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# Impact of urbanization on precipitation and temperature over a lake-marsh wetland: A case study in Xiong'an New Area, China

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ABSTRACT

Considering the future rapid economic development and large population growth, Xiong'an New Area (known as a lake-marsh wetland) has been undergoing rapid urbanization especially under the background of the Xiong'an New Area Project, which has caused considerable regional climate changes in local area and has proven to be a research focus for studying various problems/aspects in the process of urbanization in the new era.. Both lake-marsh wetlands and urbanization have a significant impact on the local climate, and they also interact with each other. However, few studies focus on simulating and analyzing the interaction mentioned above. In this paper, we use the Weather Research and Forecasting (WRF) model to quantitatively analyze the effects of urbanization on regionals climate in Lake- Marsh Wetland area. To depict the process of urbanization and differences/changes in temperature and precipitation induced by urbanization, five scenarios were set up, including 1980, 2000, 2015, design, and urban scenarios. The results suggest that: (i) Urbanization surrounding the lake-marsh wetland increases local precipitation. The precipitation center is concentrated in the lake area and its surrounding area, and Baiyangdian Lake has a great influence on precipitation. (ii) Urbanization slightly increases the local temperature. The design and urban temperatures increased by 0.063 and 0.104 ℃ compared with the 1980 temperatures. The design scenarios have the highest temperature in the southeast, the lowest temperature in the central lake area, and the overall spatial distribution of temperature decreases from southeast to northwest. (iii) In/during the urbanization process of Xiong'an New Area, the increase of rainstorm precipitation is more significant, which increases the potential risk of urban flood, and indicates a much more urgent practical need for the construction standard of local drainage pipeline network. (iv) The temperature in/near the lake area is lower, which has played a cooling role. The temperature difference between the inside and outside of the lake is about 1 □. There are different responses to temperature and precipitation inside and outside the lake area in the same established urbanization process. Precipitation inside the lake area varies greatly under the influence of urbanization, while the temperature increases slightly.

## 1. Introduction

Rapid development of economy plus explosive population growth unceasingly speeds up the progress of urbanization (Shimadera et al., 2015; Yang et al., 2014), by which climate change caused has become a widespread concern accordingly(Su et al., 2019; Trenberth, 2011). Especially, the urbanization occurred in a lake-marsh wetland or around a lake will result in significant difference form others. With the expansion of urban land and the increase of urban buildings, the urban underlying surface properties (e.g., surface roughness, surface heat capacity, albedo and vegetation coverage) have been greatly changed, which not only changes the original climate physical process (such as surface energy balance) and hydrological cycle process (such as the distribution of precipitation), but also produces new dynamic and

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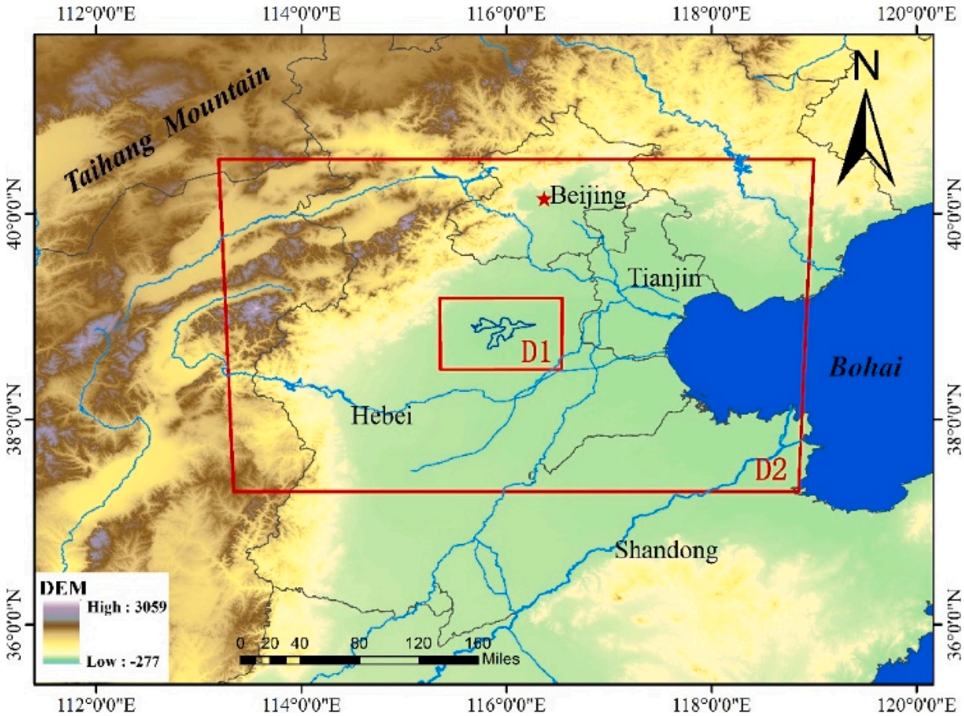


**Fig. 1.** Study area and domain setup.

thermal processes (such as urban heat storage, canyon effect of buildings and the increase of human heat). All the changes caused by urbanization discussed above can be concluded into the "five island effect" (Xiao-ying, 2012), that is, the impact of urban heat island (Rizwan et al., 2008; Dixon and Mote., 2003), urban wet island, urban dry island, urban rain island and urban turbid island where the temperature and precipitation are most closely related to environment, ecosystem, and human daily life.

