

Analysis of Impervious Area Change in Shijiazhuang Urban Area

Xinjing Jiang

Sichuan University, Sichuan, China

199660208@qq.com

Abstract. In recent years, with the rapid development of the economy, China has attached more importance to the construction and development of cities. With the rapid increase in the number of cities, people have higher and higher requirements for modern facilities in cities. However, in the process of urbanization, we need to consider not only the facilities and planning of the city, but also more importantly, to achieve a harmonious coexistence between the city and the natural environment. At present, because the vast majority of urban ground area is used for construction, the misuse of cement and concrete has led to serious heat island effect and impermeable area problems. These two phenomena lead to urban water shortage and increasing incidence of flood disasters. This paper takes Shijiazhuang City as an example to analyze the change of impervious area and its impact on urban vegetation and water cycle through a series of data in order to promote the perfection of urbanization. It also reflects on the existing problems and defects, from the aspects of technology, material, production and life, then put forward relevant suggestions and ideas, hoping to provide certain enlightenment to solve the impervious area problems.

Keywords: Shijiazhuang; Impermeable Area; Urbanization.

1. Introduction

In recent years, China has attached great importance to urbanization construction projects, and it can be said that urbanization is the activity that has had the most profound impact on the improvement of the environment of Earth in the last 20 years. In our country, urban landscape, layout and planning are important to not only the construction of the city itself, but also to promote and facilitate the development of our population and economy. According to scientific research results, the heat island effect has troubled people in the process of urbanization. In order to solve the negative impact caused by the heat island effect, the impervious area theory can play an important role in the improvement of urban ecological environment and urban residents' quality of life. In this paper, as a typical northern city, Shijiazhuang is taken as a representative to analyze the change of impervious area during the urbanization.

Shijiazhuang, the capital of Hebei Province, is located in the center of China's Bohai Sea economic circle and the south-central part of Hebei Province. With the gradual urbanization, the urban population of Shijiazhuang increased from 1.21 million to 2.75 million between 1987 and 2010. Similarly, the urban area of Shijiazhuang was only 238.40km² in 1987 while it expands to more than 386km² in 2010. And now Shijiazhuang covers an area of 410.95 km² [1]. The Shijiazhuang city spans two major geomorphic units, the Taihang Mountains and the North China Plain. The western part, located in the middle of the Taihang Mountains, has a high topography, which covers about 50% of the total area. The eastern part is in the Hutuo River Alluvial Plain, and the earth structure within the jurisdiction is a bordering area between the Shanxi Plateau and the Bohai Depression, with a low southeast and high northwest terrain, a large gap and a complex geomorphology.

Shijiazhuang is located in the eastern edge of the Eurasia at low and middle latitudes, which belongs to the temperate monsoon climate. The seasonal changes of solar radiation are significant. There are four distinctive seasons, rainfall is concentrated in summer and autumn. The wet and dry periods are obvious, with long summer and winter, and short spring and autumn. In spring, the precipitation is low, often with 4 northerly or southerly winds, and the temperature picks up quickly in March and April. In summer, influenced by oceanic warm and humid air currents, the precipitation

in June, July, August and September accounts for 63%-70% of the annual precipitation. The weather is relatively humid, and the air humidity is as high as 100% during the three-volt days in July and August. In autumn, influenced by Mongolian high pressure, it is a pleasant climate with clear and less rain as well as moderate temperature. The average air humidity is 78%. In late autumn, there are many northeasterly winds and cold wave weather. In winter, with the influence of Siberian cold high pressure, northwesterly winds prevail and the climate is colder. with clear weather and few clouds, and snowfall often occurs [2]. The total annual precipitation in Shijiazhuang is 401.1-752.0 mm. The rainfall in the western mountainous areas is 628.4-752.0 mm while it is 401.1-595.9 mm in other areas. In winter, heavy goose snow often falls, which can reach 19.2-26.8 mm snowfall [3]. Although heavy snow brings some inconvenience to the traffic, it plays a protective role for wheat overwintering and provides favorable moisture conditions for spring rejuvenation. The total annual sunshine hours are 1916.4-2571.2 hours, with sufficient sunshine in spring and summer and low sunshine in autumn and winter.

