GIS Based Analysis of Land Use Dynamics in Bishkek

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Abstract
Residents of urban areas experience a variety of difficulties as a result of intensive urbanization, including clogged infrastructure, air pollution, and waste management. Preservation of green spaces provides a vital role in maintaining at least a minimum natural balance for residents of urban area. Maintaining and preserving the sustainable development of infrastructure is an important element of urban planning. City planners thus face a difficulty in providing urban dwellers with efficient and sustainable green spaces. Growing problems in the field of land use and landscaping of urban areas require an operational assessment of the existing situation. GIS technology offers a powerful tool for assessing these issues and developing solutions for sustainable urban development. A GIS-based land use assessment can provide valuable information on the distribution of urban land use types, which can help identify areas of high land use intensity and potential for urban green space development. The use of satellite imagery and other methods can help track changes in land-use patterns over time, which can inform urban planning and decision-making processes. Based on GIS analysis and remote sensing, an assessment was made of changes in territories and the distribution of green spaces in 4 urban districts of Bishkek. These changes were assessed using LANDSAT 4-5, LANDSAT-7, LANDSAT-8 and Sentinel-2 imagery. The evaluation category included such areas as: parks, squares and street trees. Areas with a level of green space coverage for different parts of the city were identified by utilizing GIS technology to analyze the spatial structures of green spaces. The spatial analysis also made it possible to identify priority areas for the development of new green spaces. For this study, we selected all 'green' areas within the city of Bishkek. The southern region of the city is the most interesting from the perspective of how the fabric of the city has altered as a result of the elimination of green spaces. This territory was originally designed taking into account the zone of influence of the Issyk-Ata tectonic fault and developed to achieve and comply with certain seismological standards. Our study thus explores the characteristics of the growth of the city of Bishkek over the previous few decades by providing information on the distribution of land use types and green areas.

Keywords: GIS, Landsat, Sentinel, NDVI, Bishkek and land Use

1. Introduction

Bishkek, the capital of the Kyrgyz Republic, experiences rapid growth with a high demographic density similar to all the other cities of the Central Asian Republics. Due to the dynamic growth of the urban population, the city faces major environmental problems such as lack of park areas, lack of water bodies, congestion of roads and solid waste management. Bishkek is the capital of the Kyrgyz Republic with a population of more than 1,145 million people [1].

In the Kyrgyz Republic, natural and historical processes and established cultural and traditional features influenced the formation of a specific form of urbanization. It differs from the classical type by a relatively short historical period of about 100-150 years (excluding ancient fortresses, mausoleums and caravan trading posts). This distinguishes urbanization in the Kyrgyz Republic from worldwide urbanization processes, the continuity of which has a thousand-year history.

In the last twenty years, the pace of urbanization has become spontaneous, around large cities (Bishkek, Osh, etc.) grew so-called "new buildings", built up with low-rise houses without appropriate infrastructure, which significantly worsened the sanitary-epidemiological and environmental situation [2]. The strategic development of Bishkek as the capital of the country and a major agglomeration is inseparably linked to the overall course of urbanization processes, and this indicator for the metropolitan region should be indicative and sustainable.

As was reflected in the concept of long-term urban development of the settlement system of the Chui region and Bishkek city itself for the period up to 2025, which provides for integrated sustainable environmental and economic development of architectural and planning structure of the urbanization system of Bishkek agglomeration as an area of influence with the core of Bishkek on other subsystems of agglomeration impact. In the 1940ies, evacuated enterprises were placed in Frunze and new industrial facilities were built, which influenced the sprawl of the city, a series of expansion projects appeared. In 1970, a new master plan of Frunze was approved, the development of the city went within the framework of the approved programs until the collapse of the Soviet Union and the formation of an independent state in 1991 and the renaming of the capital the city of Bishkek [2].

For the first time after independence, only in 2006, a new Bishkek Master Plan was developed and built until 2025, where the boundaries of the city, prospective areas of construction and vector of agglomeration development were approved [3]. Analysis of statistical data enables to assess the dynamics of changes in the areas of green spaces within Bishkek for the 60-year period. As can be seen, from 1940 to 1975 the area occupied by green spaces continuously increased, and by 1975 amounted to 1469 hectares. In the next 10 years (1975 - 1985) there was a sharp reduction in the area of green spaces to 1050 hectares. Subsequently, the area of green spaces changed little, and first in 2000 there was a sharp reduction to 856 hectares.