For the safety and better development of a city, it is necessary to predict the impact of urbanization in advance and grasp the laws of hydrology and climate affected by urbanization in time. Many works related to the evaluation of the urbanization effects on regional climate focused on the qualitative analysis based on observational data (Kaufmann et al., 2007; Changnon, 2016). For example, Bornstein and Qinglu, 2000 analyzed data from a surface meteorological network around Atlanta to show that the urban heat island (UHI) effect induced a convergence zone that initiated storms during the summer of 1996. However, it cannot satisfy the need of urban planning just by observational data (Han et al., 2014). In this paper, we choose the Weather Research and Forecasting (WRF) Model to simulate and analyze the effect of urbanization on regional climate which is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications and serves a wide range of meteorological applications across scales. WRF model has been successfully used on the aspect of precipitation simulation all over the world. Hamill et al. (Hamill, 2014) conducted a simulation of a heavy rainfall process in Colorado area in the United States using WRF. Their results showed that WRF model could better simulate the process and spatial distribution of a rainfall and also helped analyze the cause of the formation of the rainfall. Evans et al. (Evans et al., 2012) simulated a rainfall process in southeast Australia using WRF model. The results showed the simulation of precipitation process could be realized under different physical parameter combination schemes where only simulation effects were different. Kryza et al.(2013) used WRF to simulate precipitation in southwest Poland for a long period of time. The results show that WRF can reproduce the precipitation process in this period better, especially when the precipitation intensity is low; A case study conducted by Shepherd et al. (Shepherd et al., 2010) indicated that simulations without urban produced less cumulative rainfall in the area to the northwest of Houston than simulations with the urban represented.

The studies cited above demonstrated that WRF model has a solid application foundation on the aspect of precipitation simulation, while using the model to simulate the urbanization effects on regional climate was not that popular, not to mention using more than two scenarios to conduct simulations on the effects of urbanization. Besides, most of previous studies have focused merely on the relationship between urbanization and regional climate ignoring the interference of background. The urbanization effects in a specific context such as the urbanization effects on regional climate around the Lake-Marsh Wetland is rarely discussed, which plays important role in regional climate. In our research, we find lake-marsh wetland can play a very good role in regional regulation and weaken the adverse effects in the process of urbanization especially on the aspects of temperature and precipitation which can provide new ideas for better urban planning in the future.

Around the Baiyangdian lake-marsh wetland, “Xiong’an New Area” project was approved as a national-level new area by the China State Council in 2017, and since then, the project was under construction. It means another considerable potential urbanization surrounding the Baiyangdian lake-marsh wetland in future. As a function of the non-capitalization of Beijing, “Xiong’an New Area” will be built into a super-level modern city and become an important pole of the world-class Jing-Jin-Ji (short for Beijing, Tianjin, and Hebei) Economic Belt. In order to get better and more reasonable simulation results, we designed and modeled five scenarios in WRF model, including 1980, 2000, 2015, design 2030 and urban scenarios, to simulate the urbanization effects on regional climate in Xion’an New area which is a typical lake-marsh wetland. To initial the background and period of the simulation, we chose the period of simulation from June 7, 2000 to September 22, 2000. By comparing the simulations of the five scenarios, the differences in temperature and precipitation, and the differences between in-lake and out of lake, the urbanization effects were more

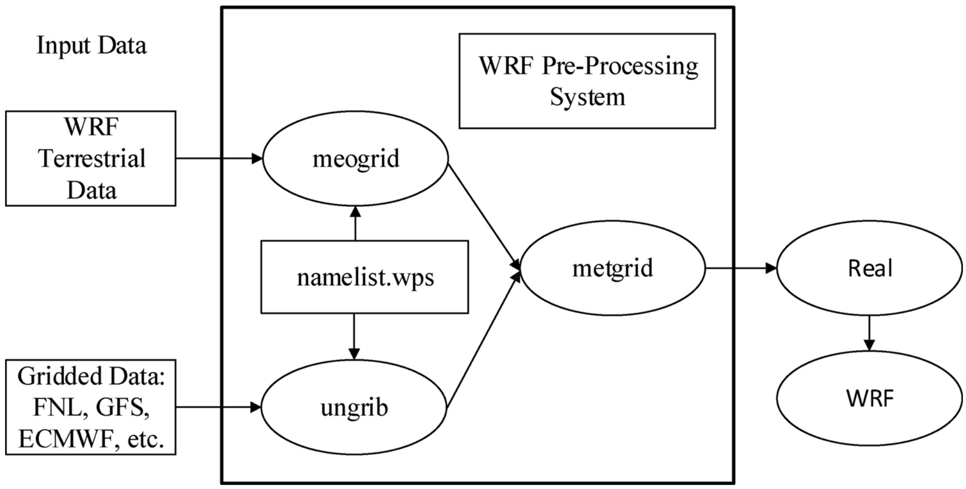


**Fig. 2.** WRF Model Preprocessing System.

**Table 1**
WRF model experimental details.

| Parameter | Setting Scheme | Subject | Chosen option |
|---|---|---|---|
| Projection mode | Lambert | Driving data | 6 h FNL |
| Power frame | Non-hydrostatic | Land use | Noah |
| Vertical stratification | 40 layers | Microphysics scheme | Lin |
| WRF output interval | 6 h | Cumulus convection | KF |
| Grid center of Baiyangdian domain | 116°05′38″N | Planetary boundary layer | YSU |
| | 38°57′00″E | Integration time-step | 30 s for D2 |
| Horizontal grid number | 42 × 32, 40 × 30 | Projection resolution | Lambert |
| Horizontal resolution | 12 km,3 km | Longwave radiation | RRTM |
| Pressure | 50 hPa | Shortwave radiation | Dudhia |

(3) case design.

convincingly quantified. The results could not only help to deliver some recommendations on urban construction policy programs in local wetlands for relevant departments and researchers, but could also provide a reference for the urbanization of similar wetland systems in other regions and even other developing countries.