The rivers in Shijiazhuang City belong to the Daqing River basin and the Ziya River basin in the Haihe River basin. There are six major flooding rivers, including the Shahe River, the Maghe River, the Hutuo River, the Xiao River, the Jin River, the Huai River and the Yanghe River. The total watershed area of 33,500 square kilometers. As of 2013, the amount of surface water resources in Shijiazhuang is about 781 million cubic meters, and the amount of underground water resources is about 1.718 billion cubic meters. Deducting the double counting amount of surface water and groundwater resources, the total amount of water resources is about 2.151 billion cubic meters, which has an increase of 191 million cubic meters in comparison of that in 2011. An increase of 0.35 billion cubic meters than the average annual value of 2.116 billion cubic meters. The city's water supply is about 3.189 billion cubic meters, in which 595 million cubic meters is from surface water supply, accounting for 18.7% and 2.594 billion cubic meters is from groundwater supply, accounting for 81.3%.

2. Impact of Impermeable Surface

As a typical type of urban subsurface, impermeable surface generally refers to the area that water cannot directly penetrate into the soil of artificial landform features. It includes roads, parking lots, building roofs, etc. Impervious surface has characteristics of strong heat storage capacity, weak evapotranspiration capacity and obstruction of airflow transmission, which have great influence on the energy radiation balance, surface thermal environment, surface runoff and local climate of the city.

During the process of urban urbanization, we pay attention not only to the economic and technological progress, but also to the ecological and environmental protection. The urban landscape of most cities in China can reflect not only level of local urban development, but also the overall expression of the influence of residents on the natural system. At present, the main urban landscape of most cities in China is composed of concrete, asphalt other materials of various industrial buildings, roads and urban infrastructure. By definition, land built industrially on impermeable materials is called impermeable area. The spatial and temporal dynamics of impervious area not only reflects the trend of urban expansion and the process of shelter, but is actually a kind of damage to the natural environment system by human beings. The impervious area has the following aspects for the damage of the environment: First, impervious area changed the water cycle process in city region. When the water cycle is disturbed, it might increase the risk of flooding, nonpoint source pollution and deterioration of living conditions for residents, which leads to a threat for sustainable development of the city. Secondly, the change of urban vegetation area replaced by impervious area may affect urban microclimate environment, which is also one of the causes of urban heat island effect [4].

Similar to the dilemma faced by most cities in China in the urbanization process, the main challenge of urban construction in Shijiazhuang is to solve the heat island effect. According to relevant data, the temperature in Shijiazhuang's urban area was only 1.6°C higher than the standard

for temperate continental monsoon climate in around 1980 while it had reached 30.7°C in 2019. Even more alarmingly, just one year later, the maximum temperature in Shijiazhuang's summer had soared to 41.8°C in June 2010[5]. In addition, from the perspective of urban water consumption, the urban water consumption of Shijiazhuang has shown a rapid increase year by year. In 2009, the water consumption has exceeded 3×10^9 m³. As a result of the continuous over-exploitation of groundwater in Shijiazhuang in recent years, the buried depth of groundwater has been drastically reduced. Shijiazhuang's previous urban dilemma is what we call the "heat island effect". The urban heat island refers to the phenomenon that the temperature of urban areas is significantly higher than that of the surrounding rural areas, including the urban heat island characterized by the surface temperature and air temperature. At the same time, with the accelerated urbanization process, the impervious area within the city is in a phase of rapid expansion in order to further strengthen the economic and industrial construction of the city. This trend is continuously taking away the vegetation and water areas that are already present in the city, and is likewise exacerbating the severity of the urban heat island.

