the water stored in the upper vadose zones (mm^3), W denotes rainfall (mm^3/s), $IN(t)$ is the total infiltration flow (mm^3/s), CW and $O(t)$ denote the cumulative rainfall (mm^3) and overland flow (mm^3/s), respectively.

Evaporation is disregarded in the above equation, and seepage flow in the region remains stable, but the infiltration amount in e differs. W is the time constant of the regional experiments. In addition, the overland flow plume includes DS areas where water acc during the water inflow period and other areas where water inflow is not enough to maintain free water at the soil surface.

The water content depends on saturated and unsaturated infiltration flows:

$$IN(t) = IN_{sat}(t) + IN_{unsat}(t) \qquad (6)$$

where $IN_{sat}(t)$ is the transient, saturated infiltration flow under DS conditions (mm^3/s) and $IN_{unsat}(t)$ is the transient, non-saturated infiltration flow under non-DS conditions (mm^3/s). In this paper, infiltration was assumed to occur under saturated conditions. Therefore, $IN_{sat}(t)$ can be calculated as follows:

$$IN_{sat}(t) = K_{sat} \times \left[\psi_f \times \left(\frac{\theta_s - \theta(t)}{F} \right) + 1 \right] \times A_{DS} \tag{7}$$

$$F = zf(t) \times \left(\theta_s - \theta(t) \right) \tag{8}$$

where K_{sat} is the saturated hydraulic conductivity (mm/s), ψ_f is the suction at the wetting front, θ_s is the saturation in the wetting front (dimensionless), $\theta(t)$ is the instantaneous volumetric water content in the wetting front (dimensionless), F is the cumulative infiltration (mm), A_{DS} is the DS area (mm^2), and $zf(t)$ is the instantaneous water infiltration depth (mm).

In the land plume region without DS, assuming that water infiltration occurs under unsaturated conditions, the following applies:

$$IN_{unsat}(t) = K_h(\theta(t)) \times \left[\psi_f \theta(t) \times \left(\frac{\theta(t) - \theta_i}{F} \right) + 1 \right] \times \left(A(t) - A_{DS} \right) \tag{9}$$

where $K_h(\theta(t))$ is the variable hydraulic conductivity, θ_i is the antecedent soil-water content, $A(t)$ is the saturated area of the overland plume at time t (mm^2), $K_h(\theta(t))$ and $\psi_f \theta(t)$ are adopted to predict the relative hydraulic conductivity based on the soil-water retention curve.

2.4 Model validation

The considered catchment area is Wangmaogou. A 2-m grid is selected for model validation purposes, and the Wangmaogou hydrological station at the outlet of the Wangmaogou watershed is selected to acquire rainfall data. The rainfall period lasts from 0:25 on July 15, 2012, to 5:25 on July 15, 2012, and the rainfall return period is 100 years, as shown in Fig. 3. Measured discharge data are also provid hydrological station. The Manning coefficient of the different land uses is determined based on the Manning coefficient of Engman (1986), and the parameters of the Green-Ampt infiltration model are retrieved from the literature(Zhong, Chao, & Dong, 2008)The simulation time is set to 10 h. Because of heavy rain, the simula evapotranspiration and plant interception performance of the model is evaluated with the Nash-Sutcliffe efficiency (NSE).

$$\mathrm{NSE}=1-\frac{\sum_{i=1}^{n_d}(\mathrm{M}_i-\mathrm{S}_i)^2}{\sum_{i=1}^{n_d}(\mathrm{M}_i-\overline{M})^2} \tag{10}$$

where n_d is the length of the data series, M_i is the observation date, S_i is the simulated date, and $\overline{M}$ is the mean observed value. When NSE is 1, the simulation result is ideal, and when NSE varies between 0.75 and 1, the simulation result is very good. When NSE varies between 0.65 and 0.75, the simulation result is good, and when NSE ranges from 0.5 0.65, the simulation result is satisfactory. In contrast, when NSE is lower than 0.5, the simulation result is unsatisfactory (Moriasi et al., 2007).

Fig. 3 Rainfall process in the study area

Fig. 4 shows that in the case of the 2-m grid, the simulation results pertaining to the whole study area are consistent with the trend of t measured data, but the peak lag is approximately 0.5 h. Moreover, the flow dissipation process occurs slightly faster, which may be caused by error in land use interpretation based on remote sensing data, b overall effect is good. The NSE value is 0.78, requirements.