## 2. Study area and method

### 2.1. Study area and case design

The study area is located in downstream of the Daqing River Basin in the North China Plain (Fig. 1). It is a warm temperate semi-humid continental monsoon climate zone with four distinct seasons, the Taihang Mountains in the northwest and the Bohai Sea in the east. The average annual precipitation is 529.7 mm, the average temperature is 12.2 °C, and the extreme maximum temperature is 40.7 °C. The minimum temperature is -26.7 °C. The total landform of Baiyangdian is slightly inclined from northwest to southeast. The terrain is flat, the slope of the ground is 1:2000, the highest elevation in the western half is 10 m, and the lowest elevation in the eastern half is 5.5 m. Fig. 2

Baiyangdian Lake is located in the hinterland of Beijing, Tianjin and Baoding, away from them are 105 km, 105 km, and 30 km, respectively. Around Baiyangdian Lake, the planning scope of the new area includes the administrative jurisdictions of Xiong County, Rongcheng County, and Anxin County, with a planned total area of approximately 2000 square kilometers.

### 2.2. WRF model and case design

(1) WRF model

The WRF model embodies a new generation of mesoscale numerical model. Its developers include the National Center for Atmospheric Research, USA (NCAR), the National Oceanic and Atmospheric Administration, USA (NOAA), the National Centers for Environmental Prediction, USA (NCEP), the Forecast Systems Laboratory (FSL), and other collaborators (Kalnay et al., 1996). The WRF incorporates advantages of the Penn State–NCAR fifth-generation Mesoscale Model (MM5) and improves the disadvantages of MM5 model. It is more suitable for mesoscale weather simulation and prediction (http://www.wrf-model.org/index.php).

(2) Parameter Scheme

The parameters scheme of WRF model adopted in the experiments is shown as Table 1. In this study, The WRF model was configured with two one-way nests (offline, without feedback) of 12 × 12 km (D2) and 3 × 3 km (D1), with a centre at (116°05′38″E, 38°38′00″N). The horizontal resolution of National Centers for Environmental Prediction Final (NCEP FNL) operational global analysis data driven by WRF model is 1°×1°. For the setting of outer grid, D1, we cover the whole research area and consider the influence of the weather system around the research area. Therefore, the D1 designed in this paper covers the core Lake area of Baiyangdian Lake and the whole Xiong'an New Area, in which the lake area accounts for about a quarter of the total D1. For the setting of outer grid, D2, the influence of external boundary environment, surrounding terrain environment, and underlying surface should be considered. For example, the designed scope of D2 includes not only the Taihang Mountains, but also the Bohai Sea, as well as the major cities of Beijing, Tianjin and Hebei. The simulation period extended from June 7 to September 22, 2000. This is due to the concentration of precipitation during this period, which accounts for 70 % of the annual precipitation. In addition, the time integration step of the mode is set to 6 s, and the time interval of output data is 1 h. The model atmosphere includes 40 vertical layers extending from the surface to top layer, whose atmospheric pressure is 50 hPa. The Lambert projection is selected for its better applicability in midlatitude area.

Different physical parameterization schemes in WRF model can achieve different simulation results for different regions and rainfalls (Knievel et al., 2004; Chambon et al., 2014). The main physical parameterization schemes involved in the model are cloud microphysical parameterization scheme, cumulus convection parameterization scheme, planetary boundary layer scheme, land surface model and radiation scheme. Among these schemes, the land surface model and radiation scheme mainly affect the energy propagation, and the sensitivity

