# Bioclimatic Conditions of the Classic Tourist Route Tashkent-Samarkand-Bukhara-Khiva in Uzbekistan

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*Abstract:* - This article is devoted to assessing the bioclimatic conditions of the most popular route among foreign tourists in Uzbekistan – Tashkent-Samarkand-Bukhara-Khiva based on statistical processing of meteorological observation data for the period 2011-2020 and the use of the thermohygrometric coefficient of air dryness (THC) and Missenard's Effective Temperature (ET). Climatic descriptions of the cities of Tashkent, Samarkand, Bukhara, and Khiva include information on the regime of air temperature, precipitation, air humidity, and cloudiness, which were used to compile the Climate-Tourism-Information-Scheme (CTIS). The results obtained show that in the cities under study, there are two seasons with the most favorable thermal comfort conditions throughout the year. In Tashkent, these are the periods April-May and September-first ten days of November, in Samarkand – March-June and September-October, in Bukhara – April-May and September-October, and Khiva – from the second ten days of April to June and from the third ten days of August to the second ten days of October.

*Key-Words:* - tourism, bioclimate, thermal sensation, index, Uzbekistan, Tashkent, Samarkand, Bukhara, Khiva.

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## 1 Introduction

Information about the nature of weather and climatic conditions is usually presented using bioclimatic indices. The assessment of bioclimatic and meteorological conditions is carried out using such basic parameters as air temperature, air humidity, wind, intensity, and duration of sunshine. In addition, it should take into account the number of wet days, the amount of precipitation, as well as weather phenomena such as fog, thunderstorms, dust storms, and others. From a tourism perspective, knowing these conditions will help people choose the best time to travel based on their individual needs and circumstances.

A large number of scientific works devoted to the research of bioclimatic conditions for the use of tourism purposes have been published worldwide, [1], [2]. During the last hundred years, "empirical indices" and "rational indices" have been widely used in these scientific works to assess the comfort conditions for the human body. "Empirical indices" include Effective Temperature (ET), [3], Tmperature-Humidity Index (THI), [4], Wind Exposure Index (WEI), [5] and numerous other indices that describe the subjective feelings or physiological reactions of the human body. "Rational indices" are based on specific calculation models, such as Tourism Climate Index (TCI), [6], Physiological Equivalent Temperature (PET), [7], Climate Index for Tourism (CIT), [8], Universal Thermal Climate Index (UTCI), [9] and consists of a group of other indicators. A detailed comparative analysis of bioclimatic indices is given in, [1], [2], [10], [11], [12], [13], [14].

Most of the bioclimatic indices used in the world are insufficient to fully characterize existing bioclimatic conditions, [1], [2]. In this regard, the most effective for characterizing bioclimatic conditions are the UTCI and PET indices, which take into account the thermophysiological state of the human body. UTCI and PET have been successfully applied by several researchers for the climatic conditions of various countries in Europe, Asia, Australia and Africa, [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28]. However, because their calculation is based on the value of radiant temperature, the possibility of their use in the conditions of Uzbekistan is limited due to the lack of measuring instruments of this kind in the meteorological observation network. Taking into account this circumstance, in this work, the assessment of bioclimatic conditions was carried out based on two empirical indices: the new bioclimatic index – thermohygrometric coefficient of air dryness (THC), proposed by Uzbek scientists, [29] and ET, [30].

Uzbekistan, with the peculiarities of its geographical location and relief, climatic conditions, the wealth of natural, historical-cultural, and tourist-recreational potentials, objectively has all the prerequisites for the intensive development of domestic and foreign tourism. Acquaintance with the listed tourism potential usually takes place outdoors. In this case, weather has a huge impact on the physiological state of a person. First of all, this is thermal comfort, i.e. a condition in which as much heat is removed from a person as his body produces. In other words, a person does not feel either cold or overheating. The climate in general and its biometeorological characteristics are one of the most important resources for the development of tourism, which should be included in tourism promotions. In this regard, it is necessary to have accurate bioclimatic information, which is very useful for improving the quality of tourism services. Thus, tourism, as one of the main sectors of the world economy, is influenced by weather and climate. From this point of view, weather and climate should be considered as a limiting and developing factor for tourism.

As a result of our search for a climatic and, especially, bioclimatic description of the territory of Uzbekistan, in addition to our recent study, [31], we found the work, [32]. It examines the bioclimatic comfort conditions of the Fergana Valley using the TCI index. This circumstance prompted the authors to carry out a study that, to a small extent, fills the existing gap.

This paper presents the results of an assessment of the bioclimatic conditions of the capital of Uzbekistan, Tashkent city, and the world-famous tourist destinations of Uzbekistan – the cities of Samarkand, Bukhara, and Khiva. We hope that the article will be useful for both domestic and foreign tourists visiting these tourist destinations.

# 2 Study Area and Data Used

## 2.1 Description of the Study Objects

Uzbekistan is located in the central part of Central Asia, mainly between Amudarya and Syrdarya. The northernmost point of Uzbekistan is located at lat 45° 36′N north-east of the Ustyurt plateau. The southernmost point is near the city of Termiz, on the banks of the Amudarya at lat 37° 11′ N. The westernmost point is on the Ustyurt plateau at long 56° 00′ E. The easternmost point is in the eastern part of the Fergana Valley at 73° 10′ E. The distance between Uzbekistan's most northern and southernmost points is 925 km, and the distance between the most western and eastern points is 1400 km (Figure 1).

Uzbekistan is bordered by Kazakhstan to the northwest and north, Kyrgyzstan and Tajikistan to the east and southeast, Afghanistan to the south, and Turkmenistan to the southwest. The Republic of Karakalpakstan is located in the western part of the country.

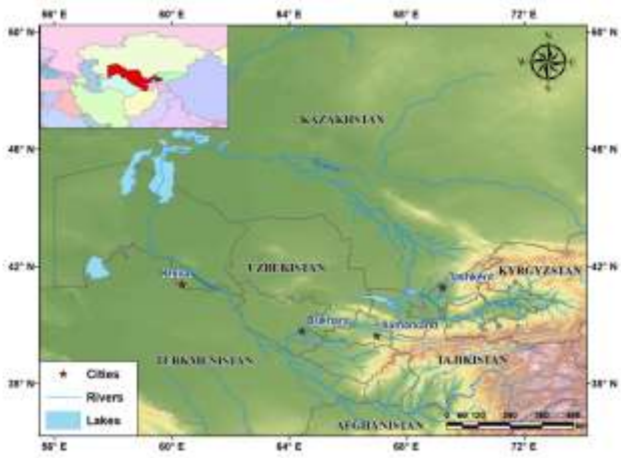

Fig. 1: Location of research objects

Uzbekistan has favorable natural and geographical conditions, and its territory consists of lowlands and mountain reliefs. A large part of the territory of Uzbekistan (about 4/5) is made up of lowlands. The most important of them is the Turan Plain. The Tien-Shan and Pamir mountain ranges are located in the east and northeast of the country (the highest point of the country is 4643 m). One of the largest deserts in the world – Kizilkum lies in the center of the territory of Uzbekistan, [33].

The territory of Uzbekistan is located in two climatic zones – the southern part of the temperate zone and the northern arid part of the subtropical zone. It consists of a desert region in the temperate climate zone, and a subtropical desert region in the subtropical zone. In Uzbekistan, the presence of natural latitude zones and corresponding height regions within the class of plain landscapes in the territory of the country includes desert (temperate, subtropical) and oasis, foothills and mountain class, stag deserts, mountain steppes, mountain-forest steppes, mountain meadows, mountain forests, mountain tundras, glacial-naval landscape types can be distinguished, [33].

There are more than 9,600 cultural objects in the country. More than 7,300 of them are ancient architectural and archeological objects, 200 of which are included in the list of UNESCO's World Cultural Heritage. Most of them are located in the cities of Samarkand, Bukhara, Khiva, Shakhrisabz, Termez, and Kakand.

Samarkand, one of the ancient cities of Uzbekistan, is more than 2750 years old. It is equal to the city of Rome, one of the oldest cities in the world, [34].