Fig. 4 Comparison of the observed and simulated discharge processes

3. Results and discussion

3.1 Effect of the DEM accuracy on depression storage (DS) in overall study area under infiltration

The resolution of the original DEM of the m×2 m and contains 1606×1710 cells. To determine the influence of grid coarsening on the level of detail generated with the DEM, computing regions with resolutions of 4 m×4 m, 10 m×10 m, 20 m×20 m and 40 m×40 m are obtained via resampling, and the corresponding grid numbers are 803×855, 321×342, 161×171 and 80×86, respectively. The input DEMs in each simulation case are shown in Fig. 5. To reveal the effect of the grid resolution on the terrain more clearly, the local terrain is enlarged. The differences between these seven DEMs resulted from the interpolation stage during DEM construction. Fig. 5 show increasing grid resolution, the map gradually appears to be blocked.

Fig. 5 Comparison of the computational regions with the different resolutions

Under rainfall return periods of P=1, P=2, P=10 and P=50, the DS time lags behind the rainfall, which is manifested as the maximum D time occurring later than the peak rainfall time (Fig. 6). Under a rainfall return period of P=1 (Fig. 6 (a)), the rainfall peak occurs at 3060 s, the maximum rainfall reaches 59.796 mm, and the corresponding maximum DS time is 6300 s, which is 3240 s behind the rainfall peak. Under rainfall return period of P=2 (Fig. 6 (b)), the peak rainfall occurs at 3060 s, the maximum rainfall reaches 84.560 mm, and the c maximum DS times are 5220 s, 5580 s, 6660 s, 7020 s and 7200 s at grid resolutions of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the rainfall peak, the time lag is 2160 s, 2520 s, 3600 s, 3960 s and 4140 s, respectively. Under a rainfall return period of P=10 (Fig. 6 (c)), th rainfall peak occurs at 3060 s, and the maximum 142.058 mm. The corresponding maximum DS time is 4680 s at a grid resolution of 2 and 4 m, 6300 s at a grid resolution of 10 m, 7380 s at a grid resolution of 20 and 40 m. Compared to the rainfall peak, the time lag is 1620 s, 1800 s, 3240 s, and 4320 s, respectively. Under a rainfall return period of P=50 (Fig. 6 (d)), the peak rainfall occurs at 3060 s, and the maximum rainfall reaches 199.552 mm The corresponding DS maximum times are 4320 s, 4500 s, 5400 s, 7380 s and 7380 s at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the rainfall peak, the peak value time lag is 1260 s, 1440 s, 2340 s, 4320 s and 4320 s, respectively.

Based on the above data, it is found that under a rainfall return period of P=1, because the rainfall is relatively low, the maximum DS time is consistent and unaffected by the grid resolution. With increasing rainfall intensity, the occurrence time of the maximum DS value co rainfall return periods of P=2, P=10 and P=50 gradually increases with increasing grid resolution, but certain differences remain. For example, considering rainfall return periods of P=1 and P=50 and a grid resolution of 20 and 40 m, the maximum DS value occurs at 7380 s, which indicates that the calculated results remain basically consistent when the rainfal intensity is sufficiently high and a coarse grid resolution is adopted. In addition, Fig. 6 shows that the grid resolution exerts a certain impact on DS. With the occurrence of rainfall, the DS value sharply increases first, then tends to remain stable and finally gradually decreases.

Fig. 6 shows the variation in the DS value over time with the rainfall at the different grid resolutions. As shown in Fig. 6 (a), the DS trend is 10 m > 20 m > 40 m > 4 m > 2 m, and Fig. 6 (b) shows that the DS trend is 20 m>40 m>10 m>2 m>4 m, while based on Fig. 6 (c), the DS trend is 40 m>20 m>10 m>4 m>2 m. As shown in Fig. 6 (d), the DS trend is 40 m>20 m>10 m>4 m>2 m.The grid resolution imposes little effect on DS when the rainfall return period is P=1 and P=2 (Fig. 6 (a) and Fig. 6 However, under rainfall return periods of P=10 and P=50, the trend of 40 m > 20 m > 10 m > 4 m > 2 m is observed. Moreover, the results based on the 50-year return period reveal that the grid resolution greatly influences DS under heavy rainfall.