According to Kyrgyz State Design Institute of Urban Planning and Architecture, the area of green spaces is about 500 to 600 hectares. A sharp reduction in the area of green spaces is associated with their displacement as a result of the construction of buildings and structures on the territory of Bishkek. The level of green areas in the total balance of the territory of the city has reached a catastrophic figure - 28.44% in all categories of plantings, which is almost two times lower than necessary (40 - 50%) to ensure normal sanitary and hygienic conditions. There is a decline in the provision of public plantations due to the growth of the population, the lack of new plantings and the loss of existing ones. This indicator was 17.96 m^2/per person on January 1st, 1997, however it was just 11 m^2/per person on January 1st, 2005. The area of green spaces per citizen in the last decade decreased from 78 to 68 m^2. Since 2014, 479 hectares of plantations have disappeared in Bishkek, and only 250 hectares have been added. Now the city has only 9 percent of its territory covered by green spaces, although the global recommendation is 40 percent [4] and [5]. The quality of life in cities is greatly influenced by the availability of attractive and easily accessible green places; they are essential for recreation and for mental and health recovery. In urban areas, green spaces play a critical role in maintaining quality of life.

Residents' access to parks and open spaces is a major factor in the livability of the city itself [6] [7] and [8]. Little attention has been paid to the natural environment close to where people live and work, although it has been demonstrated time and again that green spaces are extremely beneficial to citizens [9]. The planning and management of green spaces is a complex task, especially in urban areas with a dynamic population density [10]. Intensive urbanization in developing countries is characterized by the absorption of agricultural land, a process of rapid land use change. This process poses a serious challenge for balanced and sustainable growth planning and expansion of urban centers [11] [12] and [13]. Currently, in Bishkek there are 3.5m^2 of green space per capita, and by world standards should be 21m^2, that is, less than the put in 7 times, although this figure in 1997 for Bishkek was 17.9 m^2/person, which was a total decrease of 5 times over a 25-year period [14].

2. Method

Urban greening is an important aspect of sustainable urban development, aiming to improve the quality of life in cities by incorporating vegetation and green spaces. GIS (Geographic Information Systems) offers a powerful tool for assessing urban greening problems and understanding their spatial characteristics [15]. This paper will explore the application of GIS to assess urban green space problems, highlighting its importance in solving problems and promoting sustainable urban development.

3. Study Area

Bishkek is a major city and the economic capital of the Kyrgyz Republic. Bishkek is the capital and economic as well as population center of Kyrgyzstan, and the city produces about 50% of the country's total gross domestic product (GDP). Its significant economic importance is primarily due to internal migration and its important geographical position. The current estimated population of the city is about 1,145,000 people with a density of about 4600 people per km^2 (Figure 1).

The population growth rate in Bishkek was approximately 90% from 1990 to 2023, and the population grew from 653,000 to 1.15 million in that period. According to the statistical data the population of the city in these little over 30 years has increased by about 60%, and thus in 2025 will reach 1,2 million inhabitants (Figure 2). However, according to unofficial sources, the city's population has long exceeded 1.5 million residents.