## 2.2 Datasets

To carry out the research, we used daily 8-time observations in local time from the weather stations Tashkent-Observatory, Samarkand, Bukhara, and Khiva. These observations covered 10 years (2011-2020) and were obtained from the meteorological archive of the Agency of Hydrometeorological Service of the Republic of Uzbekistan. The data observed include air temperature, precipitation, vapor pressure (VP), relative humidity (RH), dew point ($\tau$), wind speed, and cloudiness. In addition, climate norms were used for the indicated weather stations for the periods 1961-1990, 1971-2000, 1981-2010, and 1991-2020 were used, [35], [36], [37], [38]. These data served as the basis for climatic descriptions of the cities of Tashkent, Samarkand, Bukhara, and Khiva. These results were also used in the compilation of the CTIS.

# 3 Methods

Statistical processing of meteorological quantities was carried out using standard methods recommended by the World Meteorological Organization (WMO), [39].

The assessment of the conditions of thermal sensation was carried out based on THC, which expresses the simultaneous influence of temperature and air humidity, [29], [31]:

$$K = \frac{T-\tau}{T} = \frac{\Delta}{T}, \tag{1}$$

Where:
$T$ – air temperature (Kelvin), $\tau$ – dew point, $\Delta$ – dew point deficit.

Being a dimensionless quantity, this coefficient shows how far water vapor is from the state of saturation for a given content and at a given air temperature. To identify the role of changes in air temperature and humidity in the change in THC, we take the logarithm and then differentiate equation (1), and move on to finite differences.

$$\ln K = \ln\left(\frac{T-\tau}{T}\right),$$

$$\ln K = \ln(T-\tau) - \ln(T),$$

$$\frac{dK}{K} = \frac{dT - d\tau}{T-\tau} - \frac{dT}{K},$$

$$\frac{dK}{K} = \frac{\tau dT - T d\tau}{T(T-\tau)},$$

$$\frac{dK}{K} = \frac{\tau dT}{T(T-\tau)} - \frac{d\tau}{T-\tau},$$

$$\left.\frac{\Delta K}{K}\right|_{T=const} = \frac{\Delta\tau}{T \quad \tau}, \qquad (2)$$

$$\left.\frac{\Delta K}{K}\right|_{\tau=const} = \frac{\tau\Delta T}{T(T \quad \tau)}. \qquad (3)$$

According to equation (2), an increase in moisture content at a constant air temperature reduces dryness. From equation (3) it follows that an increase in temperature in the case of constant moisture content leads to an increase in air dryness. As you know, not every combination of temperature and air humidity provides comfortable conditions. Each of these parameters can vary, and only within certain limits does the thermal sensation provide comfort conditions.

The nomogram categorizes human thermal sensations based on air temperature and THC into 6 distinct zones, [31], (Figure 2). This nomogram builds upon the framework proposed in, [40], which determines thermal sensation zones based on air temperature and RH. Zone 3 signifies conditions of thermal comfort for the human body, while zone 2 indicates adverse effects (pessimum) at low temperatures, and zones 4 and 5 at high temperatures. Zones 1 and 6 correspond to extremely unfavorable thermal conditions, where hypothermia can occur at low temperatures and heat stroke at high temperatures.

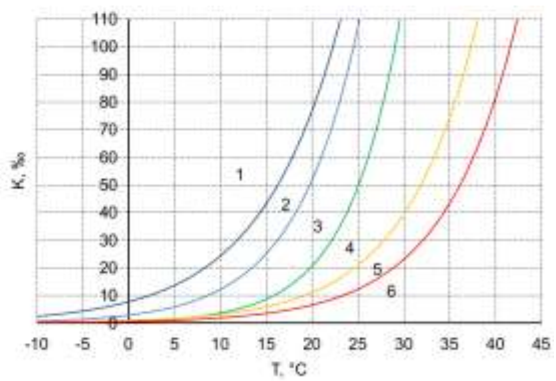


Fig. 2: Nomogram for determining zones of thermal sensations 1-6 – thermal sensation zones

Heat sensation zones according to THC are given in Table 1.

Table 1. THC zones of thermal sensations.

| THC zones | Thermal sensation |
|---|---|
| 1 | Very cold |
| 2 | Cold |
| 3 | Comfort |
| 4 | Relative comfort |
| 5 | Hot |
| 6 | Very hot |

In, [30], the following mathematical formulation for effective temperature developed:

$$ET = 37 - \frac{37-T}{0{,}68 - 0{,}0014RH + \frac{1}{1{,}76+1{,}4V^{0{,}75}}} - 0{,}29T \cdot \left(1 - \frac{RH}{1000}\right) \qquad (4)$$

Where:
$T$ – air temperature (Celsius), $RH$– relative humidity (%), $V$ – wind speed (m/s).

The index establishes a connection between the human body's thermoregulatory capacity (sensing warmth and cold) and the varying temperature and humidity of the surrounding environment. It enables the calculation of the perceived temperature experienced by the human body, based on meteorological parameters such as air temperature, relative humidity, and wind speed. These parameters impact the exchange of heat between the environment and the body. ET is still widely used in many countries of the world. The classification of heat sensation according to ET values is given in Table 2.

Table 2. Assessment scale of ET.

| ET, °C | | Thermal sensation |
|---|---|---|
| from | to | |
| >30 | | Heavy thermal load |
| 24 | 30 | Moderate heat load |
| 18 | 24 | Comfort - warm |
| 12 | 18 | Comfort - moderately warm |
| 6 | 12 | Cool |
| 0 | 6 | Moderately cool |
| 0 | -6 | Very cool |
| -6 | -12 | Moderately cold |
| -12 | -18 | Cold |
| -18 | -24 | Very cold |
| <-24 | | Risk of frostbite |

ET was used to compare the results obtained by THC.

Based on the calculated THC values, daily distributions of long-term average thermal sensation conditions for each month were identified. The approach given in, [41], made it possible to compile the Climate-Tourism-Information-Scheme (CTIS). CTIS, along with the conditions of thermal sensation, provides information about two other components – aesthetic and physical. In it, the conditions of thermal sensations are presented as follows: cold stress – corresponds to zone 1, thermal comfort – zone 3, and hot stress – zone 6. Aesthetic components inform about sunny days (cloudiness < 5 points) and foggy conditions (relative humidity > 93%), and the physical components are stuffiness (vapor pressure > 18 hPa), dry days (precipitation < 1 mm), rainy days (precipitation > 5 mm) and stormy conditions (wind speed > 8 m/s at the height of the weather vane). The CTIS we compiled differs from the scheme proposed in, [41] in that in our scheme the conditions of thermal sensations are presented based on THC in place of PET.

To facilitate tourists' understanding of CTIS, the scheme is presented in seven classes from "extremely unfavorable" to "ideal", which corresponds to a 14% probability for each class, [41].

# 4 Results

## 4.1 Climatic conditions of Tashkent, Samarkand, Bukhara and Khiva Cities

Data on long-term average air temperatures (Table 3) and precipitation amounts (Table 4) in the cities of Tashkent, Samarkand, Bukhara, and Khiva indicate the presence of significant changes, especially in the temperature regime, from period to period. Thus, if the long-term average annual temperature in Tashkent in the base climatic period (1961-1990) was 14.2°C, in the period 1971-2000 it decreased to 13.5°C, and in 1981-2010 it increased to 14.8°C. In the last 30-year period (1991-2020), the long-term average annual temperature increased to 15.1°C, and in the 10 years 2011-2020 it was 15.4°C.