Fig. 6 Effect of the different DEM spatial resolutions on DS

Under a rainfall return period of P=1, topographic water maps at grid resolutions of 2 m, 4 m, 10 m, 20 m and 40 m are shown in Fig. The results indicate that at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, the corresponding maximum DS capacity re m^3, 80186.597 m^3, 80654.204 m^3, 80321.643 m^3 and 79849.370 m^3 respectively. Compared to the 2-m grid resolution, the maximu capacity increases by 0.77%, 0.66%, 0.25% and - resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 7 Corresponding time of maximum storage and DS distribution (P=1)

Considering a rainfall return period of P=2, topographic water maps at grid resolutions of 2 m, 4 m, 10 m, 20 m and 40 m are shown in Fig. 8. The results reveal that when the grid resolution is 2 m, 4 m, 10 m, 20 m and 40 m, the corresponding maximum DS capacity reaches 119592.273 m^3, 120517.364 m^3, 124033.924 m^3, 123953.299 m^3 and 123264.262 m^3, respectively. Compared to the 2-m grid resolution, the maximu capacity increases by 0.77%, 3.71%, 3.65% and 3.07% at a grid resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 8 Corresponding time of maximum storage and DS distribution (P=2)

Under a rainfall return period of P=10, topographic water maps at grid resolutions of 2 m, 4 m, 10 m, 20 m and 40 m are shown in Fig. 9. The results show that the corresponding maximum DS 202162.555 m^3, 204898.850 m^3, 216961.492 m^3, 226299.138 m^3 and 227446.224 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, the maximu capacity increases by 1.35%, 7.32%, 11.94% and 12. resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 9 Corresponding time of maximum storage and DS distribution (P=10)

Considering a rainfall return period of P=50, topographic water maps at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m are shown in Fig. 10. The results demonstrate that at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, the corresponding maximum DS capacity reaches 279762.009 m^3, 283762.567 m^3, 300493.363 m^3, 326691.991 m^3 and 331127.814 m^3, respectively. Compared to the 2-m grid resolution, the ma capacity increases by 1.43%, 7.41%, 16.77% and 18. resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 10 Corresponding time of maximum storage and DS distribution (P=50)

The above results indicate that the grid resolution exerts an important influence on the DS capacity under the different rainfall return periods (Figs. 7-10). Except for the rainfall return period of P = 50, the influence of the grid resolution on the maximum DS capacity reveal maximum storage capacity first increases and increasing grid resolution. Considering rainfall return periods of P=1 and

P=2, the peak DS value occurs at the 20- and 10-m grid resolu respectively, and the maximum DS value differs little between the 10- and 20-m grid resolutions (with a relative error of 0.06%). H maximum DS capacity is observed under a rainfall return period of P=10 and P=50 (Fig. 11), where the difference in maximum DS value between the grid resolutions of 20 and 40 m is only 0. respectively. Compared to the total area, these differences Therefore, although a maximum DS value is not found when P=10 and P=50, compared to the low grid resolution, a certain grid resolution trend exists involving DS maximization. This result is expected cons that the peak discharge remains the same for models of all grid sizes in the extreme cases with (1) no surface saturation at a very low rainfa intensity and (2) complete surface saturation at a very intensity.

This result indicates that there is a DEM grid resolution value beyond which the computed hydrologic response is less sensitive to the grid size. This may be attributed to soil-water deficiency inconsistencies and t consideration of stable infiltration in the models. The variation in rainfall return period leads to different rainfall amounts, and rainfall must meet the infiltration demand before runoff can be generated. How infiltration rate in the area remains constant, wh generation of rainfall runoff under a short return period occurring later than that occurring under a long return period. This suggests that the soil is more likely to become quickly saturated under a long rainfall return period, the saturated area increases, and a large so saturated. Therefore, the probability of runoff generation is higher, and runoff occurs earlier. When the rainfall return period is P = 50 in th study, heavy rainfall completely saturates the soil surface within a short time, resulting in a certain unpredictability of the calculation results. The reason for this phenomenon is that with increasing grid resolution, t grid spacing gradually increases, and the grid size varies due to changes in the grid resolution. In this process, a grid "blanket" phenomenon occurs, which results in parts of the terrain belonging to depres previous resolution no longer contributing to depressions resolution. Although the number of depressions decreases, the area of the determined depressions increases (Fig. 11), which also in Therefore, under the same rainfall return period, DS increasing grid resolution. However, a certain grid resolution value exists where the peak DS value is attained.