3. Data and Analysis

By analyzing the urban surface cover type of Shijiazhuang, it can be found that Shijiazhuang has developed its urban area mainly along the east-west direction in the urbanization process, showing an "axial" pattern. According to the data of 2019, the percentage of impervious area in Shijiazhuang has exceeded 52%, while the vegetation cover is only 275 km²[6]. This is due to the gradual increase in the number of urban buildings during the urban construction process in Shijiazhuang, which also leads to the expansion of impervious area in the city. The increase of impervious area will further affect the subsurface, which is located in the underground layer, and will lead to the formation of stormwater runoff. At the same time, the increase in population density during urbanization will lead to a dramatic increase in water demand. However, as the amount of urban sewage also tends to increase, this has a significant impact on the spatial and temporal distribution of healthy water resources, the water cycle and the physicochemical properties of water in cities. Next, let's further deepen our understanding by analyzing the specific data of the impervious area of Shijiazhuang City. Impervious surface data is obtained from annual urban impervious surface data (1985-2018) with a global resolution of 30 meters, annual maps of global artificial impervious area between 1985 and 2018, which is later referred to as "GAIA" (<http://data.ess.tsinghua.edu.cn/gaia.html>). Based on Google Earth Engine cloud computing platform, the research team studied the mapping of Landsat optical images (nearly 1.5 million views) and other auxiliary data (night light data and Sentinel-1 radar data) based on long time series. The average overall accuracy of the data reached 90%.

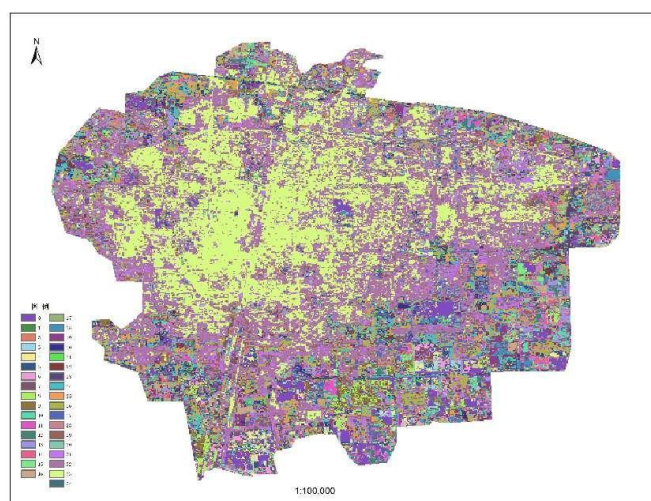


Figure 1. Raw data map of impervious surface

First and foremost, I downloaded the required data from the website above. Then, according to the boundary of village administrative districts of Shijiazhuang City, combined with the images, I screened out the scope of the main urban area of Shijiazhuang City. After that, the newly added impervious surface area in the main urban area of Shijiazhuang from 1985 to 2018 was cut out by the scope of the main urban area, and the newly added impervious surface area in the main urban area of Shijiazhuang was obtained. And spatial analyst-extraction analysis-attribute extraction tool was used to extract the annual variation of impervious surface from 1985 to 2018. Finally, using the data management tool Raster-Raster Dataset - Mosaic to New Raster tool, the newly added impervious surface of each year is superimposed to obtain the annual impervious surface area.

The variations of impervious area in Shijiazhuang city from 1985 to 2018 are shown in Table 1 and Figure 1.

Table 1. The impervious area in Shijiazhuang city

Year	Area(ha)	Year	Area(ha)
1986	2998.23	2002	10283.90
1987	5869.46	2003	10405.57
1988	6512.85	2004	10507.94
1989	6754.21	2005	10619.97
1990	7338.81	2006	10755.84
1991	7633.02	2007	10877.23
1992	7982.09	2008	10999.06
1993	8473.16	2009	11103.08
1994	8781.17	2010	11209.73
1995	9101.76	2011	11350.52
1996	9277.40	2012	11460.16
1997	9408.42	2013	11561.28
1998	9519.88	2014	11667.30
1999	9663.60	2015	11765.73
2000	9987.33	2016	11876.85
2001	10184.22	2017	11935.39
		2018	11990.73