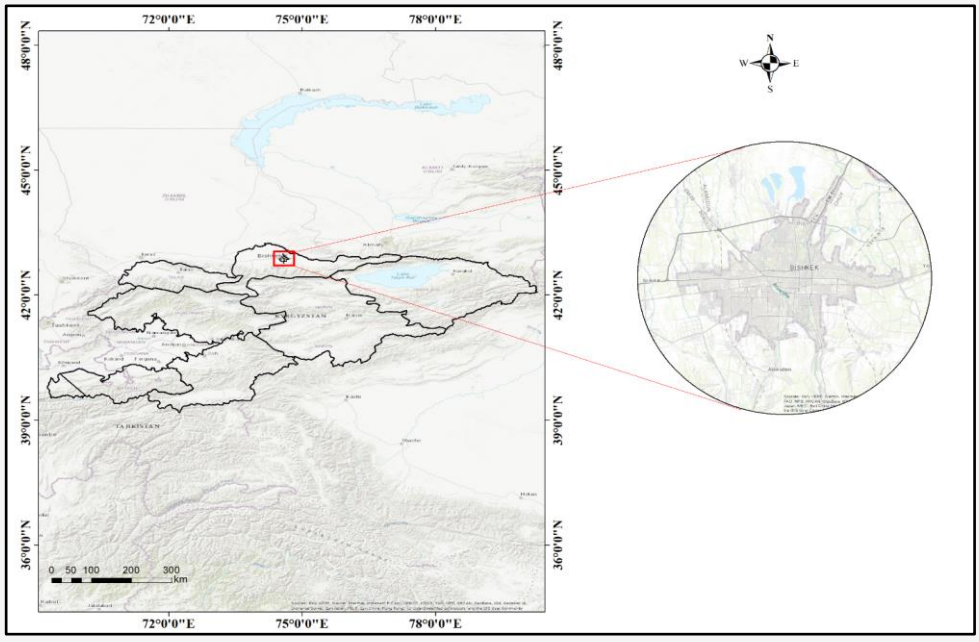

Figure 1: The location of Bishkek city

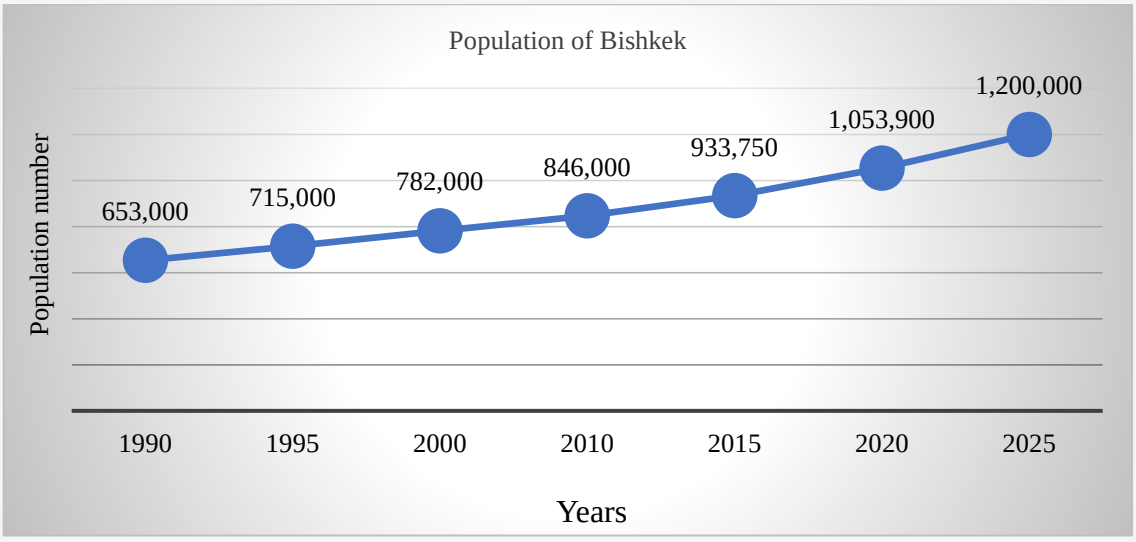

Figure 2: Bishkek population dynamics [1]

4. Results

4.1 Assessment of Land Use Dynamics

We assessed the dynamics of changes in the territory of Bishkek using remote sensing. To perform this task, we used Landsat 4-5; Landsat 7; Landsat 8 and Sentinel-2 satellite images for the last 30 years. As the diagram shows the area of Bishkek in 1990 was 137 km^2, and then increased to 232 km^2 by 2020 and according to master plan Bishkek area will increase to 300 km^2 by 2025 (Figure 3).

