

Article

Land Use Changes and Spatiotemporal Distribution of Domestic Water Consumption in the Northern Slope of Tianshan Mountains

Menglin Zhang ¹, Zhao Li ^{1,2,*}, Gang Chen ³  and Fadong Li ¹ 

- ¹ Shandong Yucheng Agro-Ecosystem National Observation and Research Station, Yucheng Comprehensive Experiment Station, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; zhangml603@126.com (M.Z.); lifadong@igsnrr.ac.cn (F.L.)
- ² Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
- ³ Department of Civil and Environmental Engineering, Florida A&M University (FAMU)-Florida State University (FSU) Joint College of Engineering, Tallahassee, FL 32310, USA; gchen@eng.famu.fsu.edu
- * Correspondence: liz.18b@igsnrr.ac.cn; Tel.: +86-18801171184

Abstract: Rapid population growth and subsequent urbanization pose significant challenges of water shortage in arid regions. As an important area along the One Belt and One Road line, the Northern Slope of Tianshan Mountains (NSTM) has suffered from water shortages owing to rapid urbanization in recent decades. To conserve water resources and protect the ecosystem, understanding the temporal and spatial variations of the domestic water consumption, availability, and its influencing factors is essential. According to water resource regionalization and its characteristics in NSTM, it was divided into three sections, namely the west section, the middle section, and the east section. In addition, this work characterized the temporal and spatial variation of domestic water consumption in NSTM with a focus on the understanding of the influence of urbanization on domestic water consumption from 1990 to 2020 based on three sections. The results showed that during this period of time, construction land use increased by 2256 km² corresponding to the population increase of 158.58×10^4 . Subsequently, the total domestic water consumption increased from 7.55×10^7 m³ in 1990 to 2.60×10^8 m³ in 2020. The eastern section demonstrated steady growth, while the western and middle sections experienced larger fluctuations in domestic water consumption. Urbanization has been identified as a significant factor influencing the shift in domestic water consumption. This study offers a scientific foundation for the sustainable management of water resources in arid areas.

Keywords: domestic water consumption; water resource; urbanization; Northern Slope of Tianshan Mountain



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1. Introduction

The distribution of water, the most crucial natural resource for sustainable development and quality of life, is uneven across the world [1]. While water scarcity is one of the major challenges facing the world, climate change deteriorates the situation with increased stress on freshwater availability, especially in arid and semi-arid regions [2]. Approximately one in five people worldwide resides in areas with limited access to water, while one in four faces severe water scarcity [3]. Domestic water consumption varies widely from country to country, with factors such as population size, climate, and infrastructure playing a significant role. In some countries, access to clean and safe drinking water is limited, leading to higher levels of water scarcity and increased pressure on domestic water resources. On the other hand, in more developed countries with advanced water management systems, domestic water consumption may be more efficient and sustainable. At the global scale, domestic water consumption accounts for only a small portion of overall human water usage, estimated to be about 10% [4]. The majority of freshwater resources are used for agriculture and industry. However, it is important to note that even though domestic use

represents a smaller percentage of total water consumption, it still plays a crucial role in meeting basic human needs and supporting daily life activities.

Water scarcity has significantly impeded sustainable socioeconomic development [5]. In many developing countries such as China, India, South Africa, and Brazil, domestic water consumption increases rapidly because of population growth and increasing socioeconomic activities, which may change the hydrological cycle significantly on local and regional levels, particularly in urban areas with high population density [6]. China's rapid economic development and growing population have led to a significant increase in water demand, resulting in an imbalance between supply and demand at an alarming rate [7]. In Northwestern China, where water shortages prevail owing to the dry climate, water scarcity has emerged as the primary impediment to socioeconomic development [8,9].

This is due to a variety of factors, such as larger populations, increased industrialization, and higher standards of living. As a result, the pressure on water resources becomes even more pronounced, leading to potential shortages and competition for access to clean water. In addition, rapid urbanization can also lead to environmental degradation and pollution of water sources, further exacerbating the challenges faced by these communities [10,11]. Research on the dynamic change in climate showed that the disturbance of hydrological cycle will have a great impact on water supply, especially with the involvement of human activity-induced land use change. In the land use change, the change in construction land is the most important factor in the process of Land-Use and Land-Cover Change [12,13]. Therefore, population growth and associated increased water demands and construction expansion significantly affect domestic water supply [14].

The Northern Slope of Tianshan Mountain (NSTM) is a pivotal region for the economic, technological, and social advancement of Xinjiang [15]. It also serves as a significant gateway connecting Central Asia and Europe along the Silk Road. With rapid economic development, resource exploitation, urbanization, and population growth in recent years, the land use structure has transferred significantly in this region [16]. The NSTM had the highest proportion of unused land from 2000 to 2018, which was subsequently transformed into the increase in grassland and cultivated land, and the expansion of construction land. The increase in cultivated land area is closely related to population growth and urbanization, which leads to a significant increase in the demand for water resources, especially for surface water resources [17]. The expansion of construction land directly increases the demand for domestic water, especially the demand for tap water in the newly developed residential and industrial land during the urbanization process. At the same time, the increase in water area may be related to the construction of artificial lakes and reservoirs in the process of urban development, which provides more water regulation and storage bodies for cities, and then may affect the water cycle and water use pattern in a certain range [17]. However, the decrease in woodland and grassland may be related to over-exploitation, which not only affects the ecological balance, but also may reduce the source of surface water resources. In the past study of domestic water consumption on the NSTM, the relationship between the changes in domestic water consumption and land use patterns in the whole region in the past about 30 years (1990–2017) was explored [18]. However, there is a significant variation in water resources across the NSTM, leading to diverse domestic water consumption and lifestyles in each region. Currently, there is a lack of research on the relationship between domestic water usage and local social development in these areas. Meanwhile, the current water pattern may not be suitable to sustain the NSTM's ongoing economic development [19]. Concurrently, domestic water consumption has witnessed a sharp surge, leading to constraints on water use [15].

The understanding of the evolving pattern of domestic water demands is crucial in light of the discrepancy between water supply and the escalating water demands. The primary objective of this study is to characterize the spatial and temporal distribution of domestic water consumption in the NSTM from 1990 to 2020, map the land use changes, and assess the impacts of land use change on the domestic water consumption in the NSTM.

This research offers valuable insights for promoting sustainable domestic water resource management in the NSTM.