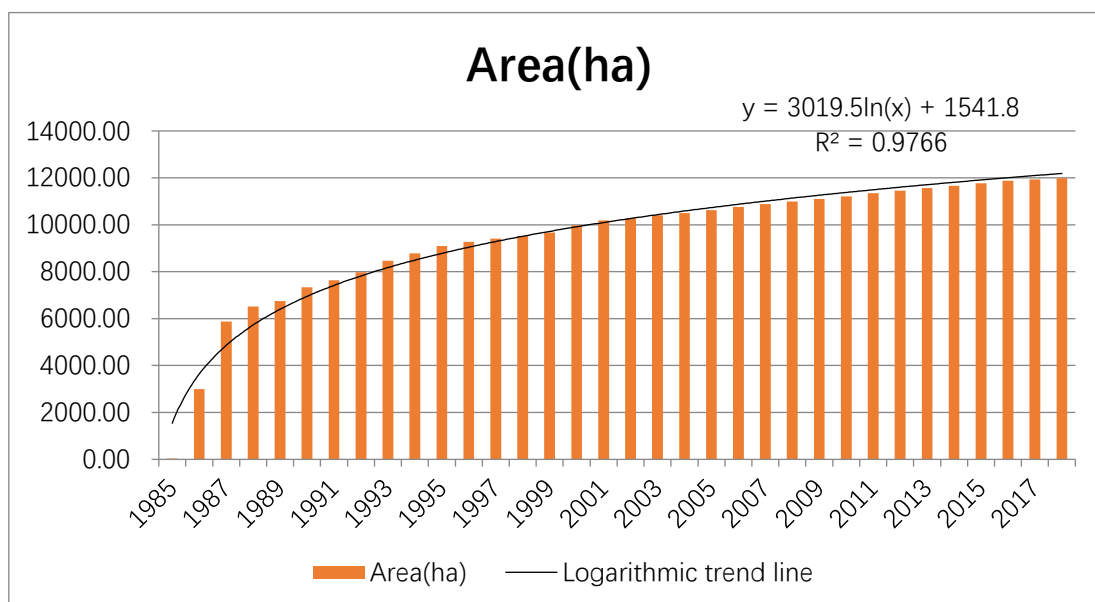


Figure 2. The change of impervious area

It is noticeable that the impervious area in Shijiazhuang city only reached 33.63 hectares in 1985 and it is the lowest value in all years. Shown directly in the table 1, in the first decade (from 1986 to 1995), the impervious area increased from 2998.23 hectares in 1986 to 5869.46 hectares in 1987 with the increase proportion of about 49%. It reveals that the impervious area increases above 200 hectares per year mainly occurred in the first decade. When it comes to the end of the 20th century, the impervious area began to increase steadily, from 1995 to 1999, starting from 9101.76 hectares in 1995, undergoing 9277.40 hectares in 1996, 9408.42 hectares in 1997 and 9519.88 hectares in 1998, and eventually ended up with 9663.60 hectares in 1999. By contrast, between 1999 and 2000 the impervious area underwent a relatively increase from roughly 9770 hectares in 1999 to approximately 10000 hectares in 2000. The impervious area increased by 58.54 ha and 55.34 ha during 2016-2017 and 2017-2018, respectively.

It can be seen that the figures in impervious area underwent a significant increase from 2998.23 hectares in 1986 to 5869.46 hectares in 1987. Since 1987, there has been a steady growth in impervious area with the value of 2998.23 hectares in 2018, 9277.40 hectares in 1996 and 11990.73 hectares in 2017 finally. To be specific, the overall impervious area in Shijiazhuang increased by 8992.5 hectares during the period of 1986 to 2018.