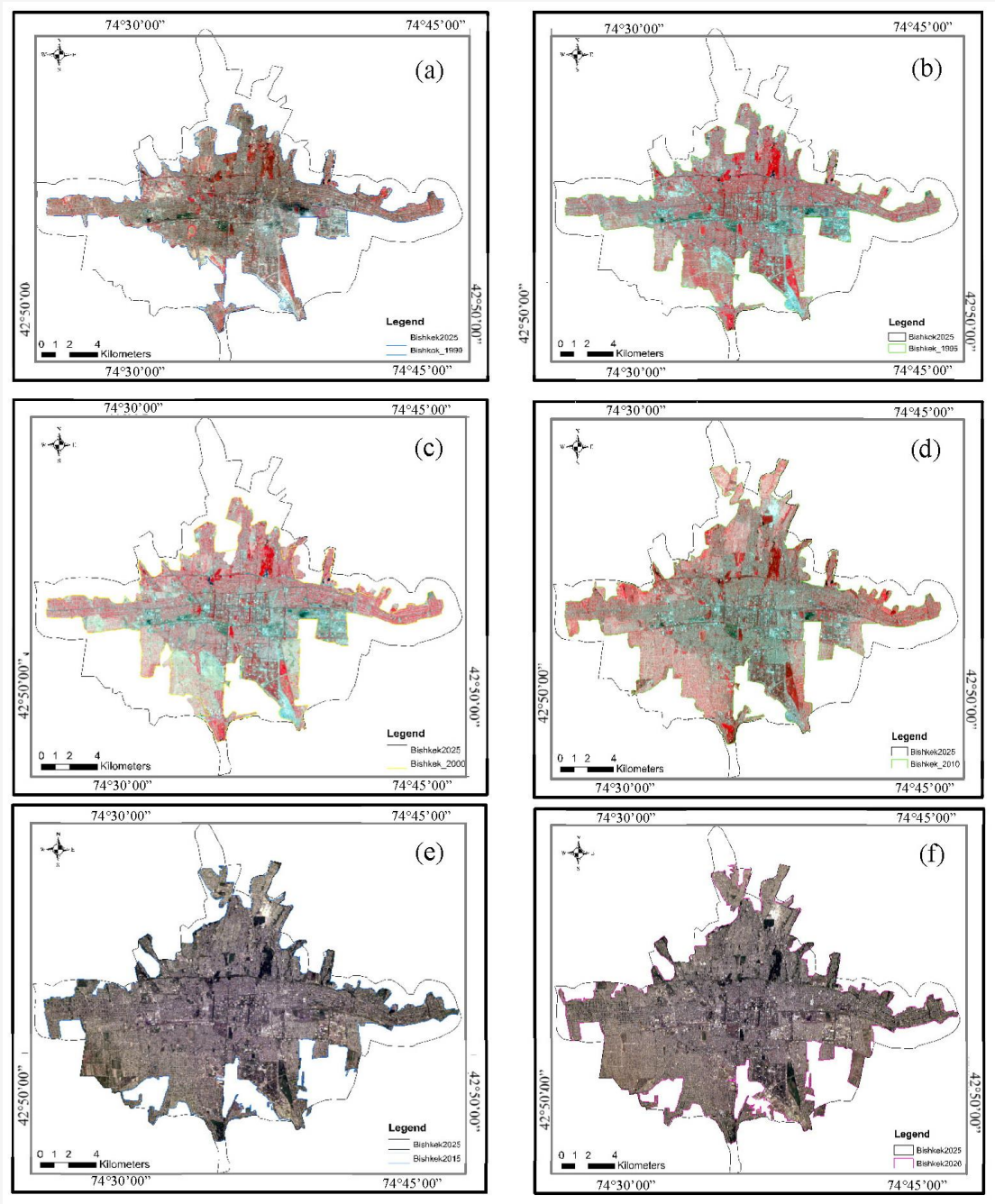

Figure 3: The dynamics of Bishkek territory changes from (a) 1990, (b) 1995, (c) 2000, (d) 2010, (e) 2015, (f) 2020. The black polygon is the Bishkek planning borders according to general plan of Bishkek administration by 2025

The territory of the city during this period has expanded mainly due to the development of adjacent areas, or more precisely due to the transformation of agricultural land of Alamedin and Sokuluk districts. In general, the city has expanded along the entire perimeter of the inherited territory since 1990. However, the development of the territories of the southwestern part of the city occurred at a faster pace (Figure 3). The rate of expansion of the urban area has varied with varying degrees of intensity and these expansions have varied between 3.1 % and 18.0 % between 1990 and 2020. However, the latest version of the city's Master Plan promises an even more dynamic rate of urban expansion by 2025, where it will reach up to 22%. The rate of population growth and urban expansion are shown in (Figure 4 and Figure 5).

4.2 NDVI

One of the main applications of GIS in assessing urban greening problems is identifying and mapping areas with low vegetation cover or limited green spaces [16] [17] [18] and [19].