2. Materials and Methods

2.1. Study Area

The study area of the NSTM ($42^{\circ}36' \text{ N}$ – $47^{\circ}60' \text{ N}$, $79^{\circ}42' \text{ E}$ – $96^{\circ}36' \text{ E}$) is from the east of the Aratao Mountains on the China-Kazakhstan border to the north of the Balikunshan and Karlik Mountains watershed. The NSTM overlaps with the Northern Slope, which is about 1300 km, including the Yili River valley, the western, middle, and eastern sections of the NSTM. The climate in the NSTM ranges from humid to semi-arid, with an annual average temperature of 0.9°C . The extreme minimum temperature reaches -37°C , while the extreme maximum temperature can reach up to 33°C . The average annual precipitation ranges between 450 and 800 mm.

The natural landscape of the NSTM shows a transitional change feature of “mountain—plain oasis—desert—oasis—desert”. The NSTM mainly includes six third-order basins: Emin River, Ebinhu Lake system, middle river, east river, Gurbantunggut desert area, and Bai Yi Basin [20]. In addition, the western section of the NSTM includes the Emin River basin and the Ebinhu Lake drainage system. The middle section of the NSTM includes the middle river basin and the Gurbantunggut desert region. The eastern section of the NSTM includes the eastern river basin and the Baiyi Basin (Figure 1).

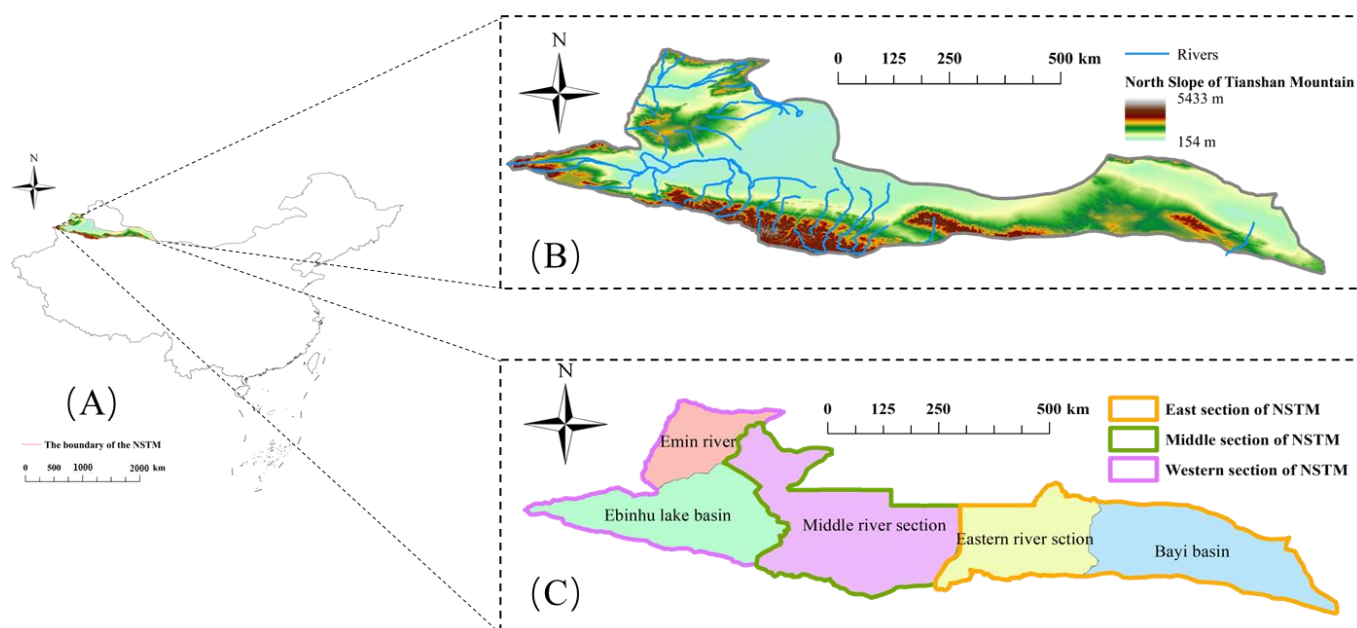


Figure 1. Location map of the study area (A), DEM of study area (B), Eastern, Middle and western section of study area (C).

2.2. Data and Methods

2.2.1. Data

The statistical data were from Xinjiang Statistical Yearbook (1990–2020), Bortala Mongol Autonomous Prefecture Water Resources Bulletin (2010–2020), Hui Autonomous Prefecture of Changji Water Resources Bulletin (2010–2020), Hami Water Resources Bulletin (2010–2020), Karamay Water Resources Bulletin (2010–2020), Tacheng prefecture Water Resources Bulletin (2010–2020), and Urumqi Municipality Water Resources Bulletin (2010–2020). Land use data with resolution of $1 \text{ km} \times 1 \text{ km}$ in 1990, 1995, 2000, 2005, 2010, 2015, and 2020 were obtained from the Resource and Environment Science Data Platform (<https://www.resdc.cn/Default.aspx> (accessed on 15 August 2024)).

2.2.2. Land Transition Matrix

The land use data from 1990 to 2020 was processed to extract land use classifications for different temporal intervals within the study area, serving as the basis for constructing the transition matrix. Land use data from various periods was clipped to the boundary of the NSTM using ArcGIS (10.2), followed by the creation of a raster attribute table of land type codes, with an added year field to distinguish time points. Then, the data were converted to vector format, and similar land type features were merged. An intersection analysis was conducted on the merged data at five-year intervals to calculate areas, and the results of all land type transitions were aggregated to derive the transition amounts between different land use types over time, resulting in the construction of the following transition matrix [21]:

$$Q = \begin{bmatrix} Q_{11} & \cdots & Q_{1n} \\ \vdots & \ddots & \vdots \\ Q_{n1} & \cdots & Q_{nn} \end{bmatrix}$$

Each element of the transition matrix Q_{ij} represents the area of land use type i in the initial state that transitioned to land use type j in the final state during the study period. The rows of the matrix represent the land use types in the initial state, while the columns represent the land use types in the final state. This matrix facilitates the quantification of the transition processes between different land use types, revealing the dynamic characteristics of land use changes [22].