Fig. 11 Change in the maximum DS capacity with the grid resolution in the overall study area under infiltration

3.2 Effect of the DEM accuracy on depression storage (DS) in a local study area under infiltration

To further examine the effect of the different DEM resolutions on DS, a local study area is selected within the overall study area (as shown in Fig. 12). The resolution of the newly generated DEM is 2×2 m, with a total of 486×326 grids. Through resampling, new local calculation areas with DEM resolutions of 4 m×4 m, 10 m×10 m, 20 m×20 m and 40 m×40 m are obtained, and the corresponding grid numbers are 243×163, 97×65, 49×33 and 24×16, respectively. Any differences between these DEMs are the result of the interpolation stage during DEM construction.

Fig. 12 Comparison of the computational regions with the different resolutions

When the rainfall return period is P=1, P=2, P=10 and P=50 (Fig 12), the water storage time in the local study area is the same as that in the whole study area, which demonstrates that the water storage process in depressions lags behind the rainfall process, and the maxim storage time in depressions lags behind Under a rainfall return period of P=1 (Fig. 12 (a)), the peak occurs at 3060 s, the maximum rainfall reaches 59.796 mm, corresponding maximum DS time is 3240 s, 6660 s, 6660 s and 6840 s at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the rainfall peak, the time lag is 180 s, 3600 s, 3600 s, 3780 s and 3600 s, respectively. Considering a rainfall return period of P= 2 (Fig. 12 (b)), the rainfall peak occurs at 3060 s, the maximum rainfall reaches 84.560 mm, and the corresponding maximum DS time is 3240 resolution of 2 m and is 7380 s at a grid resolution of 4 m, 10 m, 20 m and 40 m. Compared to the rainfall peak, the time lag is 180 s, 4320 s, 4320 s, 4320 s and 4320 s, respectively. When the rainfall return period is P=10 (Fig. 12 (c)), the peak rainfall occurs at 3060 s, and the maximum rainfall reaches 142.058 mm. The corresponding maximum DS time is3240 s at a grid resolution of 2 m and is 4860 s at a grid resolution of 4 m, 10 m, 20 m and 40 m. Compared to the rainfall peak, the time lag is 180 s, 4320 s, 4320 s, 4320 s and 4320 s, respectively. Under a rainfall return period of P=50 (Fig. 12 (d)), the peak rainfall occurs at 3060 s, the ma rainfall reaches 199.552 mm, and the corresponding maximum DS time is 3240 s at a grid resolution of 2 m and is 7380 s at a grid resolution is 4 m, 10 m, 20 m and 40 m. Compared to the rainfall peak, the time lag is 180 s, 4320 s, 4320 s, 4320 s and 4320 s, respectively.

The above results demonstrate that except for the rain period of P = 1, the maximum DS value under the other three rainfa return periods at the different resolutions occurs at the same time. Except for the 2-m grid resolution, the time to reach the maximum DS va remains the same (7380 s). This may be related to the area si rainfall level. In addition, considering a rainfall return period of P=1, the maximum DS time remains consistent due to the relatively low rainfall, which is unaffected by the grid resolution. In addition, Fig. 13 shows that the change in grid resolution impacts DS. With increasing rainfall return period, the DS capacity first sharply increases and then tends to steadily decrease (Fig. 13), and the variation in DS at the different grid resolutions reveals the same trend (20 m>40 m>10 m>4 m>2 m), which does n change with the rainfall return period. The results show that the DS capacity increases with increasing grid resolution, and the DS capacity is the highest at a grid resolution of 20 m.This trend is basically consistent with the trend of the overall study area, which further verifies that the grid resolution influences DS. However, the results obtained with the 20-m resolution grid do not follow this rule, which may occur because the DS capacity increases with increasing grid resolution within a certain range, and beyond this range, the DS capacity decreases with increasing g resolution. Zhang and Montgomery (Zhang & Montgomery, 19 assessed the impact of the DEM grid size on landscape representation and hydrologic simulations. Their analyse landscapes, a 10-m grid size represents a rational tradeoff between t resolution and data volume in the simulation hydrological processes.