Satellite images were utilized to investigate the expansion dynamics of Bishkek city through the application of INDVI and GIS analysis. LANDSAT 4-5, LANDSAT-7, LANDSAT-8 and Sentinel-2 images and a GIS tool was used to assess the dynamics of the area and its vegetation cover. This information also provides a visual representation of areas requiring intervention to improve greening. In order to analyze the ratio of green space to building area, we used the well-known NDVI evaluation method. For the clearest result, the decision was made to reduce the percentage of cloud cover, which in this result does not exceed 10%. Consequently, 1990, 1995, 2000, 2010,2015 and 2020 were chosen as the years in which the clearest images were taken (Table 1). The NDVI analyses were conducted over six observation times, encompassing time intervals of every five years, exc ept for the period between 2000 and 2010. Unfortunately, we were unable to find a reliable image for the year 2005 during that timeframe. In general, this analysis includes the period from 1990 to 2020 (Figure 6).

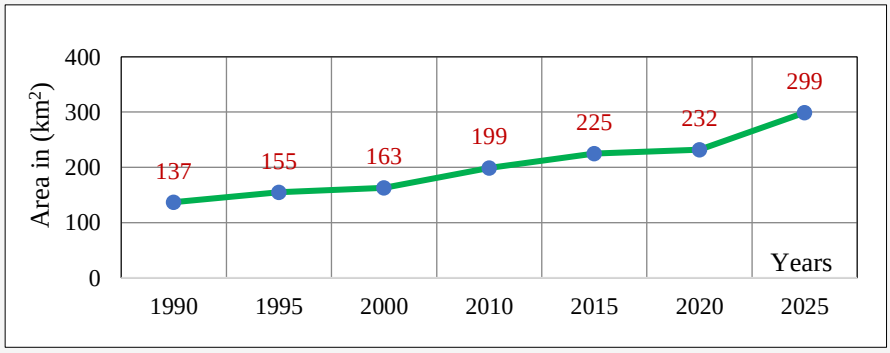

Figure 4: Dynamics of growth of the territory of the city of Bishkek

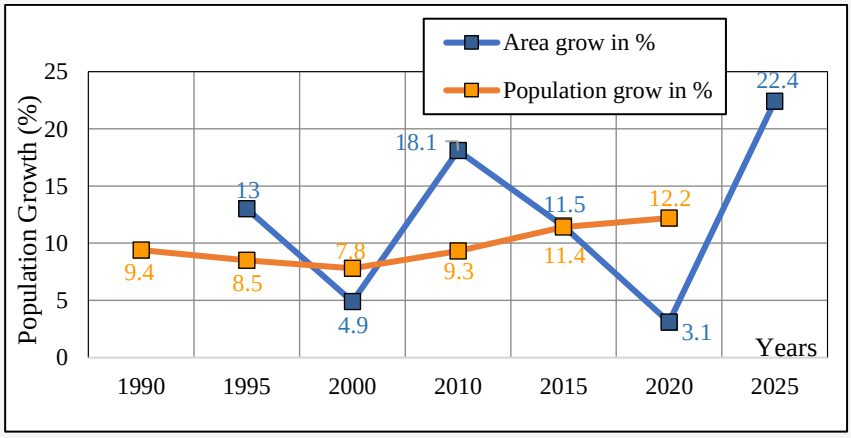

Figure 5: Bishkek city area and population growth dynamics between 1990 – 2025 and 1990-2020 respectively

Table 1: Satellite imagery acquisition dates

Acquisition date: (YYYY:MM:DD)	1990/03/30	1995/05/15	2000/07/07	2010/04/22	2015/05/06	2020/06/04
Satellite	Landsat 4-5	Landsat 7	Landsat 7	Landsat 5	Landsat 8	Landsat 8
Max. Cloud cover (%)	10	10	10	10	10	10