2.2.3. Sankey Diagram

A Sankey diagram is an efficient tool that visually represents the flow and conversion of different land cover types. This visualization allows for a better understanding of the changes in land use over time and can help identify patterns and trends in the conversion results. The land use transition matrix describes changes in the number of land features from the previous year to the later year [23]. In this study, Sankey diagrams were used to visualize the evolution of land use since the 1990s in the NSTM.

2.2.4. Estimation of Domestic Water Consumption

The data of domestic water consumption were mainly obtained from various city and county water resources bulletins in Xinjiang. When data from the water bulletin were not available, they were estimated using the following formula:

$$DWC = P \times PCW$$

where DWC is domestic water consumption, m^3 , P is permanent resident population, and PCW is per capita water consumption, m^3/per .

2.3. Data Analysis

All domestic water consumption and ancillary data processing were conducted using SPSS (Version 23.0, SPSS Inc., Chicago, IL, USA). Pearson correlation analysis was then conducted to assess the relationships between domestic water consumption and construction land use. One-way analysis of variance (ANOVA) was applied to test for differences among groups' domestic water consumption in the western section, middle section, and eastern section. ArcMap (10.2) was used to visualize the spatial variation of domestic water consumption on the NSTM.

3. Results

3.1. Domestic Water Consumption Trend in NSTM

The temporal changes in domestic water consumption of the NSTM from 1990 to 2020 are presented in Figure 2. The total annual domestic water consumption in the NSTM gradually increased for the study period. Specifically, the total domestic water

consumption from 1990 to 2020 increased by about four times, from $7.55 \times 10^7 \text{ m}^3$ in 1990 to $2.60 \times 10^8 \text{ m}^3$ in 2020.

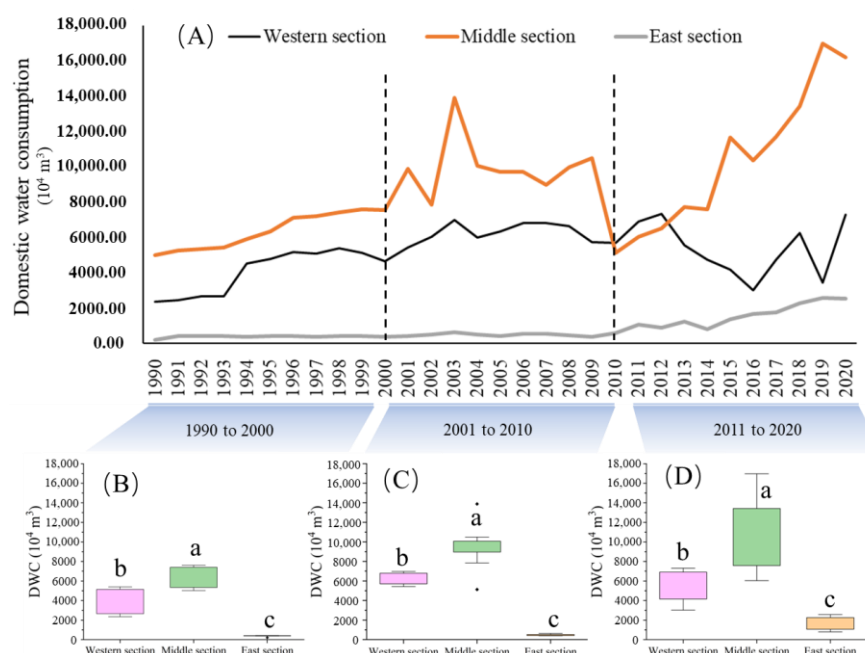


Figure 2. Changes in domestic water consumption of the NSTM from 1990 to 2020 (A). (B) Box plot of domestic water consumption of surface water in the western, middle, and eastern sections of the NSTM from 1990 to 2000; (C) Box plot of domestic water consumption of surface water in the western, middle, and eastern sections of the NSTM from 2001 to 2010. (D) Box plot of domestic water consumption of surface water in the western, middle, and eastern sections of the NSTM from 2011 to 2020. Different lowercase letters above the bars indicate the significant differences at the $p < 0.05$ level among the various events based on a one-way ANOVA with Turkey's HSD test.

During the period from 1990 to 2000, there was an overall upward trend in domestic water consumption across the western, middle, and eastern sections of the NSTM with an overall growth of $5.01 \times 10^7 \text{ m}^3$. Specifically, in the western section, domestic water consumption increased by 98%, from $2.3 \times 10^7 \text{ m}^3$ in 1990 to $4.6 \times 10^7 \text{ m}^3$ in 2000. In the middle section, domestic water consumption increased by 51%, from $5.0 \times 10^7 \text{ m}^3$ in 1990 to $7.5 \times 10^7 \text{ m}^3$ in 2000. Meanwhile, the eastern section experienced a growth of domestic water usage growth by 75%, from $2.0 \times 10^7 \text{ m}^3$ in 1990 to $0.36 \times 10^7 \text{ m}^3$ in 2000. The western and middle sections contributed significantly to the increase in domestic water consumption from 1990 to 2000, accounting for 46.0% and 51.0% of the increase, respectively.

From 2000 to 2010, divergent trends emerged in domestic water consumption across the western, central, and eastern regions. During this period, domestic water consumption of NSTM as a whole showed an overall trend of growth followed by a decline, culminating in a reduction in domestic water consumption in 2010 as compared to 2000 of $1.13 \times 10^7 \text{ m}^3$. The middle section experienced an overall decline in domestic water consumption, while both the western and eastern sections showed an upward trajectory. Specifically, in the western section, domestic water consumption increased by 21.1%, from $4.65 \times 10^7 \text{ m}^3$ in 2000 to $5.7 \times 10^7 \text{ m}^3$ in 2010. The middle section witnessed a decrease from $7.5 \times 10^7 \text{ m}^3$ in 2000 to $5.1 \times 10^7 \text{ m}^3$ in 2010, with significant fluctuations in between. In contrast, the eastern section exhibited relatively stable changes, with domestic water consumption gradually increasing from $3.6 \times 10^6 \text{ m}^3$ in 2000 to $5.9 \times 10^6 \text{ m}^3$ in 2010.