Fig. 13 Effect of the different DEM spatial resolutions on DS

A topographic water map under a rainfall return period of P= shown in Fig. 14. The results reveal that the maximum DS capacity i 3442.324 m^3, 6974.789 m^3, 8888.885 m^3, 9468.357 m^3 and 8945.866 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respec Compared to the 2-m grid resolution, the maximum DS capacity increases by 100.03%, 100.58%, 100.75% and 100.60% at a grid resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 14 Corresponding time of maximum storage and DS distribution (P=1)

As shown in Fig. 15, the topographic water map considering a rainfall return period of P=2 shows that the maximum DS capac 4962.456 m^3, 10704.740 m^3, 13617.712 m^3, 14478.020 m^3 and 13718.646 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, at a grid resolution of 4 m, 10 m, 20 m and 40 m, the maximum DS capacity increases by 115.71%, 174.41%, 191.75% and 176.45%, respectively.

Fig. 15 Corresponding time of maximum storage and DS distribution (P=2)

Under a rainfall return period P=10, a topographic wate shown in Fig. 16. The results indicate that the maximum DS capa reaches 8482.841 m^3, 19425.126 m^3, 24680.039 m^3, 26176.840 m^3 and 24914.727 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m resolution grid, the ma capacity increases by 128.99%, 190.94%, 208.59% and 193.71% at a grid resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 16 Corresponding time of maximum storage and DS distribution (P=10)

A topographic water map considering a rainfall return period of P=50 is shown in Fig. 17. The results reveal that the maximum DS capacit reaches 11970.784 m^3, 28136.921 m^3, 35741.983 m^3, 37875.764 m^3 and 36110.953 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, the maximu capacity increases by 135.05%, 198.58%, 216.40% and 201.66% at a grid resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 17 Corresponding time of maximum storage and DS distribution (P=50)

According to the above results and relationship between the maximum DS capacity and grid resolution (Fig. 18), the grid resolution exerts an important influence on the DS capacity. With increasing grid resolution, the maximum DS capacity exhibits a trend of increasing first and the decreasing, and peak values are observed at the 20-m grid resol Compared to the whole calculation area, the DS tren calculation area is more stable. This phenomenon verifies that under the same conditions, the trend obtained describing the overall study area is also suitable for the local study area, and the simulated DS trend in the local area remains more stable. The reason for these results is similar to that for the overall research area (as described in section 3.1).

Fig. 18 Change in the maximum DS capacity with the grid resolution in the local study area under infiltration

3.3 Effect of the DEM accuracy on depression storage (DS) of t overall study area without infiltration

Considering that infiltration also affects DS, sections (sections 3.1 and 3.2) adopted a constant infiltration rate in the calculations, and thus, in this section, DS variations considering different grid resolutions and rainfall return periods are studied by s infiltration rate to 0 in the overall study area of Wangmaogou.

Fig. 19 shows the relationship between the DS variation over time as a function of rainfall at the different grid resolutions. The results reveal that the change in grid resolution also impacts DS when infiltration is not considered, and with increasing rainfall return period, the DS variatio trend shape is similar to the quasi-axisymmetric shape of the trend, which deviates from the DS change trend reported in sections 3.1 and 3.2. However, in regard to the rainfall peak, the peak values are the same with and without infiltration, and the DS trend is 20 m>4 m>2 m>10 m>40 m under the different rainfall return perio consistent with the results when considering infiltration.

occurs because the initial rainfall infiltrates into the soil when infiltration is included, and runoff can only be produced when the soil is completely saturated. In this process, because the rainfall infiltration rate into soil under a short return period is lower than that under a long retu period, the DS capacity is also affected. However, in the ideal case of no infiltration, rainfall directly generates runoff, the DS curve rises sharply after rainfall initiation and then slowly decreases after it numerical difference at the end of the curve is relatively small between the different resolutions. Hence, the DS c axisymmetric shape.

Fig. 19 Effect of the different DEM spatial resolutions on DS

Fig. 20 shows a topographic water map under a rainfall return period of P=1. The maximum DS capacity reaches 32391.163 m^3, 32387.163 m^3, 32305.166 m^3, 32497.578 m^3 and 31311.627 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, the maximum DS capacity differs by -0.01%%, -0.02%, 0.03% and -3.33% at a grid resolution of 4 m, 10 m, 20 m respectively.