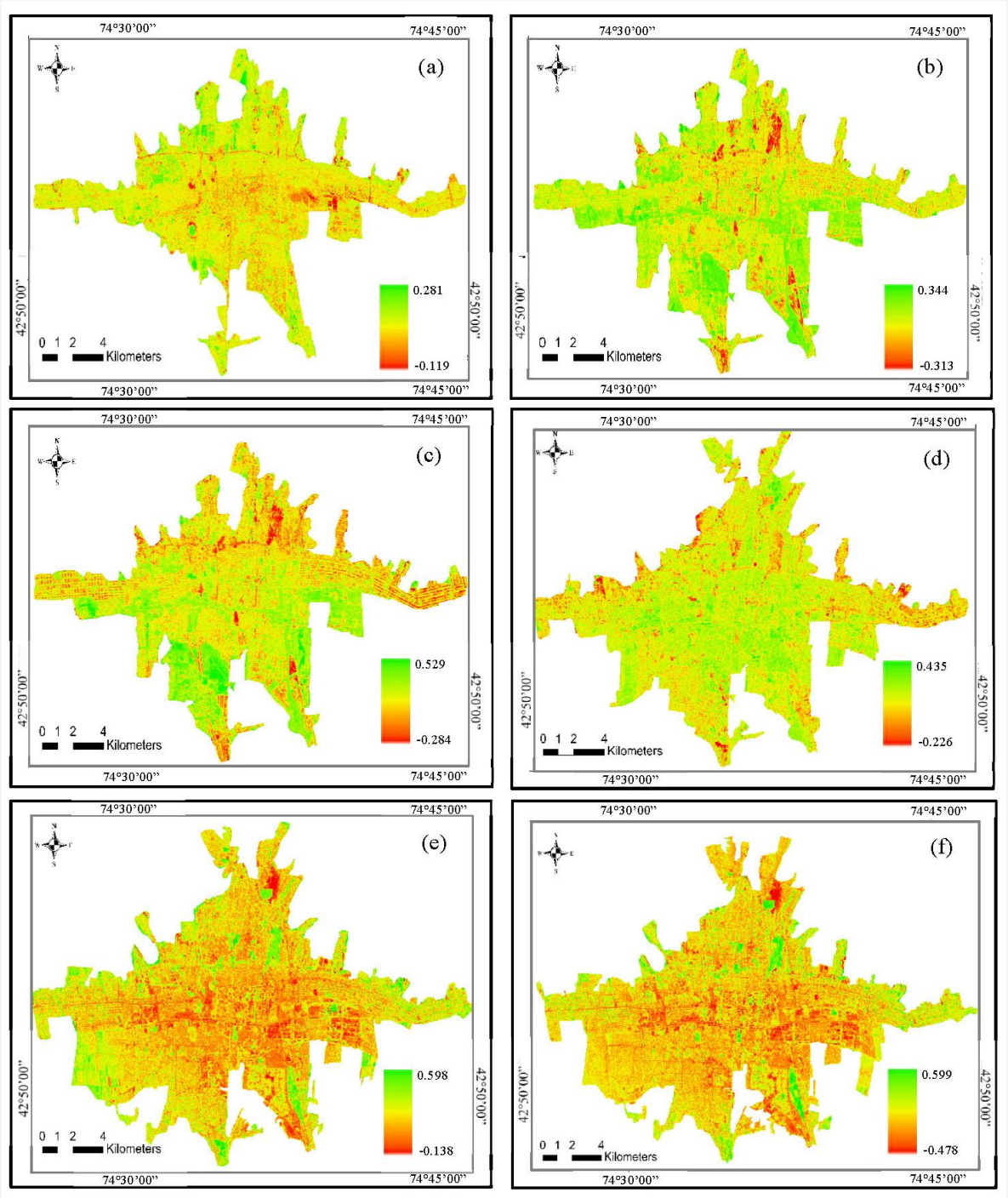

Figure 6: NDVI analysis result of Bishkek for different time (a) 1990, (b) 1995, (c) 2000, (d) 2010, (e) 2010, (f) 2020

Additionally, we conducted an analysis to examine the land use dynamics in Bishkek using NDVI analysis. This approach enabled us to identify and visualize vegetation-covered areas on the map, as well as detect any unusual changes that occurred over time. In the period 1990-1995, the vegetation of the city shows some anomalous areas with unhealthy green spaces. According to the analysis in 1995, anomalous areas are observed mainly in the park areas.

Beginning in 2000, the areas with green areas tended to deteriorate as the adjacent areas were taken over by private construction. The last two images from 2015 and 2020 show a sharp deterioration of the vegetation cover along the entire perimeter of the city. While in the early and mid-1990s we could observe some anomalous areas of unhealthy background vegetation, over the past ten years we have seen a widespread reduction in both adjoining and inner-city areas. Thus, during these 30 years, the Bishkek city administration has struggled to maintain the integrity of parks located only in the central part of the city, while in other parts of the city park areas have undergone severe changes.

4.3 Mapping of Parks

Currently, there is an intensive process of degradation of all large and medium-sized park and forest-park zones. Forest parks and groves are almost completely given up for individual housing construction, the remaining forest park areas are slowly degrading. The park areas in Bishkek have been gradually decreasing each year as a result of land extraction for construction purposes. One specific example is Ata-Turk Park and its surrounding areas, which have experienced significant reduction since 2004. In 2005, the park's territory, including the adjacent southern zone, was estimated to be approximately 350 hectares. However, by 2010, the park had significantly diminished in size, shrinking to only 131 hectares. Furthermore, based on digital images, it was observed that the park's territory experienced an additional reduction of 10 hectares in 2022. As a result, the current size of the park is estimated to be 121 hectares.