Table 3. Long-term average air temperature (°C) in Tashkent, Samarkand, Bukhara and Khiva during periods 1961-1990 (1), 1971-2000 (2), 1981-2010 (3), 1991-2020 (4), 2011-2020 (5).

| City | Period | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tashkent | 1 | 0.6 | 2.5 | 8.5 | 15.4 | 20.3 | 25.6 | 27.6 | 25.5 | 20.0 | 13.3 | 7.8 | 3.4 | 14.2 |
| | 2 | -0.6 | 1.9 | 7.9 | 14.7 | 20.1 | 24.9 | 27.0 | 25.0 | 19.6 | 12.8 | 6.6 | 1.9 | 13.5 |
| | 3 | 1.9 | 3.9 | 9.4 | 15.5 | 20.5 | 25.8 | 27.8 | 26.2 | 20.6 | 13.8 | 8.5 | 3.5 | 14.8 |
| | 4 | 2.3 | 4.2 | 10.2 | 15.9 | 21.1 | 26.2 | 28.2 | 26.6 | 21.0 | 14.3 | 8.1 | 3.5 | 15.1 |
| | 5 | 3.2 | 3.8 | 10.6 | 16.1 | 22.0 | 26.6 | 28.7 | 27.1 | 21.7 | 14.5 | 7.5 | 3.3 | 15.4 |
| Samarkand | 1 | 0.6 | 2.2 | 7.7 | 14.4 | 19.4 | 24.5 | 26.2 | 24.2 | 19.2 | 12.7 | 7.4 | 3.4 | 13.5 |
| | 2 | 0.2 | 2.8 | 7.4 | 14.1 | 19.2 | 23.7 | 25.5 | 23.8 | 18.9 | 12.7 | 6.4 | 2.5 | 13.1 |
| | 3 | 1.9 | 3.6 | 8.5 | 14.8 | 19.8 | 25.0 | 26.8 | 25.2 | 20.2 | 13.6 | 8.4 | 3.8 | 14.3 |
| | 4 | 2.3 | 4.0 | 9.3 | 15.2 | 20.4 | 25.4 | 27.2 | 25.6 | 20.6 | 14.1 | 8.0 | 3.8 | 14.7 |
| | 5 | 3.3 | 3.5 | 9.9 | 15.3 | 21.5 | 26.1 | 27.8 | 26.1 | 21.3 | 14.3 | 7.4 | 3.5 | 15.0 |
| Bukhara | 1 | 0.1 | 2.6 | 8.7 | 16.6 | 22.5 | 27.3 | 28.8 | 26.0 | 20.2 | 13.1 | 7.3 | 2.5 | 14.6 |
| | 2 | 0.0 | 2.6 | 8.3 | 16.4 | 22.2 | 26.4 | 28.0 | 25.4 | 20.0 | 13.0 | 6.4 | 2.2 | 14.2 |
| | 3 | 1.4 | 4.0 | 9.7 | 17.0 | 22.8 | 28.1 | 29.5 | 27.2 | 21.2 | 14.2 | 8.1 | 2.8 | 15.5 |
| | 4 | 1.8 | 4.1 | 10.3 | 17.2 | 23.4 | 28.4 | 29.8 | 27.6 | 21.7 | 14.6 | 7.6 | 2.8 | 15.8 |
| | 5 | 2.5 | 3.4 | 10.6 | 16.9 | 24.1 | 28.8 | 30.0 | 27.8 | 22.3 | 14.7 | 7.2 | 2.5 | 15.9 |
| Khiva | 1 | -2.8 | -0.9 | 6.2 | 14.9 | 21.9 | 26.6 | 27.9 | 24.8 | 19.0 | 11.5 | 5.3 | -0.1 | 12.9 |
| | 2 | -3.7 | -1.0 | 5.6 | 14.7 | 21.7 | 26.0 | 27.6 | 25.0 | 19.1 | 11.8 | 4.1 | -1.6 | 12.4 |
| | 3 | -1.7 | 0.5 | 7.0 | 15.5 | 22.0 | 27.4 | 28.7 | 26.3 | 20.0 | 12.7 | 5.6 | 0.2 | 13.7 |
| | 4 | -1.4 | 0.7 | 7.9 | 15.9 | 22.7 | 27.9 | 29.2 | 26.7 | 20.4 | 13.1 | 5.2 | -0.1 | 14.0 |
| | 5 | -0.8 | -0.4 | 8.5 | 15.9 | 23.6 | 28.2 | 29.7 | 26.7 | 20.8 | 12.7 | 4.9 | 0.0 | 14.2 |

Table 4. Long-term average precipitation (mm) in Tashkent, Samarkand, Bukhara and Khiva during the periods 1961-1990 (1), 1971-2000 (2), 1981-2010 (3), 1991-2020 (4), 2011-2020 (5).

| City | Period | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tashkent | 1 | 54.5 | 46.8 | 72.3 | 63.6 | 32.0 | 7.1 | 3.5 | 2.0 | 4.5 | 34.1 | 45.0 | 53.4 | 418.8 |
| | 2 | 49.0 | 52.0 | 73.0 | 57.0 | 32.0 | 11.0 | 3.0 | 2.0 | 4.0 | 27.0 | 41.0 | 54.0 | 405.0 |
| | 3 | 53.3 | 63.8 | 70.2 | 62.3 | 41.5 | 14.3 | 4.5 | 1.3 | 6.0 | 24.7 | 43.9 | 58.9 | 444.7 |
| | 4 | 54.9 | 72.1 | 66.4 | 63.3 | 41.1 | 16.8 | 3.4 | 2.1 | 4.6 | 23.7 | 51.2 | 58.4 | 458.0 |
| | 5 | 55.1 | 74.2 | 74.9 | 59.9 | 34.4 | 17.0 | 0.9 | 1.9 | 3.8 | 31.4 | 58.8 | 51.7 | 464.0 |
| Samarkand | 1 | 43.9 | 39.2 | 70.5 | 63.2 | 33.2 | 4.0 | 4.3 | 0.4 | 3.8 | 24.0 | 28.2 | 40.5 | 355.2 |
| | 2 | 44.0 | 46.0 | 75.0 | 61.0 | 34.0 | 6.0 | 2.0 | 1.0 | 2.0 | 20.0 | 29.0 | 38.0 | 358.0 |
| | 3 | 41.2 | 46.4 | 68.8 | 60.5 | 36.3 | 6.1 | 3.7 | 1.2 | 3.5 | 16.8 | 33.9 | 47.0 | 365.4 |
| | 4 | 41.1 | 52.2 | 73.2 | 62.9 | 40.0 | 6.8 | 1.6 | 1.6 | 2.7 | 16.0 | 40.3 | 39.2 | 377.6 |
| | 5 | 33.6 | 57.8 | 77.1 | 54.0 | 28.9 | 7.4 | 0.7 | 0.4 | 2.2 | 20.6 | 42.8 | 27.1 | 352.7 |
| Bukhara | 1 | 19.3 | 17.8 | 29.7 | 23.1 | 8.7 | 1.0 | 1.1 | 0.3 | 0.5 | 4.8 | 11.9 | 19.0 | 137.2 |
| | 2 | 18.0 | 21.0 | 28.0 | 26.0 | 10.0 | 3.0 | 1.0 | 0.0 | 0.0 | 5.0 | 13.0 | 16.0 | 143.0 |
| | 3 | 19.1 | 18.9 | 29.5 | 20.1 | 12.4 | 1.8 | 0.7 | 0.2 | 1.0 | 2.0 | 12.0 | 17.3 | 135.0 |
| | 4 | 16.5 | 24.1 | 25.1 | 22.3 | 11.1 | 1.8 | 0.4 | 0.3 | 0.8 | 2.7 | 14.5 | 12.8 | 132.4 |
| | 5 | 13.9 | 33.3 | 31.0 | 18.7 | 6.1 | 0.5 | 0.2 | 0.1 | 0.2 | 5.7 | 17.7 | 10.0 | 137.3 |
| Khiva | 1 | 8.7 | 8.7 | 18.9 | 15.9 | 9.9 | 2.3 | 5.4 | 1.4 | 2.7 | 6.0 | 8.4 | 12.7 | 101.0 |
| | 2 | 9.0 | 12.0 | 22.0 | 15.0 | 9.0 | 3.0 | 3.0 | 1.0 | 2.0 | 5.0 | 8.0 | 11.0 | 100.0 |
| | 3 | 10.1 | 10.6 | 15.2 | 10.6 | 12.6 | 3.3 | 4.1 | 1.9 | 1.9 | 4.4 | 8.5 | 9.5 | 92.7 |
| | 4 | 9.3 | 9.6 | 12.8 | 11.0 | 10.7 | 3.8 | 0.9 | 0.8 | 1.6 | 3.9 | 8.2 | 8.1 | 80.7 |
| | 5 | 5.2 | 10.3 | 15.2 | 10.4 | 5.1 | 3.4 | 0.5 | 0.0 | 2.2 | 4.4 | 7.0 | 6.4 | 70.0 |

The same trend in air temperature occurs in Samarkand, Bukhara, and Khiva cities. The increase in long-term average annual temperature in the period 2011-2020 relative to the base climatic period (1961-1990) was 1.2°C in Tashkent, 1.5°C in Samarkand, and 1.3°C in Bukhara and Khiva.