Fig. 20 Corresponding time of maximum storage and DS distribution (P=1)

Fig. 21 shows a topographic water map considering a rainfall return period of P=2. The maximum DS capacity is 45828.779 m^3, 45838.984 m^3, 45802.897 m^3, 45993.106 m^3 and 44714.091 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, the maximum DS capacity increases by 0.02%, -0.06%, 0.36% and -2.43% at a grid resolution of 4 m, 10 m, 20 m respectively.

Fig. 21 Corresponding time of maximum storage and DS distribution (P=2)

Fig. 22 shows a topographic water map under a rainfall return period of P=10, the results demonstrate that the maximum DS capacity reaches 77031.272 m^3, 77047.177 m^3, 77025.945 m^3, 77283.935 m^3 and 75198.877 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Compared to the 2-m grid resolution, the maximum DS capacity increases by 0.02%, -0.01%, 0.33% and -2.38% at a grid resolution of 4 m, 10 m, 20 m and 40 m, respectively.

Fig. 22 Corresponding time of maximum storage and DS distribution (P=10)

With the use of a rainfall return period of P=50 (Fi maximum DS capacity is 108240.254 m^3, 108324.944 m^3, 108168.570 m^3, 108613.341 m^3 and 105779.238 m^3 at a grid resolution of 2 m, 4 m, 10 m, 20 m and 40 m, respectively. Based on a comparison to the DS capacity at the 2-m grid resolution, it is found that at a grid resolution of 4 m, 10 m, 20 m and 40 m, the maximum DS capacity increases by 0.03 0.05%, - 0.36% and - 2.26%, respectively.

Fig. 23 Corresponding time of maximum storage and DS distribution (P=50)

Figs. 20-23 show the impact of the rainfall return period on DS. The above analysis indicates that the rainfall return period also affects DS in the ideal case without infiltration, but the impact is smaller than that in the case with infiltration. The numerical difference is within ± between the grid resolutions of 2 m, 4 m and 10 m. The DS capac reaches its maximum value at a grid resolution of 20 different rainfall return periods. Therefore, it is considered that at gri resolutions ≤ 10 m, the influence of the grid resolution on DS can be ignored. At grid resolutions higher than 10 m, the DS cap increases and then decreases with increasing grid resoluti maximum DS value occurs at a grid resolution of 20 consistent with that determined in the case with infiltration. This result

agrees with the law obtained in regard to the whole study a
infiltration, and the reason for this phenomenon is the same as that for the whole research area with infiltration. However, when infiltration is no considered, the influence of the grid resolution on DS under the different rainfall return periods is smaller than that in the case with infiltration Therefore, it is concluded that infiltration also impacts DS.

Fig. 24 Change in the maximum DS capacity with the grid resolution in the overall study area without infiltration

4. **Conclusion**

Resampling is performed with 2 m as the original grid resolutio Based on the theory of **SWEs** and **DS** and GAST models, in this paper, after model validation against measured data (NSE ≥ 0.78), the influence of the grid resolution on DS is compared and analyzed between different area sizes (overall and local areas) and infiltration conditions (with and without infiltration). Conclusions are presented below:

(1) In the whole and local study areas considering infiltration, with increasing grid resolution and under a longer rainfall return period, the DS capacity gradually increases at a DEM grid resolution lower than 20 m, and the increasing trend becomes increasingly c resolution under a short rainfall return period. When t resolution is higher than 20 m, the DS increase rate tends to constant or decreases.

(2) Under infiltration conditions, although the DS values in the whole and local study areas exhibit similar change trends with the variation in grid resolution, the fluctuation range of the DS value research areas is larger than that in the whole research area under each rainfall return period.

(3)When infiltration is not considered, the DEM grid res yields little effect on DS. In this study, when the DEM grid resolution is lower than 20 m, the DS difference only ranges from approximately -0.05% to 0.36%. At a DEM grid resolution higher than 20 m, the DS capacity gradually decreases, and the change trend is the same a infiltration is considered.

The research area size and infiltration rate at the di resolutions affect DS. High-resolution terrain data of large areas increase the stability of DS simulation values. In addition, infiltration is a factor influencing DS. Therefore, it is very important to select reasonable terrain data and infiltration process conditions in DS numerical simulation.

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Figure legends

Fig. 1 Location and basic characteristics of Wangmaogou

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Fig. 3 Rainfall process in the study area

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Fig. 23 Corresponding time of maximum storage and DS distribution (P=50)

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