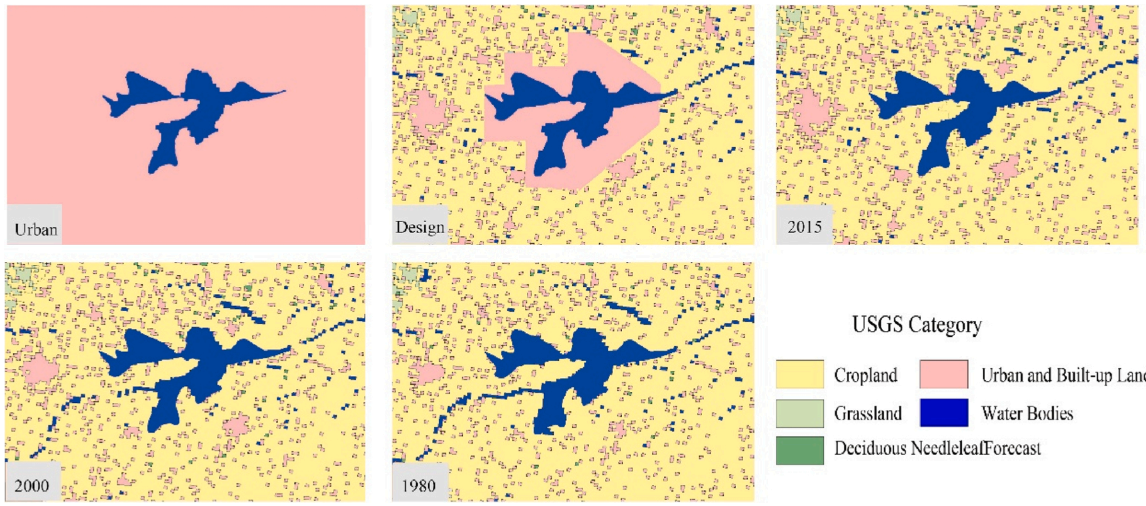


**Fig. 3.** Input land use and land cover of five cases for D1.

of rainfall simulation to these two schemes is not high. The cumulus convection parameterization scheme, cloud microphysics parameterization scheme and planetary boundary layer scheme have the greatest impact on rainfall. In the selection of Parameterization Schemes in this paper, the cloud microphysics parameterization scheme chooses Lin (ElTahan and Magooda., 2017) cumulus convection parameterization scheme chooses KF (Kain, 2004), planetary boundary layer scheme chooses YSU (Hong et al., 2006).

To depict the process of urbanization, five scenarios were set up, namely, 1980, 2000, 2015, design 2030 and urban scenarios. In these five scenarios, only the underlying surface input are different, and other input data and parameterization schemes are consistent. In order to select the climate background year which is less affected by human activities as the simulation background as far as possible, and considering the starting time of FNL data, the year 2000 was chosen. Moreover, we choose the summer as the research. Therefore, the period of simulation is from June 7, 2000 to September 22, 2000. Input land use and land cover of 1980, 2000 and 2015 scenarios are derived from remote sensing interpretation data provided by the Chinese Academy of Sciences. Input land use and land cover of design scenario is simplified design according to the planning scheme of Xiong'an New Area. And the urban scenario is that the whole D1 research area is surrounded by all the cities except the lake area, which is discussed as an extreme case. Input land use and land cover of five cases for D1 is shown in Fig. 3.

### 2.3. Evaluation index

To verify the effect of the model, we use percentage bias (*PB*) and root mean square error (*RMSE*) to analyze the long time series data. They are calculated as follows :

$$PB = \frac{SIM - OBS}{OBS} \times 100\%, \tag{1}$$

where, *PB* is the percentage bias between observed and simulated value, %; *SIM* is value simulated by WRF model; *OBS* is the observation data of gauge station.

$$RMSE = \sqrt{\frac{1}{M}\sum_{j=1}^{M}\left(S_j - O_j\right)^2}, \tag{2}$$

where, *RMSE* is root mean square error; $S_j$ and $O_j$ are the WRF simulation values and situ observations on day *j*, respectively.