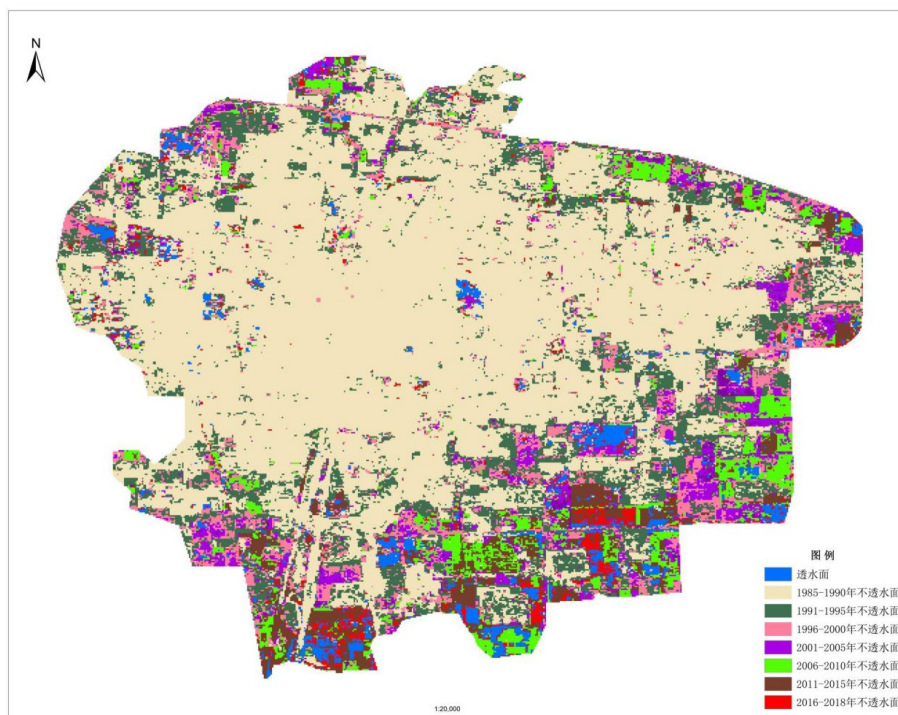


Figure 3. Plot of impervious area and permeable area of Shijiazhuang City from 1985 to 2018

We divided the area according to the development stage of Shijiazhuang City in the history of urban planning, so as to show the impervious surface more intuitively. For example, the data graph is made of different colors. The blue color represents previous surfaces. On behalf of the impervious surface area from 1985 to 1990, is the flesh color. Red is symbolized the impervious surface area in the period of 2016 to 2018. The purple and green represent the impervious surface area from 2001 to 2005 and the period of 2006 to 2010, respectively. The dark green and pink stand for the impervious surface area from 1991 to 1995 and the period of 1996 to 2000, respectively. As for the last color-brown, which represents the impervious surface area from 2011 to 2015. From 1986 to 1990, the impervious surface area increased from 2998.23 ha to 7338.81 ha, the area increased by 4340.58 ha, the proportion increased from 24.24% to 59.34%, the growth rate was 59.15%. From 1991 to 1995, the impervious surface area increased from 7633.02 ha to 9101.76 ha, the area increased by 1468.73 ha, the proportion increased from 75.03% to 80.76%, the growth rate was 16.14%. From 1996 to

2000, the impervious surface area increased from 9277.40 ha to 9987.33 ha, the area increased by 709.93 ha, the proportion increased from 75.02% to 80.76%, the growth rate was 7.11%; From 2001 to 2005, the impervious surface area increased from 10184.22 ha to 10619.97 ha, the area increased by 435.75 ha, the proportion increased from 82.35% to 85.87%, the growth rate was 4.10%. From 2006 to 2010, the impervious surface area increased from 10755.84 ha to 11209.73 ha, the area increased by 453.89 ha, the proportion increased from 86.97% to 90.64%, the growth rate was 4.05%. From 2011 to 2015, the impervious surface area increased from 11350.52 ha to 11765.73 ha, and the area increased by 556.00 ha, and the proportion increased from 91.78% to 95.14%, with a growth rate of 4.73%. From 2016 to 2018, the impervious surface area increased from 11876.85 hectares to 11990.73 hectares, with an area increase of 2.00 hectares, and the proportion increased from 96.03% to 96.96%, with an increase rate of 0.02%. From above, we can clearly know that the period from 1986 to 1990 is the period with the largest expansion rate of impervious surface.

Since the growth rate of impervious area is obviously faster than that in recent years, we cannot use simple linear fitting to analyze the growth trend. It can be seen from Figure 4 that the impervious area shows an increasing trend from 1986 to 2018. This paper uses the Mann-Kendall trend analysis approach (Figure 4) to analyze the changing trend from 1985 to 2018. Figure 5 shows that the UF curve intersected with the significant horizontal line around 1988 and exceeded the significant horizontal line after 1988. Therefore, the impervious surface area increased sharply before 1988, but the trend was not obvious, and the rising trend slowed down after 1988. Therefore, we can predict that the impervious area of Shijiazhuang City will continue to increase, but the growth rate will gradually decrease until it becomes stable.