Between 2010 and 2020, the western, middle, and eastern sections of the NSTM once again displayed varied trends in domestic water consumption. It rose from $1.14 \times 10^8 \text{ m}^3$ in 2010 to $2.6 \times 10^8 \text{ m}^3$ in 2020. In the western section, the domestic water consumption

increased by 27.7%, from $5.7 \times 10^7 \text{ m}^3$ in 2010 to $7.2 \times 10^7 \text{ m}^3$ in 2020. The middle section witnessed the most substantial increase of 215.7%, soaring from $5.1 \times 10^7 \text{ m}^3$ in 2010 to $1.6 \times 10^8 \text{ m}^3$ in 2020. Similarly, the eastern section experienced an increase of 327.4%, from $5.97 \times 10^6 \text{ m}^3$ in 2010 to $2.5 \times 10^7 \text{ m}^3$ in 2020. The middle sections contributed significantly to the increase in domestic water consumption from 1990 to 2000, accounting for 84.5% of the increase. Compared to the previous two periods, the upward trend in domestic water consumption was more pronounced during this timeframe, indicating sustained growth in water demands across all sections.

In summary, over the past three periods, the western, middle, and eastern sections of NSTM exhibited distinct patterns in domestic water consumption. As shown in Figure 2A–C, over the three periods, domestic water consumption was the highest in the middle section. During 1990 to 2000, domestic water consumption in the middle section was 52.3% and 1607.7% higher than the western and eastern sections, respectively. During 2000 to 2010, domestic water consumption in the middle section was 53.7% and 1855.9% higher than the western and middle sections, respectively. From 2010 to 2020, domestic water consumption of the middle section was 111.0% and 647.5% higher than the western and middle sections, respectively. Generally speaking, the eastern section underwent steady growth, while the western and middle sections experienced large fluctuations in domestic water consumption.

The spatial distribution of domestic water consumption in the NSTM between 1990 and 2020, depicted in Figure 3A–C, reveals discernible trends in water consumption patterns. Deep blue tones denote high water consumption, while lighter shades of blue indicate lower consumption levels. Overall, the amalgamation of data from these three periods elucidated a consistent upward trajectory in domestic water consumption demands in the NSTM. Notably, the eastern section displayed sluggish growth in water consumption, while the middle section experienced the most pronounced increase in water consumption, and the western section consistently maintained high levels of water consumption.

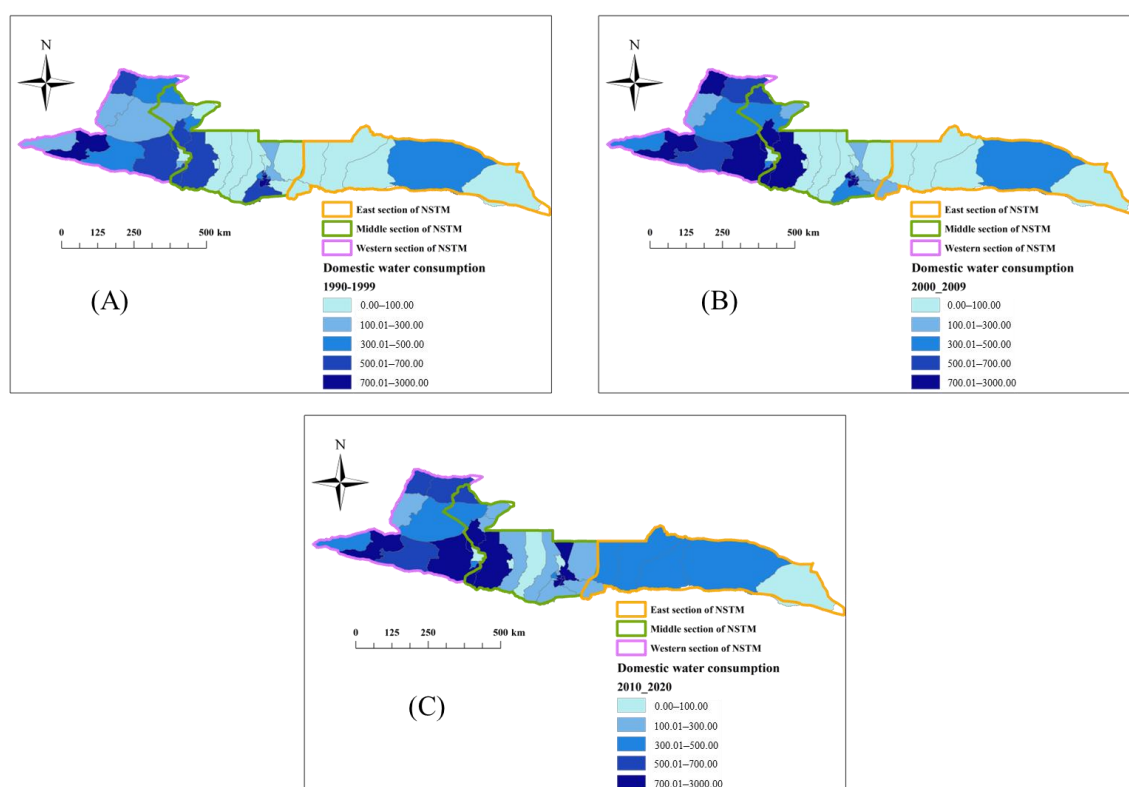


Figure 3. Spatial distribution of domestic water consumption on the NSTM from 1990 to 2000 (A), 2001–2010 (B), 2011–2020 (C).

When analyzed in conjunction with Figures 2 and 3, the trend of increasing domestic water use from 1990 to 2020 was relatively balanced across the cities, districts, and counties in the western section. Domestic water consumption in the counties and districts in the middle section increased significantly from 2010 to 2020, mainly in Manas County, Changji County, Toutunhe District, and Fukang City. Similarly, domestic water consumption in the counties of the eastern section increased significantly from 2010 to 2020, mainly in Jimushar, Qitai, and Mubi Kazakh Autonomous Counties. The increase in domestic water consumption in the cities and counties of the middle and eastern sections was not significant when compared to the 1990–2000 and 2000–2010 time periods.

3.2. Land Use Change

Spanning the years of 1990 to 2020, a transition occurred where diverse land use categories, such as cultivated land, grassland, unused land, forest land, and aquatic areas, were transformed into construction land. The converted areas were 1143 km², 767 km², 458 km², 81 km², and 21 km², respectively. Notably, the conversion rate of cultivated land stood at 7.3%. The primary regions witnessing conversion from cultivated land to construction land included the eastern section and middle section. Conversely, the middle section primarily experienced conversion from grassland to construction land, such as Midong District, Dushanzi District, and Mulei Kazak Autonomous County. Construction land in Jimusar County and Qitai County predominantly stemmed from the conversion of unused land, and a minor portion of construction land in Hutubi County was converted from water bodies (Figure 4).