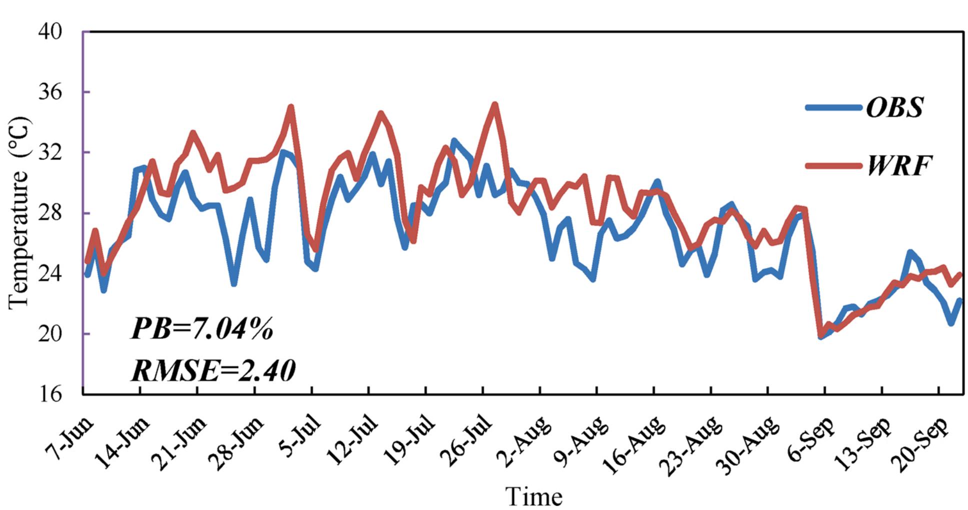


**Fig. 4.** Average temperature from June 7 to September 22.

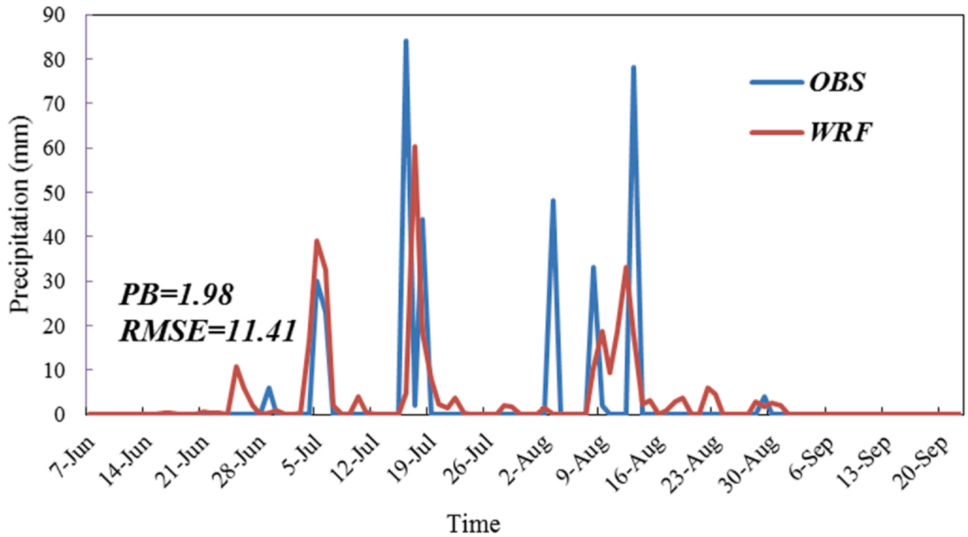


**Fig. 5.** cumulative precipitation from June 7 to September 22.

**Table 2**
Cumulative precipitation for different cases (mm).

| Cases | 1980 | 2000 | 2015 | Design | Urban |
|---|---|---|---|---|---|
| inside the lake | 367.51 | 370.19 | 376.02 | 380.10 | 383.21 |
| Total area | 619.61 | 631.35 | 643.74 | 658.43 | 666.39 |

## 3. Result

### 3.1. Model validation

To verify the simulation effect of WRF model, the WRF simulation results with the observation values of precipitation and temperature on June 7, 2000 to September 22, 2000 of Hydrometeorological station in the basin, and chooses *PB* and *RMSE* as the evaluation indexes (). The daily averaged observations were provided by the National Climate Center of the China Meteorological Administration (http://www.nmic.gov.cn). The results are shown as Figs. 4 and 5.

Compared with the observed temperature, the RMSE of WRF simulations is only 2.4 and the PB is 7.04 %. This shows that the temperature simulation effect of WRF is very good, and the trend of change is basically consistent with the actual temperature. Compared with the observed precipitation, the PB of WRF simulations is only 1.98 %, which shows that WRF basically simulates the actual precipitation process well. However, the RMSE of simulated rainfall is 11.4, which is relatively larger. It may be due to the uneven distribution of precipitation in northern China, and the inaccuracy of some heavy rainfall simulation, such as the simulated precipitation in August, there are some cases where the peak value of daily precipitation is significantly smaller than that of OBS. Therefore, the WRF model and parameterization scheme selected in this paper accurately simulate the temperature and precipitation process in Xiong'an New Area.

### 3.2. Impacts of precipitation

To study the impact of urbanization on Precipitation in Xiongan New Area, this paper simulates the changes of precipitation in the whole basin and corresponding lake areas in five different scenarios from June 7 to September 22. The results are shown in Table 2 and Fig. 6.

The cumulative precipitation distribution under five different underlying surface conditions is shown in turn (Fig. 6). The results show that: (1) The precipitation distribution in Baiyangdian Lake region is very uneven, and the maximum difference of accumulated precipitation in different locations and periods in the region is 600 mm. (2) The precipitation center is concentrated in the lake area and its surrounding area, followed by the northwest and the southeast, which shows that Baiyangdian Lake has a great influence on precipitation. (3) From scenarios of 1980–2000, 2015, desin, and ubran, the total cumulative precipitation increases gradually, which indicates that the environment around Baiyangdian Lake increases the precipitation in the lake area due to urbanization. Table 3

The statistical cumulative precipitation in the lake are shown in Table 2. Table 2 shows that the precipitation increment in the lake area is significantly larger than that outside the lake, which is about 260 mm. Moreover, urbanization is more sensitive to precipitation in the lake area, and the increase is greater.

Regardless of the lake area or the whole river basin, with the increase of urban underlying surface area, the rainfall shows an increasing trend, especially for Baiyangdian Lake area, the increase of precipitation is more obvious. Compared with the 1980 scenario, the rainfall in Urban scenario increased from 367.51 mm to 383.21 mm, with an increase of 15.7 mm. Rainfall in the lake area increased more, from 619.61 mm to 666.39 mm, and the rainfall increased by 46.78 mm. This may be due to the poor permeability of urban underlying, the rainfall cannot infiltrate into the ground after falling to the ground, only in the form of evaporation in the upper air with the movement of air, forming a new round of precipitation. For the lake area, this effect is more intense. Because of the increase of air humidity caused by regional evaporation, more water is accumulated over the central lake area, and it is easier to form a large rainfall process.

Fig. 7 shows the difference of cumulative process lines for precipitation in five scenarios. It also shows the urbanization process increased the precipitation. Although the change of precipitation is not obvious in the diurnal scale, the cumulative rainfall of different underlying surface scenarios increases after a heavy rain.

Furthermore, the effects of urbanization on different rainfall patterns during the simulation period are analyzed. Fig. 8 shows the difference of precipitation (light rain, moderate rain, heavy rain, rainstorm) between the scenario of 1980 and other four scenarios. The results show that with the urbanization process of underlying surface, the increase of heavy rain and heavy rain is the most significant, especially in the urban scenario. In contrast, the effect of urbanization on precipitation enhancement of moderate or light rain is not obvious. Because urbanization is the effect of increasing rainfall in Xiongan New Area, and the increase of