In contrast to the temperature regime, there have been ambiguous changes in the precipitation regime. In Tashkent, in the period 2011-2020, there was more precipitation (464.0 mm) than in the base climate period (418.8 mm). In Samarkand and Bukhara, precipitation remained virtually unchanged, but in Khiva, it decreased by 31.0 mm.

Considering the WMO recommendation "While such short periods cannot be considered to be climatological standard normals or reference normals, they are still useful to many users, and in many cases, there will be benefits to calculating such averages operationally", [22], the study was carried out based on observations during the period 2011-2020.

In all the cities under study, intra-annual changes in air temperature and precipitation have a general trend inherent in the continental climate. January is the coldest and July is the hottest month of the year. The long-term average monthly temperature in January is 3.2°C in Tashkent, 3.3°C in Samarkand, 2.5°C in Bukhara, and -0.8°C in Khiva. In July, this figure is 28.7°C, 27.8°C, 30.0°C and 29.7°C, respectively. The bulk of precipitation falls in the cold half of the year. In Tashkent, from October to May more than 30.0 mm falls, from November to April more than 50.0 mm, and in February and March more than 70.0 mm of precipitation per month. In July, August, and September, Tashkent receives no more than 4.0 mm of precipitation per month. In Samarkand, more than 20.0 mm falls in the period from October to May, more than 30.0 mm in January, more than 40.0 mm in November, more than 50.0 mm in February and April, and about 80.0 mm in March. As in Tashkent, July-September is very dry here, during this period no more than 2.0 mm of precipitation falls per month. In Bukhara, the highest monthly precipitation, more than 30.0 mm, is observed in February and March. January, April, November, and December are characterized by monthly precipitation of 10-20 mm. In May and October, 5.0-6.0 mm of precipitation falls here, and from June to September there is less than 1.0 mm of precipitation. In Khiva, the wettest month is March, with about 15.0 mm of precipitation. In other months, except February and April, less than 10.0 mm of precipitation falls here, and in July and August, less than 1.0 mm of precipitation falls.

The intra-annual distribution of long-term average days with precipitation shows that in the winter, spring, and autumn seasons such days in Tashkent and Samarkand are within 2-3 days (Figure 3). However, in February the number of days with precipitation exceeds 3 days. In May and June, days with precipitation in these cities occur within about 1 day per decade. From July to September, the number of days with precipitation is less than 1 day per decade. In Tashkent, the period from the second ten days of October to the first ten days of May receives more than 10 mm per decade, and in Samarkand, such precipitation is observed from the second ten days of January to the second ten days of May, in the second ten days of November and the first two ten days of December. In Bukhara, during the year, the ten-day number of days with precipitation does not exceed 2 days, and in Khiva, precipitation falls even less often – the number of days with precipitation is no more than 1 day per decade. In Bukhara, precipitation of 10 mm per decade occurs only in February, in the third ten days of March, and in the second ten days of April. Khiva is characterized by the absence of precipitation of more than 10 mm in all decades of the year.

Long-term average values of VP and RH are shown in Figure 4. In all cities, high long-term monthly average values of VP are observed in the warm half of the year, and low values in the cold half of the year. In Tashkent, the lowest VP values are observed in December and January (5.3 hPa), and the highest in June – 12.7 hPa. In Samarkand, VP values in December and January are 5.6 hPa, and in July 13.6 hPa. In Bukhara in winter, the lowest VP value is observed in December – 5.4 hPa. The highest VP values here are lower than in Tashkent and Samarkand, and amount to 10.4 hPa in May, July, and August. The greatest fluctuation in VP is observed in Khiva. The lowest VP value is observed here in February – 4.7 hPa, and the highest in July – 17.1 hPa. Unlike VP, in the intra-annual variation RH has the greatest values in the winter months, and the smallest values in the summer season. From October to May in Tashkent, RH values fluctuate between 50-70%, and in the period June-September its values are 30-40%. In Samarkand, the period November-February is characterized by an RH of more than 70%, and March with a value of about 70%. In May and October, the RH values here are less than 60%, and in June-September about 40%. In the winter months in Bukhara, RH does not fall below 70%, and in March and November below 60%. April and October are characterized here with an RH of around 50%. In other months, the RH value does not exceed 40%, and in July it is 26%. During the period from November to February in Khiva, RH values vary between 70-80%. March, April, September, and October are characterized by RH in the range of 50-60%, and in the remaining months, RH is below 50% but does not fall below 40%.

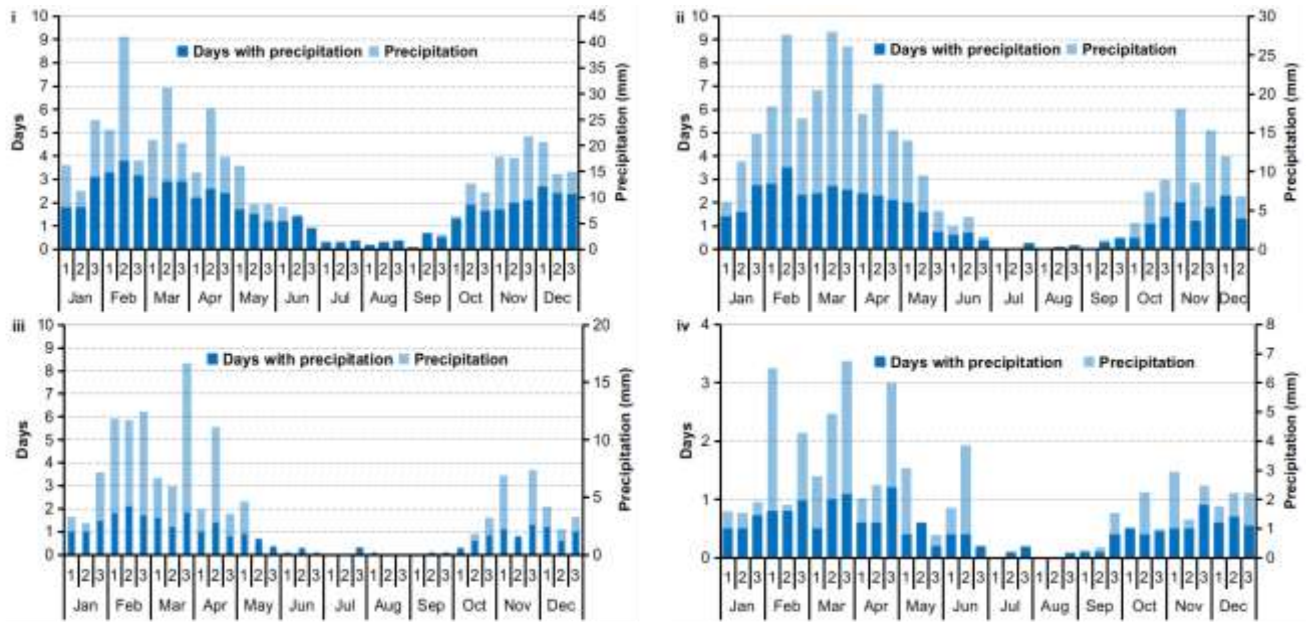


Fig. 3: Intra-annual change in long-term average days with precipitation and precipitation amount (R, mm) in the period 2011-2020
(i) Tashkent, (ii) Samarkand, (iii) Bukhara, (iv) Khiva