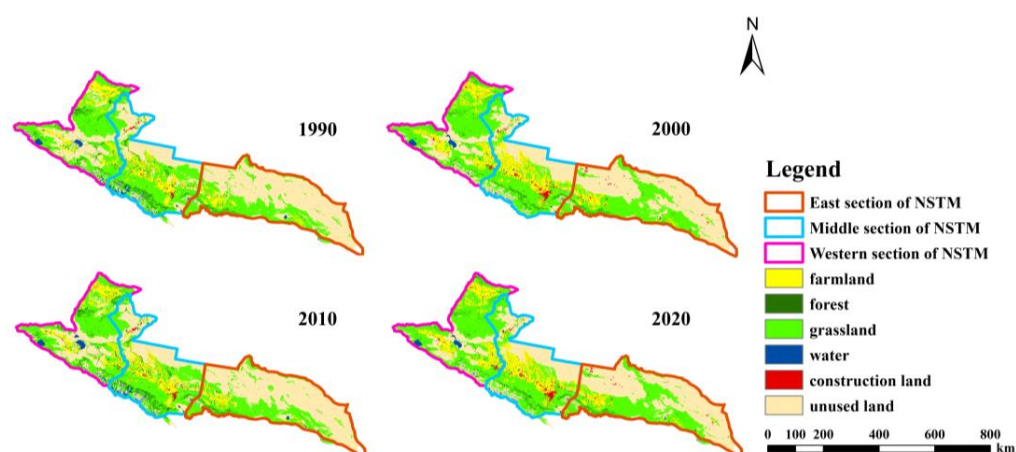


Figure 4. Land use change on NSTM from 1990 to 2020.

Between 1990 and 2020, the trends and degrees of land use change in NSTM varied differently among each of the five-year intervals (Tables 1–3). Within the 30 years, there was a noticeable acceleration in the expansion of construction land and cultivated land, predominantly at the expense of grassland and farmland. Construction land and cultivated land of the western, middle, and eastern sections increased by 567 km² (Table 1), 1113 km² (Table 2), and 576 km² (Table 3), respectively. Construction land of the three sections increased more obviously from 1990 to 2000 and from 2010 to 2020, resulting in a total increase of 2256 km². Specifically, the western section increased by 53% (1990–2000) and 78% (2010–2020), the middle section increased by 19% (1990–2000) and 61% (2010–2020), and the eastern section increased by 19% (1990–2000) and 319% (2010–2020), respectively. Figures 5–7 show the pace of land use transformation during 2000 to 2010. As shown in these figures, the expansion rate of farmland gradually decreased, while construction land continued to grow, albeit at a slower rate, with a notable increase in conversion from unused land. There was a continued reduction in grassland and unused land, but the rate of decrease slowed, gradually transitioning to other land types.

Table 1. Land use transfer matrix of western section of the NSTM in 1990–2020, unit: km².

1990	2000						
	Grassland	Construction Land	Cultivated Land	Forest	Waters	Unused Land	Total
Grassland	31,460	72	1261	2135	164	1942	37,034
Construction land	34	90	150	8	4	9	296
Cultivated land	1335	266	6033	114	145	590	8483
Forest	1724	9	99	1252	16	205	3305
Waters	107	2	34	13	1399	270	1826
Unused land	2393	15	527	231	504	16,344	20,014
Total	37,053	454	8104	3753	2232	19,361	70,957
2000	2010						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	36,211	15	965	12	14	20	37,237
Construction land	0	454	0	0	0	0	454
Cultivated land	37	5	8037	1	3	28	8111
Forest	0	1	22	3737	6	0	3766
Waters	23	2	17	0	2236	2	2280
Unused land	45	9	471	2	136	18,797	19,460
Total	36,316	486	9512	3752	2395	18,847	71,308
2010	2020						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	30,447	197	2572	1115	112	1754	36,195
Construction land	41	241	193	2	5	5	486
Cultivated land	813	307	8274	31	48	33	9506
Forest	2685	18	219	699	10	113	3743
Waters	249	14	110	4	1303	680	2359
Unused land	5891	87	988	76	170	11,564	18,777
Total	40,125	863	12,355	1926	1647	14,149	71,065

Table 2. Land use transfer matrix of middle section of NSTM in 1990–2020, unit: km².

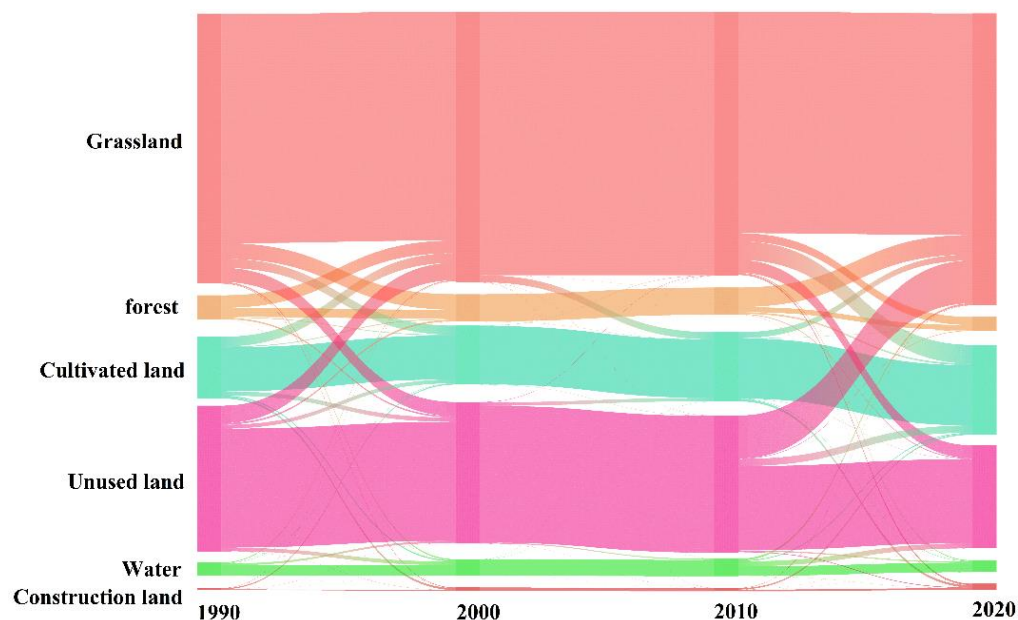
1990	2000						
	Grassland	Construction Land	Cultivated Land	Forest	Waters	Unused Land	Total
Grassland	27,975	139	1903	1517	328	1709	33,571
Construction land	95	480	326	14	7	54	976
Cultivated land	1328	427	6448	138	79	495	8914
Forest	1443	38	174	1724	31	165	3575
Waters	283	11	64	19	1516	418	2311
Unused land	1437	66	460	150	401	23,537	26,050
Total	32,561	1161	9374	3562	2362	26,378	75,397
2000	2010						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	31,813	26	695	6	47	110	32,697
Construction land	0	1156	1	1	0	3	1161
Cultivated land	42	50	9270	0	6	10	9378
Forest	0	3	50	3512	4	1	3570
Waters	23	0	2	1	2365	12	2403
Unused land	24	61	557	7	24	25,888	26,561
Total	31,902	1296	10,575	3527	2446	26,024	75,770
2010	2020						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	22,324	475	2849	753	153	5264	31,818
Construction land	94	707	365	3	7	121	1296
Cultivated land	1101	681	8589	26	57	118	10,573
Forest	2136	43	392	764	19	169	3522
Waters	356	16	61	1	693	1292	2418
Unused land	4143	167	1405	38	203	19,947	25,903
Total	30,153	2089	13,661	1585	1131	26,911	75,530