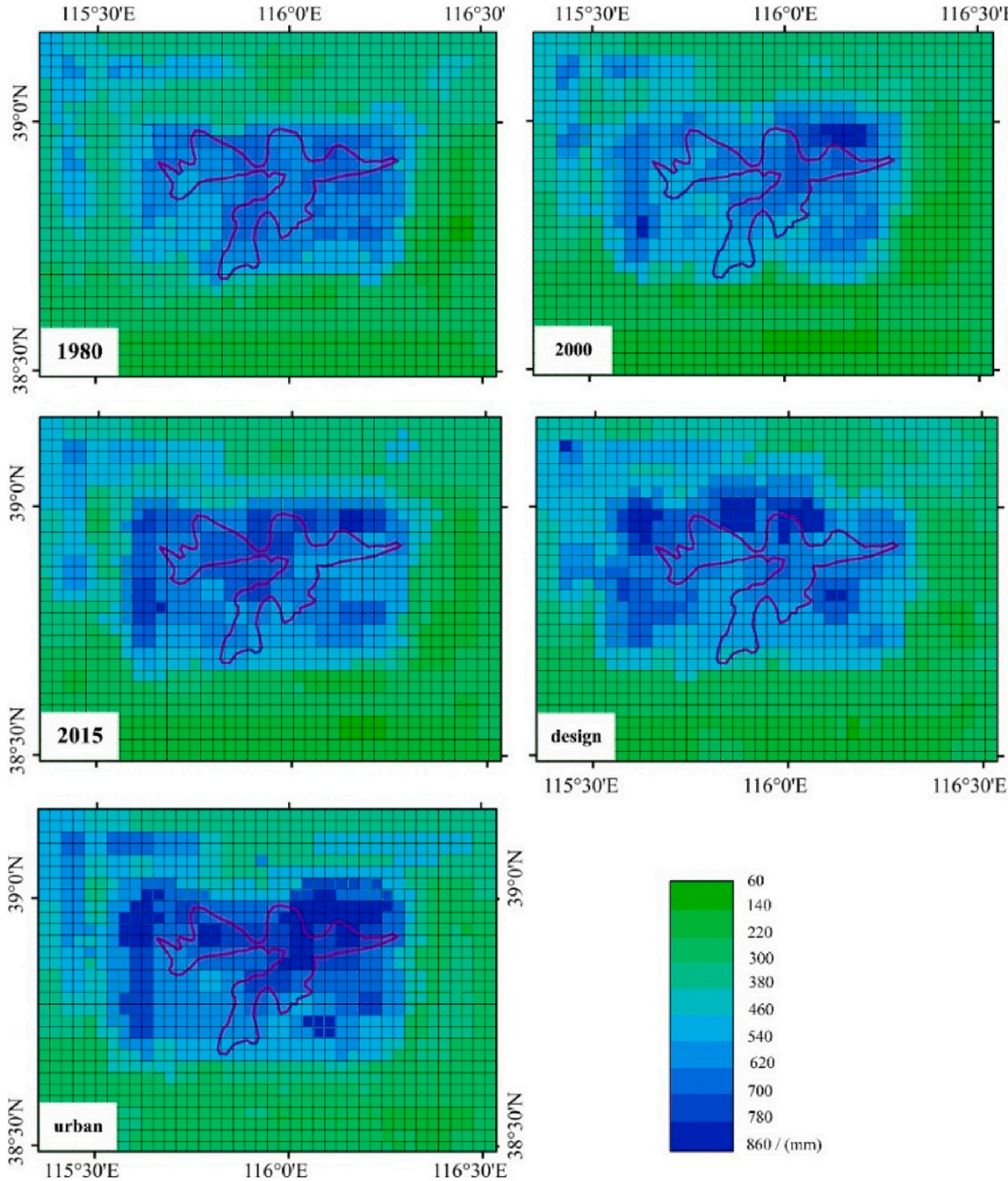


**Fig. 6.** distribution of cumulative precipitation from June 7 to September 22.

**Table 3**
Average temperature for five cases.

| Cases | 1980 | 2000 | 2015 | Design | Urban |
|---|---|---|---|---|---|
| Average of total area (°C) | 29.93 | 29.98 | 29.98 | 29.99 | 30.03 |
| average of lake (°C) | 28.89 | 28.92 | 28.93 | 28.94 | 28.97 |

rainstorm is more significant, which undoubtedly increases the risk of urban flood, so attention should be paid to the construction of drainage network.

### 3.3. Impacts of temperature

To study the impact of urbanization on temperature in Xiongan New Area, this paper simulates the changes of temperature in the whole basin and corresponding lake areas in five different scenarios from June 7 to September 22. The results are shown in Figs. 9 and 10.

Fig. 9 shows the cumulative precipitation distribution under five different underlying surface conditions one by one. As can be seen from the figure, (1) The temperature in the southeastern part of the simulation area is the highest, while that in the Central Lake area is the lowest, and the overall temperature spatial distribution decreases from southeast to northwest. (2) The temperature in the lake area is low, and the temperature difference between the inside and outside of the lake is