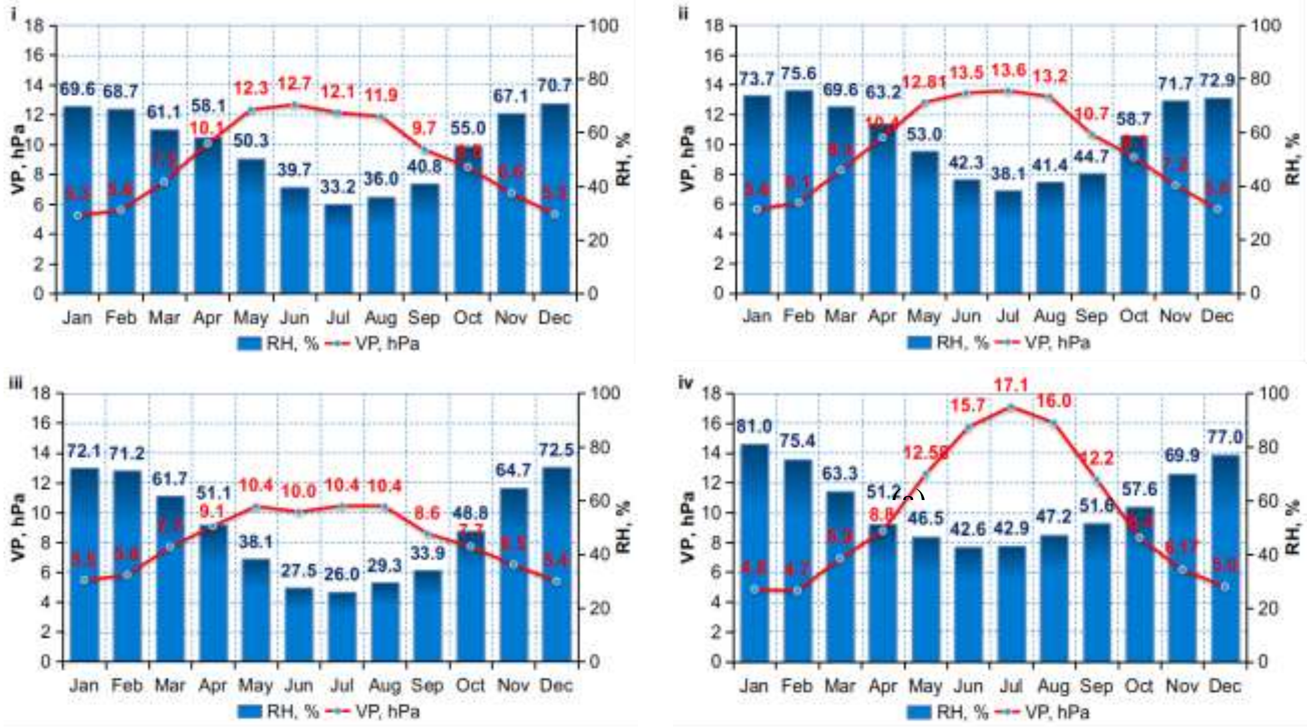


Fig. 4: Intra-annual change in average long-term values of vapor pressure (VP, hPa) and relative air humidity (RH, %) in the period 2011-2020
(i) Tashkent, (ii) Samarkand, (iii) Bukhara, (iv) Khiva

The intra-annual long-term average number of cloudy and clear days has an ambiguous distribution (Figure 5). In Tashkent and Samarkand, the number of days with cloudiness of more than 5 points is almost the same. From December to March, such days in a decade amount to 6 or more days. During this period, the number of clear days does not exceed 2-3 days. From April to the third ten days of May and from the first ten days of October to the end of November, cloudy days are 5-6 days per ten days. Starting from the third ten days of May, cloudy days decrease significantly. In the period July-September, the number of cloudy days per decade does not exceed 2 days, and in Samarkand, they are about 1 day. During this period, clear days in Tashkent are 5-6 days per decade, and in Samarkand – 7-6 days. Bukhara is characterized by cloudy days of no more than 3 days per decade throughout the year. During the periods March-April and October-November, such days do not exceed 1 day, and in June-September cloudy days are pragmatically not observed. The smallest number of clear days, about a day, are observed in the winter months, and in the summer season, the number of clear days does not fall below 9 days. In Khiva, from December to April, the number of cloudy and clear days has almost the same distribution. Their number is approximately 4-5 days per decade. Starting from April, the number of cloudy days decreases from 3-4 days per decade to 1 or fewer days in the period July-September, in which the number of clear days increases to 8-9 days per decade. Starting in October, the number of cloudy days begins to increase, and clear days decrease. During the period October-November, the number of clear days does not fall below 5 days per decade.

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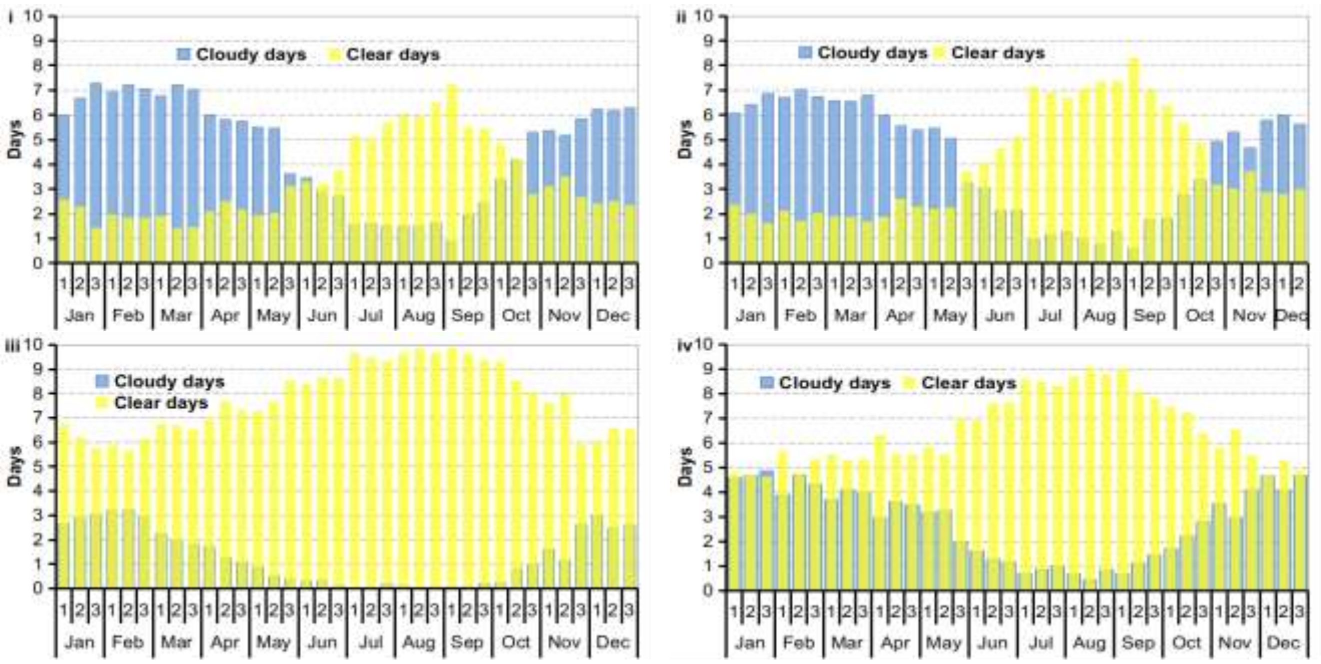


Fig. 5: Intra-annual change in cloudy and clear days in the period 2011-2020
(i) Tashkent, (ii) Samarkand, (iii) Bukhara, (iv) Khiva

### 4.2 Time Distribution of Thermal Sensation Conditions on the Base of THC and ET

The results of the analysis of intra-annual changes in thermal sensation zones in the city of Tashkent for 8 times daily meteorological observations in local time, the distribution of which was identified based on THC, showed that they have a pronounced daily and annual cycle (Figure 6). In the second half of November, winter months and the first half of March in Tashkent, the conditions of zone 1 of thermal sensation prevail during the day, i.e. "very cold". However, during the daytime hours from 11.00 to 17.00 in March and November, zone 2 conditions are established. At night, morning, and evening hours in the first half of April, at the end of September and October, zone 2 conditions (cold) prevail. The conditions of this zone during daytime observations are also observed in the first half of April and the second half of October, and in the remaining half of these months, in the first half of May and the end of September, conditions of zone 3 (comfort) are established. At 02.00 and 05.00 from the second half of April to the second half of September, thermal comfort conditions are observed in Tashkent. At 08.00, 20.00, and 23.00 in the summer season, the conditions of zone 4 of thermal sensation (relative comfort) prevail. During the daytime (11.00, 14.00, and 17.00), the conditions of this zone are observed from the second half of May to the first half of September. 5th zone (hot) conditions are noted in Tashkent in July and August at 14.00 and 17.00. Although zone 6 (very hot) conditions were observed in some years, such as 2013 and 2017 (Figure 7), it was not seen when averaging the 10-year (2011-2020) data.