Table 3. Land use transfer matrix of eastern section of NSTM in 1990–2020, unit: km².

1990	2000						
	Grassland	Construction Land	Cultivated Land	Forest	Waters	Unused Land	Total
Grassland	25,437	35	930	540	109	1812	28,864
Construction land	23	30	78	2	2	10	145
Cultivated land	1131	91	2164	74	44	89	3593
Forest	534	3	52	487	0	57	1133
Waters	29	1	16	1	172	45	264
Unused land	2112	11	218	48	53	58,786	61,227
Total	29,266	172	3458	1152	380	60,799	95,226

2000	2010						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	29,141	0	140	5	2	151	29,439
Construction land	2	167	2	0	0	1	172
Cultivated land	71	2	3304	0	0	82	3459
Forest	5	0	12	1136	0	1	1154
Waters	1	2	0	0	358	25	386
Unused land	5	1	71	0	2	60,959	61,038
Total	29,225	172	3529	1141	362	61,219	95,648

2010	2020						
	Grassland	Construction land	Cultivated land	Forest	Waters	Unused land	Total
Grassland	22,606	147	917	520	87	4820	29,097
Construction land	18	63	75	0	1	15	172
Cultivated land	514	135	2821	0	20	38	3528
Forest	634	6	53	407	2	36	1139
Waters	93	3	34	0	109	117	356
Unused land	11,075	367	223	38	56	49,309	61,069
Total	34,941	721	4123	965	276	54,336	95,361

**Figure 5.** Sankey diagram for comparison of land cover dynamics in western section of NSTM from the years 1990, 2000, 2010, and 2020.

Overall, the land use structure of the NSTM underwent significant changes over time, transitioning from drastic alterations to a gradual stabilization, which was reflected by the growth of construction land and farmland and the reduction in grassland and unused land. Compared to grassland and farmland, the conversion between forest and other land use types was relatively minimal.

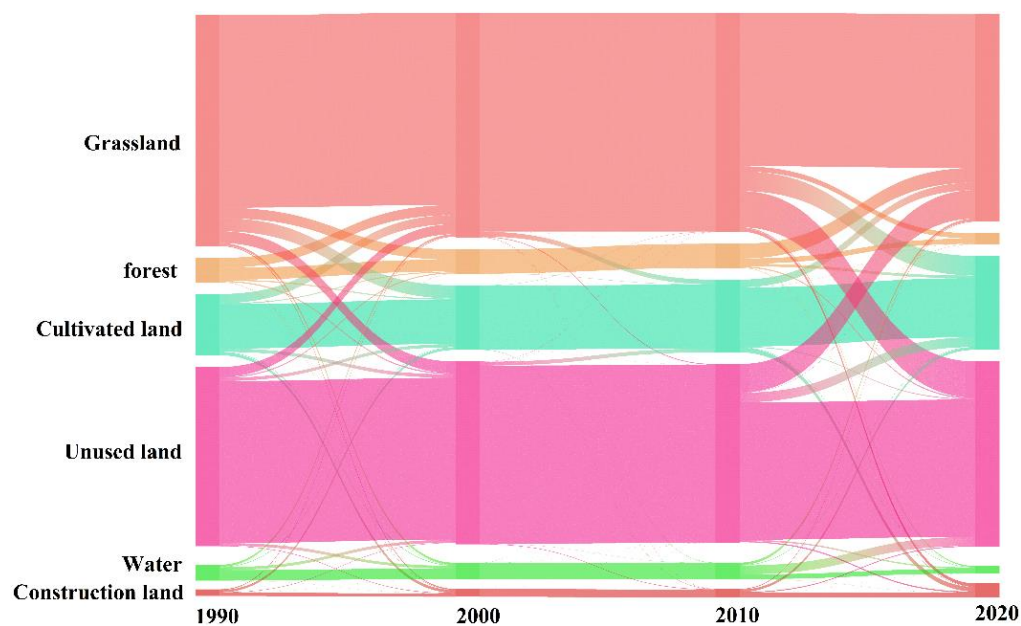


Figure 6. Sankey diagram for comparison of land cover dynamics in middle section of NSTM from the years 1990, 2000, 2010, and 2020.