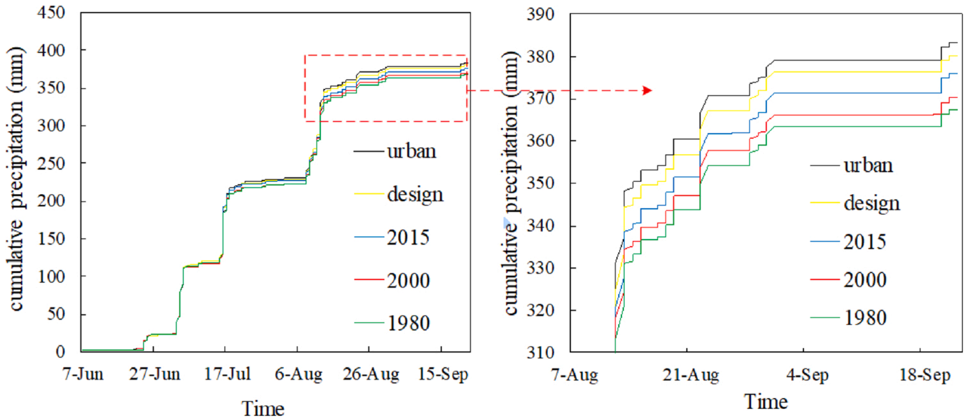


**Fig. 7.** cumulative precipitation variation with time from June 7 to September 22.

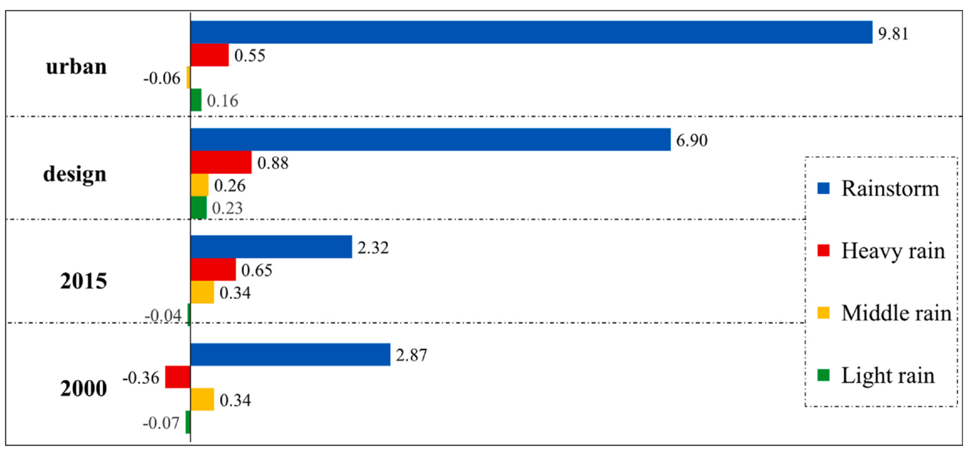


**Fig. 8.** The precipitation difference compared to land-use of 1980 under different rainfall (mm).

about 1℃. (3) Urbanization process from scenarios of 1980–2000, 2015, desin, and ubran, the temperature is gradually increasing, which indicates that the environment around Baiyangdian Lake and urbanization increase the temperature of the region. The design and urban temperatures increase by 0.063 and 0.104 degrees in comparison with the 1980 temperatures.

### 3.4. Discussion

Taking Xiongan New Area under construction as an example, this paper studies the impact of urbanization on precipitation and temperature in this area. WRF Simulation results suggest that urbanization around the Baiyangdian Lake plays an important role in precipitation and temperature variation. The results show that the construction of Xiongan New Area has increased the local temperature and precipitation. This indicates that urbanization around the lake area may cause "Rain Island Effect" and "Heat Island Effect". Due to the existence of lakes, urbanization has formed the "Rain Island Effect", which is in sharp contrast with other places. In addition, due to the influence of lakes, the effect of urbanization is less than that of other areas, which shows that the existence of lakes is conducive to alleviating the increase of temperature. In addition, the urbanization process of "Xiongan New Area" has obvious impact on the increase of rainstorm precipitation, which increases the potential risk of urban flood control warning, and the construction standard of local drainage pipeline network should be improved.

Moreover, it should be pointed out that the underlying surface, as for cities near lakes, replaced by this study is the traditional urban underlying surface. The traditional urban underlying surface will reduce groundwater infiltration. However, with the construction of "sponge city" and the rational optimization of urban layout, the actual impact of urbanization on climate may be milder than the changes predicted in this paper. In the past 20 years, the area of Baiyangdian Lake has declined to some extent, mainly due to the decrease of precipitation in the basin since 2000 and the transitional exploitation of groundwater. With the development of urbanization, buildings and roads built along the lake may affect groundwater infiltration, resulting in the reduction of water resources in the lake area, which may underestimate the prediction of urbanization on the rise of temperature.

## 4. Conclusion

The WRF model was used to simulate the effects of urbanization on regional temperature and precipitation using five scenarios in Xion'an New Area. The following main conclusions were obtained: (1) Urbanization increases local precipitation. Compared with the 1980 scenario, the Urban scenario increased by 15.7 mm, the lake area increased by more, and the rainfall increased by 46.78 mm. The precipitation center is concentrated in the lake area and its surrounding area, and Baiyangdian Lake has a great influence on precipitation. (2) Urbanization slightly increased the local temperature. The design and urban temperatures increased by 0.063 and 0.104 C compared with the 1980