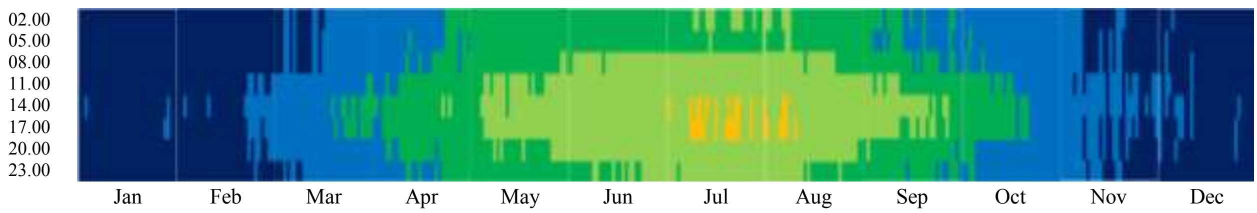


Fig. 6: Long-term average annual distribution of thermal sensation conditions during the day in Tashkent in the period 2011-2020 on the basis of THC
very cold cold comfort relative comfort hot very hot

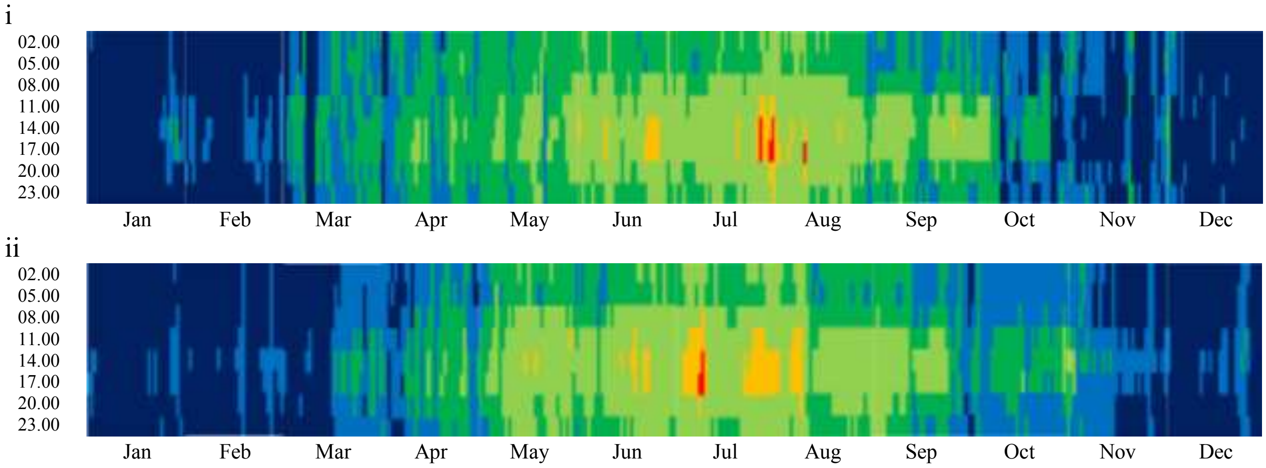


Fig. 7: Annual distribution of thermal sensation conditions during the day in Tashkent in 2013 (i) and 2017 (ii) on the basis of THC

very cold  cold  comfort  relative comfort  hot  very hot

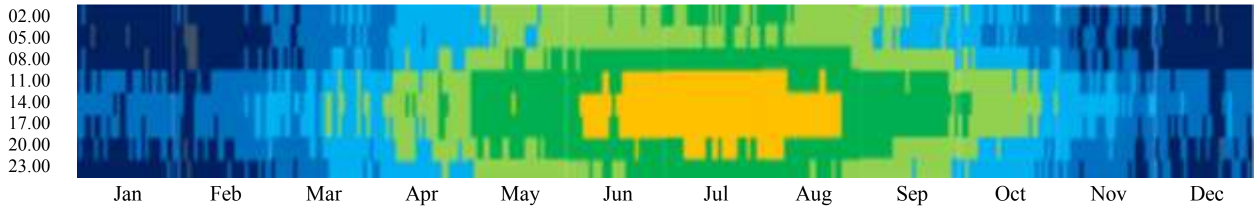


Fig. 8: Long-term average annual distribution of thermal sensation conditions during the day in Tashkent in the period 2011-2020 on the basis of ET

risk of frostbite  very cold  cold  moderately cold  very cool  moderately cool
cool  comfort - moderately warm  comfort - warmth  moderate heat load  heavy thermal load

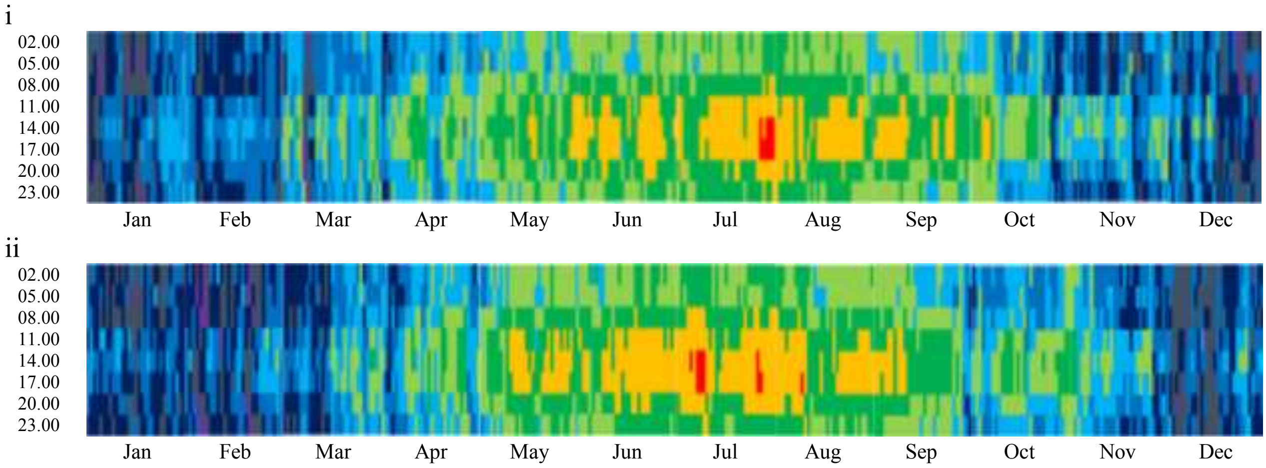


Fig. 9: Annual distribution of thermal sensation conditions during the day in Tashkent in 2013 (i) and 2017 (ii) on the basis of ET

risk of frostbite  very cold  cold  moderately cold  very cool  moderately cool
cool  comfort - moderately warm  comfort - warmth  moderate heat load  heavy thermal load

The time distribution of ET determined for the THC calculated period also has a pronounced daily and annual cycle (Figure 8). During the winter months, the first half of March and November in Tashkent, moderately cool (in the daytime periods from 11.00 to 17.00) and extremely cool (in the rest of the time) thermal sensation zones prevail. The second half of March, the first ten days of April and October will have moderately cool nights and mornings, and cool and moderately warm conditions during the day and evenings. In May, the first ten days of June, and the third ten days of August and September, warm thermal sensations during the day, and moderately warm thermal sensation during the morning and night periods prevailed. During the summer months, it is moderately hot between 11.00 and 20.00, and moderately warm and warm thermal sensation zones occur during the rest of the time. In Tashkent, in some years, extremely hot thermal sensation conditions also occurred in terms of ET (Figure 9), and due to averaging, they were not reflected in the multi-year distribution.