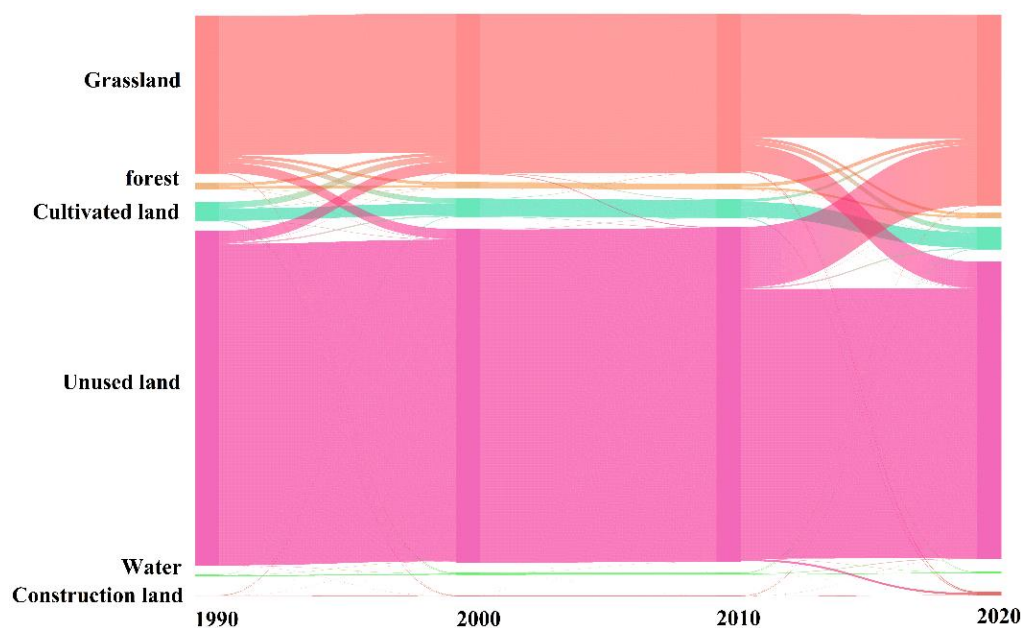


Figure 7. Sankey diagram for comparison of land cover dynamics in eastern section of the NSTM from the years 1990, 2000, 2010, and 2020.

4. Discussion

4.1. Factors of Domestic Water Consumption on the NSTM

Xinjiang province is one of the regions facing severe water scarcity in China, with high rankings in both water footprint and per capita water footprint indices significantly exceeding the national averages [7]. The complex interplay of factors shaping water utilization in Xinjiang encompassed climate variability [24], population dynamics [7], industrial expansion [7], urbanization [25], and agricultural practices [26]. The NSTM of Xinjiang Uygur autonomous region is one of the most populated regions in Xinjiang. In recent years, population growth has led to the change in domestic water consumption in the NSTM.

The observed trend in increasing domestic water consumption in the study region was attributed to several factors, each of which played significant roles in the complex dynamics of water usage. Firstly, the rapid urbanization and population growth in the region resulted in an increase in household water demands [27]. Many scholars have explored the relationship between urbanization and population growth and domestic water consumption. For example, Dawadi and Ahmad [28] developed a system dynamics model for the Las Vegas Valley from 1989 to 2035 and found that because of the population growth, the LVV would not be able to meet the water demand in the near future. Arain et al. [29] discussed the empirical relationship between foreign direct investment, population, energy production, and water resources in South Asia. Mu, Fang, Dou, Wang, Qu, and Yu [27] used the spatial panel measurement model to explore the spatial impact of urbanization on water use and its driving mechanism in Northwest China. These studies all showed that as urban areas grew and populations rose, the water demands for diverse domestic uses such as drinking, sanitation, and hygiene increased accordingly. In this study, urbanization and population growth continuously promote the growth of domestic water consumption. The specific results are urban and rural industrial land use and residential land use increased by 2256 km² corresponding to the population increase of 158.58×10^4 in the NSTM from 1990 to 2020. The total domestic water consumption increased from 7.55×10^7 m³ in 1990 to 2.60×10^8 m³ in 2020. Secondly, urban expansion brought changes in lifestyle and consumption patterns, with increased consumption for personal hygiene, gardening, and other water-intensive activities further driving up the demands for domestic water use [30]. In this study, the per capita domestic water consumption on the NSTM increased year by year, the per capita domestic water consumption in the NSTM has increased from 55.02 L/capd in 1990 to 136 L/capd in 2010 and 155 L/capd in 2020.

Water resources in the NSTM were scarce and uncertain, with unbalanced distribution in time and space [31,32]. Ma and Sun [18] showed that from 1990 to 2018, domestic water consumption increased year by year on the NSTM, and there was an important relationship between domestic water consumption and land use patterns. In this study, the spatial and temporal changes in total domestic water consumption in the NSTM from 1990 to 2020 are basically consistent with the results of Ma and Sun [18]. At the same time, domestic water consumption varied greatly among counties and districts in the NSTM. Our results indicated the eastern section demonstrated steady growth, while the western and middle sections experienced larger fluctuations in domestic water consumption. This suggests that there are regional differences in how urbanization has impacted domestic water usage (Figures 2 and 3). Specific regions within the area, apart from Wenquan County, Jinghe County, and Jimusar County, showed a significant per capita domestic water consumption increase during 1990 to 2000. Among these regions, Urumqi, Wusu City, Karamay, Shawan County, and Manas County experienced the fastest growth in domestic water consumption. These data emphasize the need for targeted conservation efforts and efficient management of water resources in these rapidly growing areas.

After 2000, domestic water consumption showed a fluctuating increase in the NSTM. With the implementation of the national strategy of Western Development, land development was encouraged from a policy perspective [33]. With the economic development of the NSTM, the living standards of the people were further improved. The per capita domestic water consumption in most areas of the study region increased significantly after 2000, especially in the new urban area. This trend was particularly noticeable in Shuimogou District and Shaibak District of Urumqi, Baijiantan district and Dushanzi District of Karamay, Bole City, Kuitun city, Shihezi city, and Changji city. The rapid urbanization and population growth in these areas have led to a higher demand for domestic water consumption. Additionally, industrial development and economic growth have also contributed to the increase in water consumption as more businesses and factories require water for their operations. Efforts to improve water conservation practices and infrastructure will be crucial in managing this growing demand for domestic water consumption.

4.2. Effects of Urbanization on Domestic Water Consumption

The rising domestic water consumption was closely linked to the rapid expansion of the population [34]. Therefore, this work primarily focused on construction land change. There was a significant increase in the expansion of industrial and residential land use in the region during the study period, which reflected the economic framework change and urbanization [35]. Additionally, human activities and climate change also led to changes in the grassland and aquatic ecosystems.

As depicted in Figure 8, over the course of the past three decades, domestic water consumption had a strong correlation with construction land use. Expansion of construction land use continued in the study region, paralleled by a steady increase in domestic water consumption. The spatial footprint of urban and rural residential areas expanded across most regions of the NSTM, consequently leading to a rapid escalation in domestic water consumption. This trend aligned with earlier research, which posited that the increase in water usage in the NSTM was primarily attributable to the expansion of both industrial and residential land use [36].