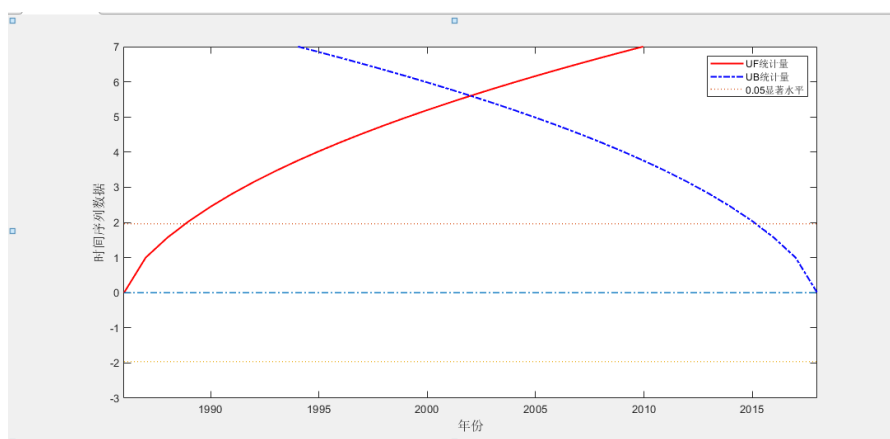


Figure 4. Analysis chart of impervious surface M-K trend from 1985 to 2018

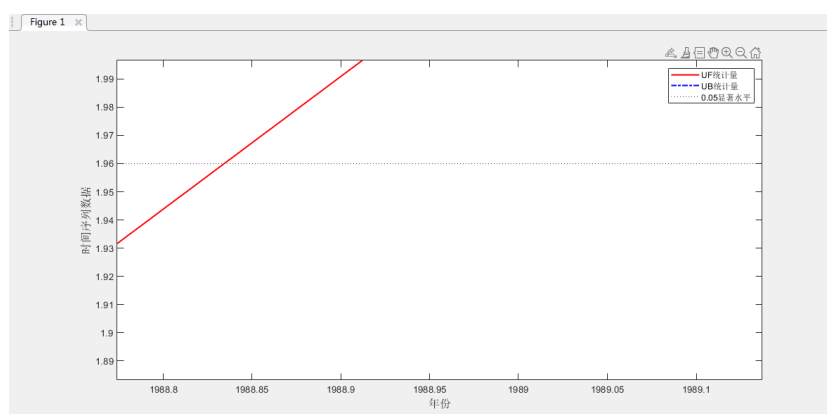


Figure 5. Analysis chart of impervious surface M-K trend from 1985 to 2018
(Local amplification at the intersection of uf and 0.05)

UF: Order column of sequential time series, namely trend change

UB: order column of the inverted time series

0.05 was considered as the significance level

UF and UB intersect within the significance level, and the intersection point is the mutation point.

There is basically no mutation in the data presented in this paper, showing a steady upward trend, so there is no intersection point in the significance interval. However, the intersection point between UF and the outermost significance level can be used as mutation for analysis.

4. Suggestions

Therefore, through the call for ecological city construction advocated by the state in recent years, we can suggest certain improvements to the current situation of impervious area in Shijiazhuang.

First, according to the principle of urban heat island effect, we find that the use of cement and concrete occupies a great proportion of the materials chosen for the current urban buildings. However, it seems that the reflectivity of cement and concrete to the sun is low, and it is an impermeable material result in high local temperature on the surface of the building, which will aggravate the heat island effect. In order to alleviate this phenomenon, we can choose or develop building materials with high reflectivity of sunlight that can cool down and save energy. For example, water-permeable floor tiles can be used to reduce heat savings and help rainfall seep into the ground, alleviating water shortages.

Secondly, for urban planning staff, it is important to identify the heat island effect and the dilemma of too much impervious area in cities, and use it as a starting point for technical reform. Now China is trying to apply remote sensing and GIS to the monitoring and analysis of urban heat island effect. However, using a single technique from a single discipline is still impossible to quantitatively study the accuracy of urban heat island effect for the time being. Therefore, the reduction of urban impervious area needs to rely on a comprehensive multi-angle, multi-scale, multi-criteria, and multi-spectral study. This advanced technology requires a cross-fertilization of urban meteorology, botany, geography, information technology, and other multidisciplinary disciplines to jointly propose improvement methods for the excessive increase of urban impervious area.