In the cities of Samarkand, Bukhara, and Khiva, which are the main tourist centers of Uzbekistan, changes in the conditions of thermal sensation over time have similar trends (Figure A1, Figure A2, Appendix A).

## 4.3 Repeatability of Different Zones of Thermal Sensation the Base of THC

The long-term average ten-day repeatability of various zones of thermal sensation, calculated based on statistical processing of all cases for the city of Tashkent, is shown in Figure 10. In the winter months in Tashkent, the thermal sensation conditions of “very cold” (zone 1) and “cold” (zone 2) prevail at all times, the frequency of which is 80-95% and 5-20%, respectively. Starting in March, their frequency gradually decreases to 60-70% (zone 1) and 20-30% (zone 2). Comfortable conditions of thermal sensation (zone 3) appear starting from the third ten days of February in the daytime and evening (recurrence within 5-15%), and at night from the second ten days of March (recurrence no more than 10%). April is characterized by the predominance of zone 2 conditions in the evening, night, and morning hours and zone 3 conditions in the daytime, the frequency of which is within 50-70% and 50-60%, respectively.

During the period May-September in Tashkent at night and morning hours (02.00 and 05.00) the frequency of zone 3 is more than 70%.In May and September, at 08.00, 20.00, and 23.00, the frequency of zone 3 is about 70%, and the frequency of the zone 4 (relative comfort) is within 20-30%. During these months, instances of zone 5 (hot) begin to occur with low frequency. The summer season in Tashkent morning, afternoon, and evening periods (from 08.00 to 20.00) are characterized by the predominance of zone 4 conditions, their frequency is within 70-90%. During this period, at 14.00 and 17.00, the frequency of zone 5 increases noticeably and reaches 30-35%. In the intervals from 14.00 to 23.00 with very low frequency (several percent), zone 6 conditions (very hot) are observed in Tashkent. The period September-November is characterized by opposite changes in the conditions of thermal sensation characteristic of the spring season.

The intra-annual change in the frequency of different heat sensation zones in Samarkand, Bukhara, and Khiva has a similar trend, but is different from a quantitative point of view (Figure B1, Figure B2, Figure B3, Appendix B).

## 4.4 CTIS

Figure 11 shows the CTIS for the city of Tashkent. In the diagram, the thermal sensation component is presented in the categories “cold stress,” “thermal comfort,” and “hot stress.” In the period from the second ten days of November to the third ten days of March, unfavorable conditions of “cold stress” are established in Tashkent. The rest of the year in this category has degrees of favorability from “acceptable” to “ideal.” However, this does not mean that favorable conditions will be observed in the “thermal comfort” category during this period. Conditions of thermal comfort from “acceptable” to “ideal” degrees in Tashkent are observed only in the periods of April-May and September-the first ten days of November. In the time interval between these periods, unfavorable thermal sensation conditions are established, associated with high air temperatures, and in the period from the second ten days of November to the third ten days of March they are associated with low temperatures. In the “hot stress” category, unfavorable conditions of the degree “very unfavorable” and “extremely unfavorable” are noted in Tashkent in the first and second ten days of June, the first and third ten days of July and August.

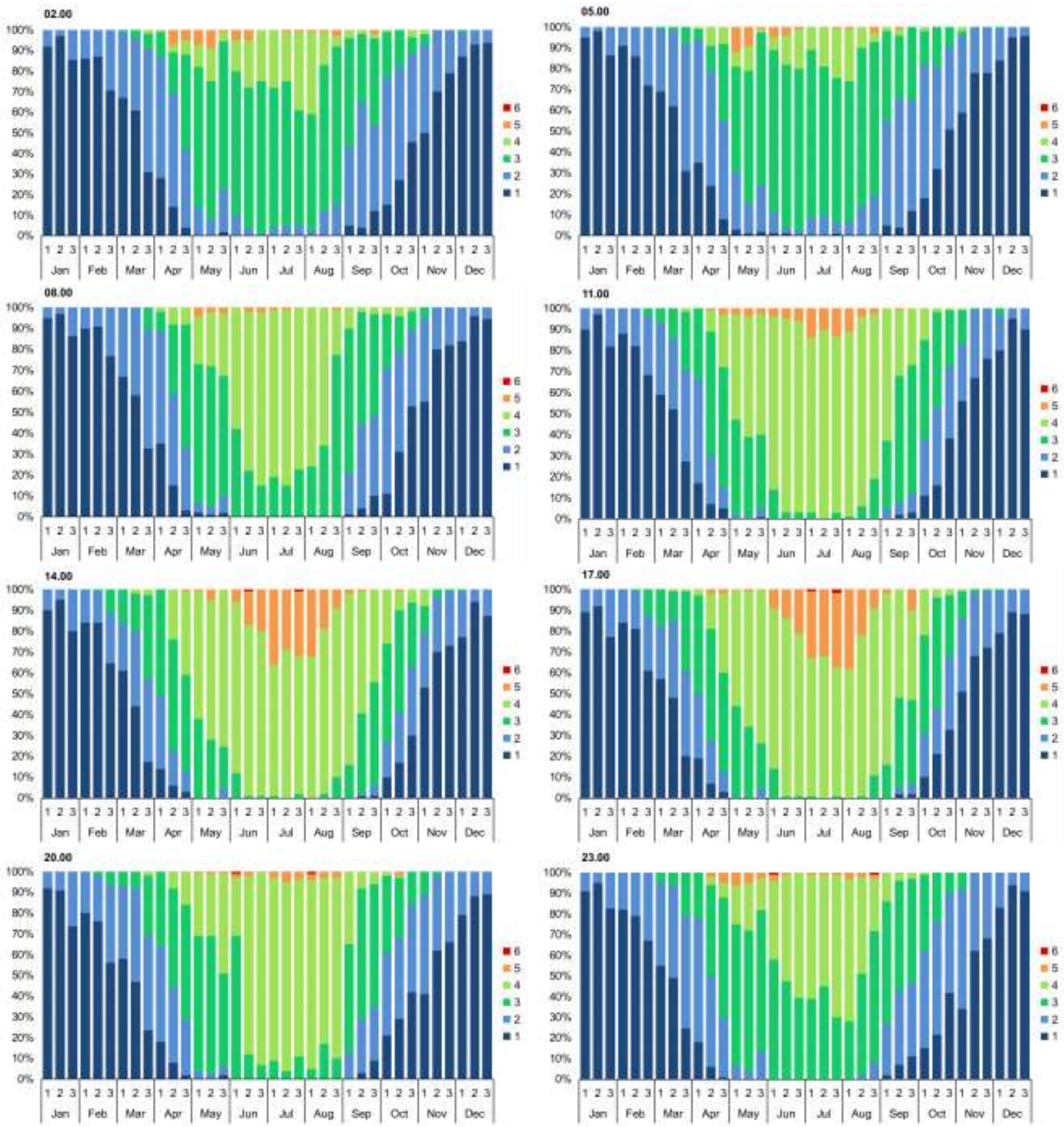


Fig. 10: Repeatability of thermal sensation conditions during the day in Tashkent (2011-2020)
1 – very cold, 2 – cold, 3 - comfort, 4 – relative comfort, 5 – hot, 6 – very hot

According to the aesthetic component, the category of cloudiness is less than 5 points, and the period from November to April has conditions of the degree "unfavorable" and "very unfavorable". For all other categories of aesthetic and physical components, Tashkent has conditions ranging from "good" to "ideal".

CTIS compiled for the cities of Samarkand, Bukhara, and Khiva are shown in Figure C1, Figure C2, Figure C3 in Appendix C.

# 5 Conclusion and Discussion

As traditional tourist centers, Tashkent, Samarkand, Bukhara, and Khiva cities each have their tourist attractions. In particular, the development of MICE, shopping, medical, educational, and gastronomic directions of tourism in Tashkent is promising. Recreational, historical-cultural, and archeological directions of tourism in the Samarkand region have high potential. In the case of the Bukhara city, supporting the development of pilgrimage, ecological, hunting, and safari tourism will have a positive effect.