The same situation is observed with Elm Grove Park at the beginning of 2005, the total area of the park was 253 hectares in 2009, and in 2020 the park area was reduced by another 10 hectares according to digital surveys, so the current size is 121 hectares. The same situation is observed with Elm Grove Park - at the beginning of 2005, the total area of the park was 253 hectares in 2009, and in 2020 the park was reduced to 150 hectares. The contours illustrating the reduction of the aforementioned parks can be seen in (Figure 7 and Figure 8).

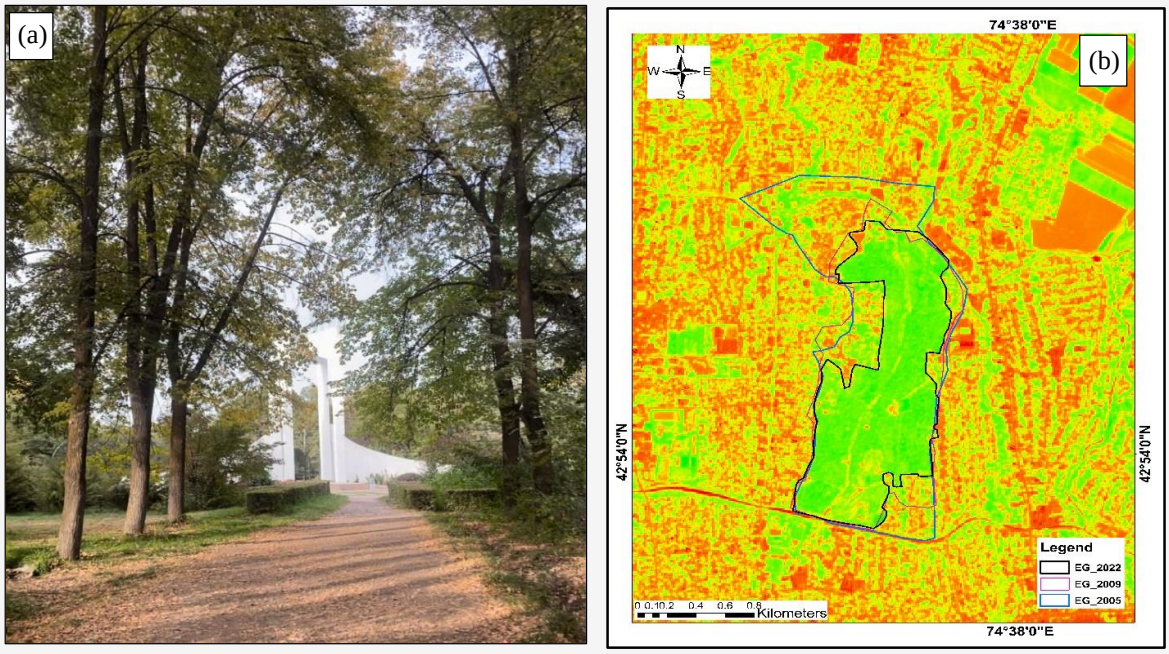

Figure 7: (a) Elm Grove Park which is located in northern part of city and (b) Elm Grove Park area shrinkage map-scheme for over different periods of time