In addition, facing the situation that the impervious area cannot be improved quickly in a short period of time, we can also improve the method of water resources storage. First of all, from the perspective of feasibility, urban rainwater storage in the use of water resources belongs to the development and management of water resources, specifically related to urban construction, administration, road garden and many other departments. So how to store and use water better are also political issues. Then, we also need to tackle the problem at an even level. As far as current technological development is concerned, the easiest source of water to store and use is natural precipitation. Rainwater utilization technology is in the stage of rapid development at present, because rainwater infiltration technology is a kind of water-saving drainage facilities with less investment, quick effect and comprehensive benefits. In order to achieve the maximum utility of rainwater utilization technology, it is necessary to make a clear, detailed and feasible scheme for the process of technology advancement. For example, for the sewer works that must be reformed or newly built, it is necessary to adopt the infiltration facilities at one time, so that the fundamental solution to the problem can achieve the purpose of saving investment and killing multiple birds with one stone. In recent years, the water supply contradiction has been the most important problem[7]. Researchers should have the consciousness of advance and speed up the application research of rainwater utilization technology.

According to the principle of adapting measures to local conditions, different cities are suitable for different reconstruction schemes. Shijiazhuang, as a core city with a large population in the north, needs to rapidly promote economic development and increase the employment rate of the population. But it also requires corresponding changes in industrial production and daily life. If "sponge city", as a new generation of urban stormwater management concept, can be successfully applied, it will play a great role in improving the impervious area of Shijiazhuang. "Sponge city" refers to a city with

good "resilience" in the face of environmental changes and natural disasters such as rain, which can also be called "water-resilient city"[8]. A good "sponge city" will absorb, store, seep, clean water when it rains, and "release" the stored water, achieving recycling. This transformation method not only helps reduce the drainage pressure of the city, but also can relieve the city's water accumulation after light rain and waterlogging after heavy rain.

Last but not least, Shijiazhuang, as a core city in the north with an increasing population, needs to rapidly promote economic development and increase the employment rate of its population. However, there is also a need to make changes in industrial production and daily life. In terms of industrial production, it is necessary to try to achieve clean production in order to reduce the aggravation of the heat island effect by industrial pollutants. In order to improve the imperviousness of Shijiazhuang more quickly, the establishment of a greening system for the city needs to be on the agenda. For the government, it is imperative to prepare a scientific proposal on the topic of greening and to set standards for qualified greening of the city. A green qualified city must meet both ecological and livability requirements. Specifically, a sufficient number and area of green parks, wetland parks and forest trails can be created in the middle of the city. Likewise, for city residents, the concept of protecting the environment and caring for greenery needs to be implemented in their daily lives so that they can contribute well to the urbanization process.

References

- [1] Li Xiaoyong, Kuang Wenhui. Effects of composition and structure characteristics of urban land cover on land surface temperature in Beijing, Tianjin and Shijiazhuang [J]. Chinese Journal of Ecology, 2019, 38 (10): 3057-3065.
- [2] Hou Xiaowei, Li Xiliang, Wang Haiting. Analysis of seasonal variation characteristics in Shijiazhuang City in recent 50 years [C]//. The 33rd Annual Meeting of the Chinese Meteorological Society S5 on Climate change, low-carbon development and ecological civilization Construction. [Publisher Unknown], 2016: 116-124.
- [3] Han Juncai, Chen Jing, Yue Yanxia, Gao Qi. Spatial and temporal distribution characteristics of precipitation days of different grades in Shijiazhuang City [J]. Journal of Meteorology and Environment, 2009, 25(06):34-38.
- [4] Yang Junjun, Long Shuangshuang, Wang Kechun. Study on the relationship between urban impervious surface and land surface thermal environment [J]. Geospatial Information, 2020, 18(09):89-90+118+8.
- [5] Li Waibin, Tang Jun, Gao Xianjun, Li Zhiyuan. Characteristics and changes of heat island in the main urban area of Shijiazhuang [J]. Science Technology and Engineering, 2021, 21(27):11858-11867.
- [6] Li H M. Study on the urbanization of Shijiazhuang in modern times (1901 ~ 1949). Hebei Normal University, 2007
- [7] Mao Jian. Present situation of rainwater utilization at home and abroad [J]. Shandong chemical industry, 2020, 49(03):59-61.
- [8] Fan Xiaosen, Cheng Yue, Xia Pengyu. Urban planning and design based on Sponge city theory [J]. Urban Housing, 2021, 28(11):134-135.