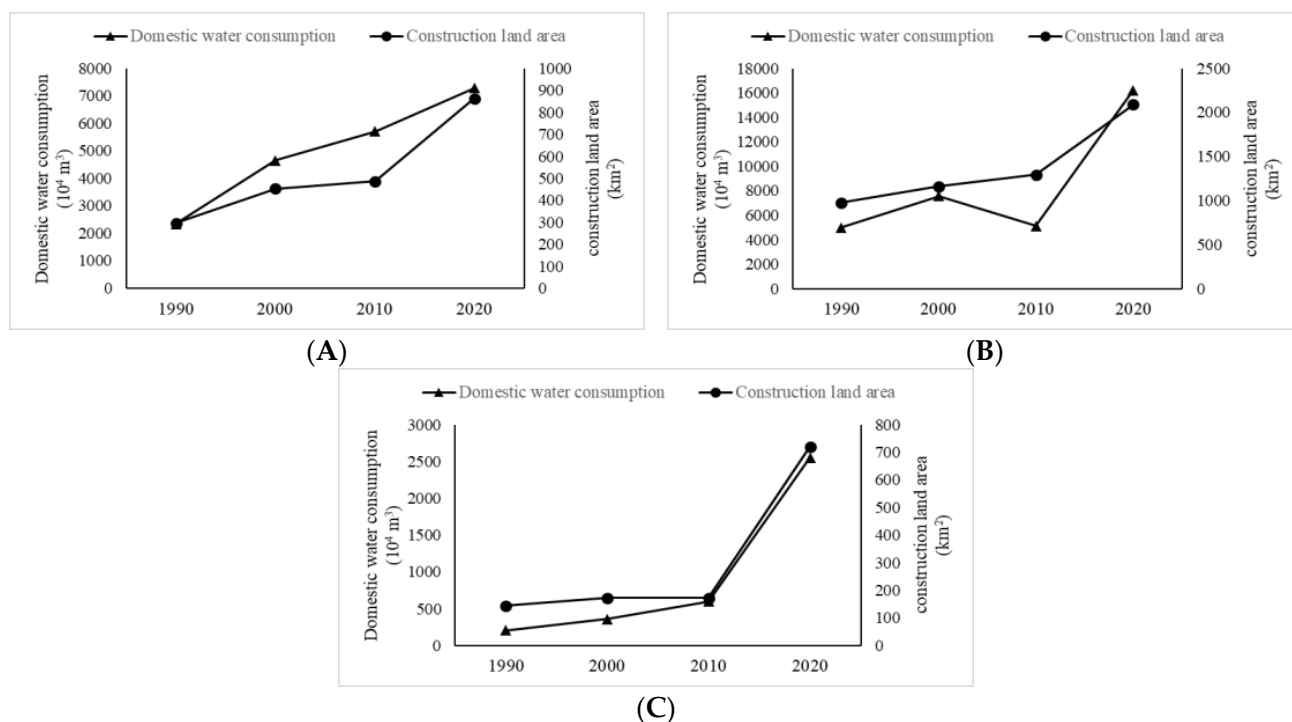


Figure 8. The correlation between domestic water consumption and construction land area in the NSTM. (A) is western section of NSTM ($r = 0.922$), (B) is middle section of the NSTM ($r = 0.947$), (C) is eastern section of the NSTM ($r = 0.993$).

The conversion of land from cultivated to construction in the eastern and middle sections has been a significant trend. This shift has been driven by urbanization and the increasing demand for residential and commercial development. In particular, areas such as Midong District, Dushanzi District, and Mulei Kazak Autonomous County have seen a rapid transformation from grassland to construction land due to their proximity to urban centers. Additionally, the conversion of unused land into construction land in Jimusar County and Qitai County reflects efforts to utilize previously underutilized or abandoned areas for development purposes. This approach not only helped meet the growing need for infrastructure but also contributed to sustainable land use practices. Furthermore, the minor conversion of construction land from water bodies in Hutubi County highlighted the complex challenges associated with balancing environmental conservation with urban expansion. It is essential for local authorities to carefully consider

the ecological impact of such conversions and implement measures to mitigate any potential harm to natural habitats. Overall, these patterns of land conversion underscore the dynamic nature of regional development and emphasize the importance of strategic planning and management in ensuring responsible use of resources.

5. Conclusions

This work characterized the spatial distribution and change in domestic water consumption in the NSTM with a focus on the understanding of the influence of urbanization on domestic water consumption. We collected and calculated the domestic water consumption data of each district and county from 1990 to 2020 and analyzed the spatial-temporal distribution characteristics of domestic water consumption on the NSTM. At the same time, combined with land use data, we analyzed the impact of urbanization on domestic water consumption on the NSTM. The results showed that from 1990 to 2020, urban and rural industrial land use and residential land use increased by 2256 km², corresponding to the population increase of 158.58×10^4 . Subsequently, the total domestic water consumption increased from 7.55×10^7 m³ in 1990 to 2.60×10^8 m³ in 2020 with a rapid growth of per capita domestic water consumption rate.

The study also revealed interesting patterns in the spatial distribution of domestic water consumption within the NSTM. Generally speaking, the eastern section demonstrated steady growth, while the western and middle sections experienced larger fluctuations in domestic water consumption. This suggests that there are regional differences in how urbanization has impacted domestic water usage. In addition, due to the Western Development strategy, the urbanization speed of the NSTM accelerated from 2010 to 2020, and there were significant increases in domestic water consumption within the NSTM. For example, Manas County, Changji County, Toutunhe District, Fukang City, Jimushar County, Qitai County, and Mubi Kazakh Autonomous Counties all saw notable rises in their domestic water usage during this period. These findings highlight the complex relationship between urbanization and domestic water consumption within the NSTM. It is clear that as urban areas continue to expand and populations grow, there will be an increasing demand for domestic water resources which will need to be carefully managed to ensure sustainable usage for future generations.

The prediction of domestic water consumption is crucial for managing water resources in the NSTM in the future. Therefore, further research needs to focus on understanding the factors influencing domestic water consumption and developing a prediction model for the NSTM. This will help assess the future trends in water supply and demand, provide a scientific basis for regional sustainable development, and offer policy suggestions to promote coordinated economic and environmental development in the region.

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