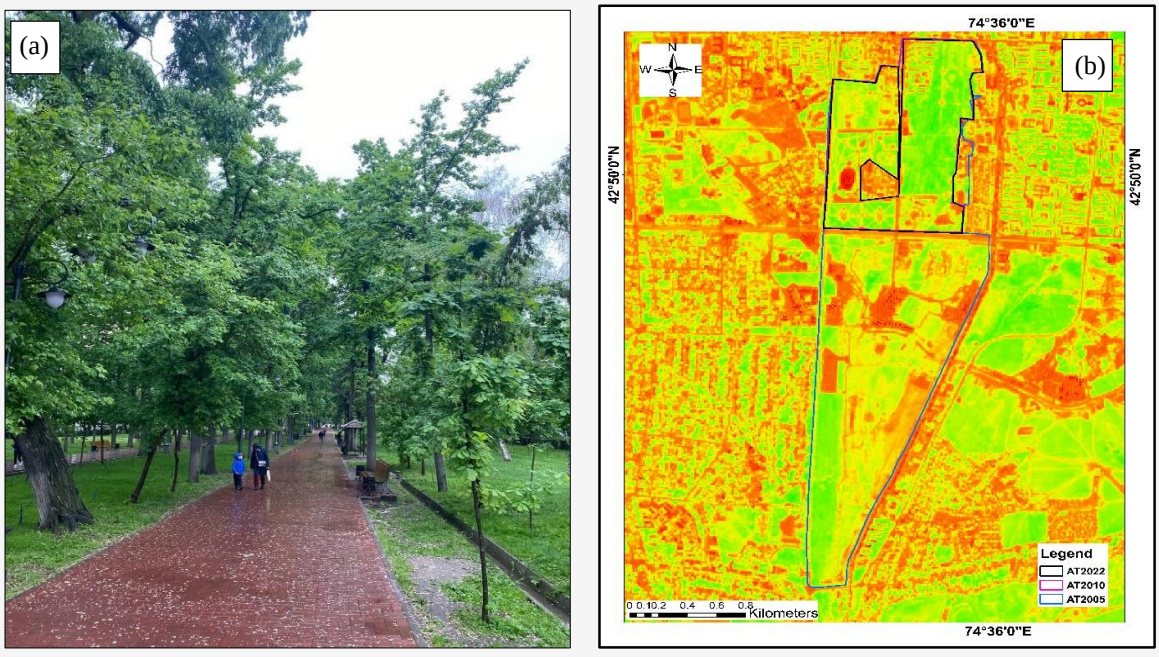

Figure 8: (a) Ata-Turk formerly (Park Pobeda) which located in southern part city and (b) Ataturk Park territory changing graph

5. Discussion

Based on the obtained data and the study's results, it is evident that the urbanization trends affecting cities in the Central Asian region exhibit distinct characteristics and share common developmental challenges. Similar patterns were particularly prevalent in these cities immediately after independence due to economic challenges, a lack of funding for balanced city growth, and "false" urbanization, which in some cases led to urban sprawl and violated the natural, architectural, and environmental framework of cities and capitals generally. It has been studied for 10–20 years, but only in the last 10 have many Central Asian nations taken steps to optimize buildings and revitalize the appearance of their cities.

Our investigation is primarily focused on the growth of the capital of Kyrgyzstan because this tendency could not have gone unnoticed in the city of Bishkek, leading to haphazard developments throughout the city. Alongside the positive growth dynamics of the city of Bishkek, including increased land use and population growth, there are also challenges in terms of urban development, particularly in the new suburban areas. Within the city itself, there is intensive construction and increased building density, which leads to a disruption of solar insolation, air circulation, and the formation of active smog zones. Separate results showed that the specific types of land use in the five capitals of the Central Asian Republics are related to the natural landscape conditions around the cities. In general, pastures, unused land and cultivated land are prevalent around these capitals. Water and unused land are the landscape characteristics that shifted dramatically, whereas the extent of land under development has consistently increased [20] [21] [22] and [23].

6. Conclusion

Insufficient greenery: Our analysis has revealed a lack of greenery in the urban structure of Bishkek due to dense construction. The research results indicate that over the past 30 years, the city's territory has increased from 137km^2 to 230km^2. The population increased from 635,000 in 1990 to 1.15 million in 2023, and this growth is anticipated to continue as the city continues to spread out along the foothill plain and adds new residents each year. The city is characterized by high building density and limited open spaces allocated for parks, gardens, and recreational areas. This trend is particularly noticeable in the central and southern parts of the city. This lack negatively impacts the city's livability since greenery plays a crucial role in providing environmental benefits such as improving air quality and regulating temperature. Insufficient forest cover: Our assessment has shown a low percentage of green cover in Bishkek. Trees are essential for improving the urban environment as they provide shade, absorb pollutants, and mitigate the urban heat island effect.

The lack of sufficient forest cover exacerbates problems related to air pollution, urban heat, and overall aesthetic appeal. In Bishkek, there is an unequal distribution of vegetation, according to our data. Central city districts have better access to parks and green areas than the periphery and residential areas, particularly in the western and eastern parts of the city. This inequality limits the fair distribution of ecological benefits, affecting the quality of life for residents in less green areas.

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