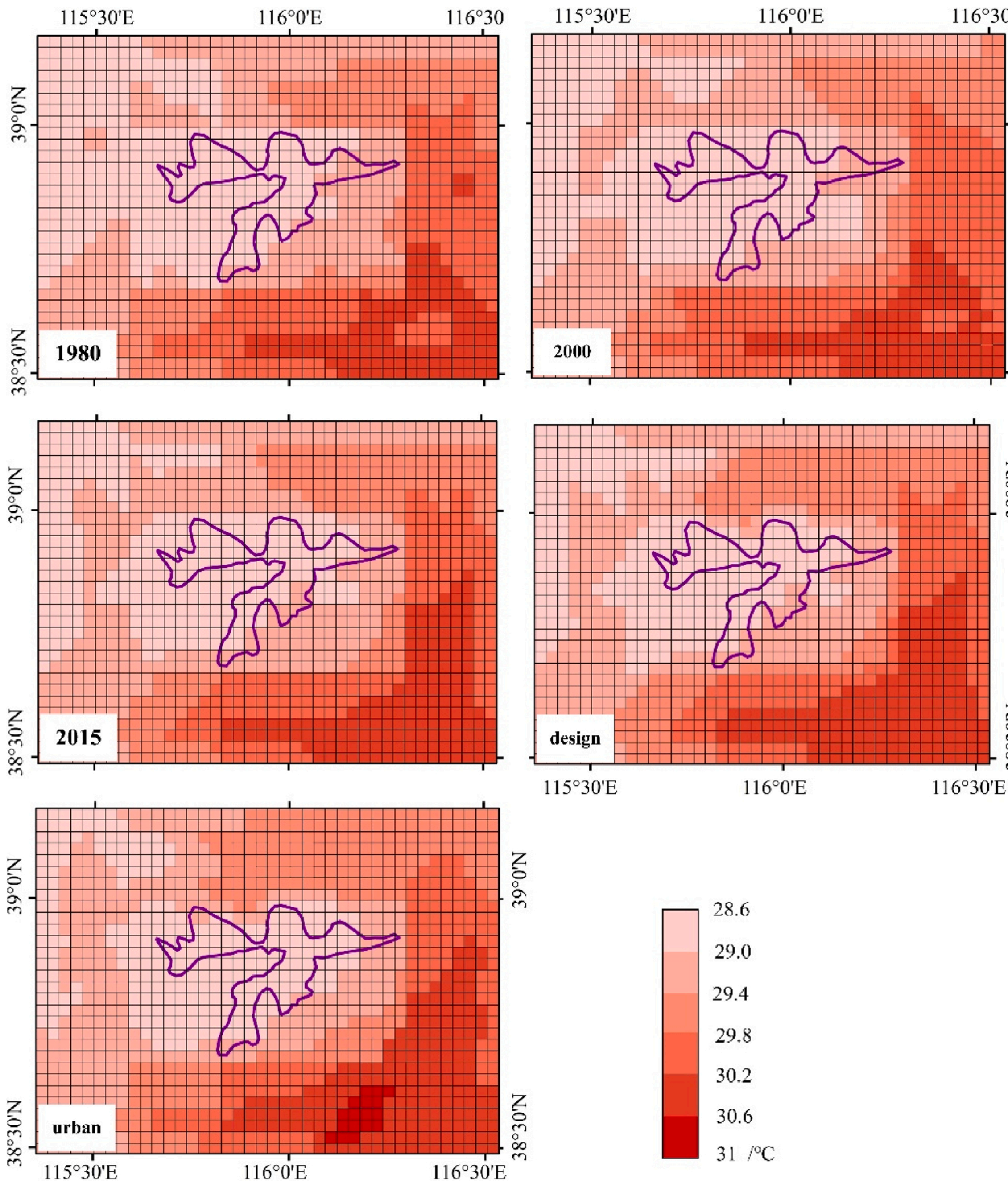


**Fig. 9.** distribution of average temperature from June 7 to September 22.

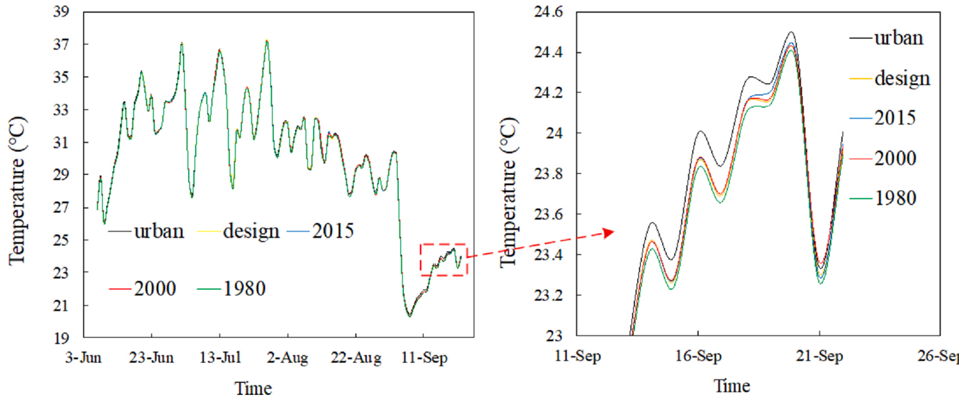


**Fig. 10.** daily temperature variation with time from June 7 to September 22.

temperatures. The design scenarios had the highest temperature in the southeast, the lowest temperature in the central lake area, and the overall temperature spatial distribution decreased from southeast to northwest. (3) In the urbanization process of Xiongan New Area, the increase of rainstorm precipitation is more significant, which increases the potential risk of urban flood, and the construction standard of local drainage pipeline network should be improved. (4) The temperature of the lake area is low, which has played a cooling role. The temperature difference between the inside and outside of the lake is about 1 C. (5) There are different responses to temperature and precipitation inside and outside the lake area. The precipitation inside the lake area varies greatly under the influence of urbanization, while the temperature increases slightly.

## Declaration of Competing Interest

The authors reported no declarations of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agwat.2020.106503.

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