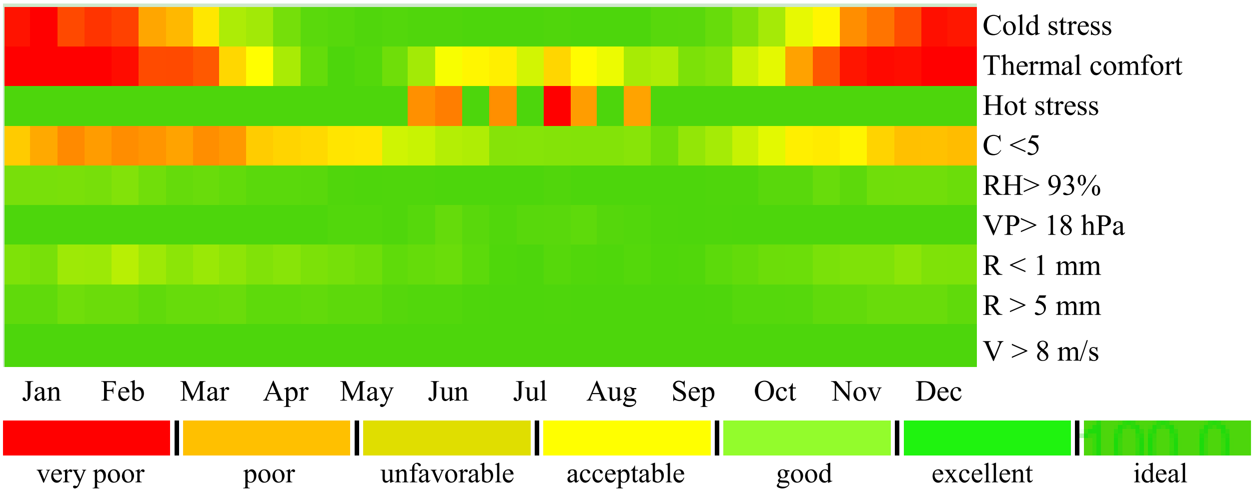


Fig. 11: CTIS for Tashkent by degree of favorability (2011-2020)

In Khiva city, there is an opportunity to combine the ethnographic and historical-cultural directions of tourism. There are opportunities for the development of tourist industries in Uzbekistan. The optimum use of internal opportunities in the tourism sector and reserves of sustainable economic growth in these cities will serve to increase the tourist flow to Uzbekistan. In particular, it is appropriate to take measures to promote promising tourism destinations, including objects included in the UNESCO World Cultural Heritage List. For this, it is necessary to develop competitive products in the global market, taking into account the bioclimatic conditions of these regions, and to reduce the impact of seasonal change factors on the attraction of tourist flow based on their bioclimatic characteristics.

Although climatological distributions of thermal sensation conditions by THC and ET show daily and inter-annual variations, when averaged over a multi-year period, they do not reflect extreme hot conditions that occur in some years. In the cold period of the year (November-March), the distribution of zones of thermal sensation according to THC and ET coincides with each other. However, there are certain differences in the warm period (April-October) reflecting hot and very hot conditions. It was found that these zones identified by ET were recorded for a longer time than the zones identified by THC. Taking into account that the THC proposed in [29] was developed for the conditions of Central Asia, the repeatability analysis of thermal sensation conditions and the creation of CTIS were performed only based on THC. According to our calculations, comfortable conditions can arise both at an air temperature of 12-15°C and high humidity, and at an air temperature of 30-35°C, but with low humidity.

According to the analysis of the bioclimatic conditions of the cities of Tashkent, Samarkand, Bukhara, and Khiva, favorable periods for tourism are determined primarily by thermal conditions and occur only during certain periods of the year and day. In Tashkent, these are the periods of April, May, September, and the first ten days of November. In Samarkand, favorable periods are March, June, September, and October. In Bukhara, it is April, May, September, and October. In Khiva, these periods start from the second ten days of April to June and from the third ten days of August to the second ten days of October. Because CTIS is compiled based on averaged data over a fairly large period, in our case 10 years, abnormal events (heat waves in the warm half of the year, heavy precipitation and winds, etc.) affecting tourism activities are poorly reflected in CTIS.

Since THC and ET do not take into account the influence of radiation flux on the conditions of thermal sensation, it is proposed to protect the human body from the effects of solar radiation individually with the help of appropriate clothing (usually cotton clothing with long sleeves), umbrellas, hats, etc. or choosing the time of stay in the open air (morning and evening hours).

Within the frame of this study, time distributions of bioclimatic conditions were obtained only for certain tourist destinations based on taking into account the influence of temperature and air humidity. Further development of this research involves considering the impact of wind on thermal sensation, identifying the spatial distribution, and mapping bioclimatic conditions throughout the territory of Uzbekistan.

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## Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Bakhtiyar M. Kholmatjanov – Conceptualization Methodology, Supervision, Project administration and Formal analysis.
- Erkin I. Abdulakhatov, Sardor U. Begmatov, Farrukh I. Abdikulov, Farkhod M. Khalmatjanov, Mukhammadismoil M. Makhmudov and Firuz B. Safarov – Data curation, Investigation and Visualization.

## Conflict of Interest Statement

The authors declare that there is no conflict of interest in this paper.

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# Appendix A

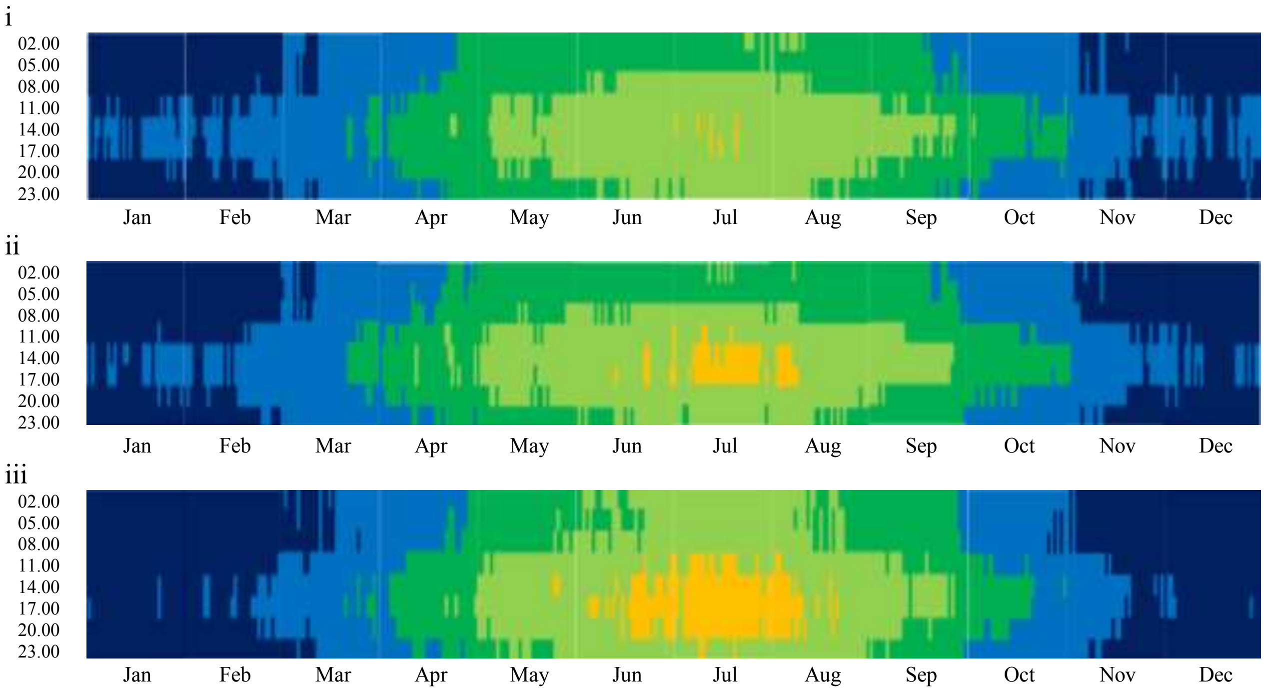


Fig. A1: Long-term average annual distribution of thermal sensation conditions during the day in Samarkand (i), Bukhara (ii), and Khiva (iii) in the period 2011-2020 on the basis of THC

very cold; cold; comfort; relative comfort; hot; very hot

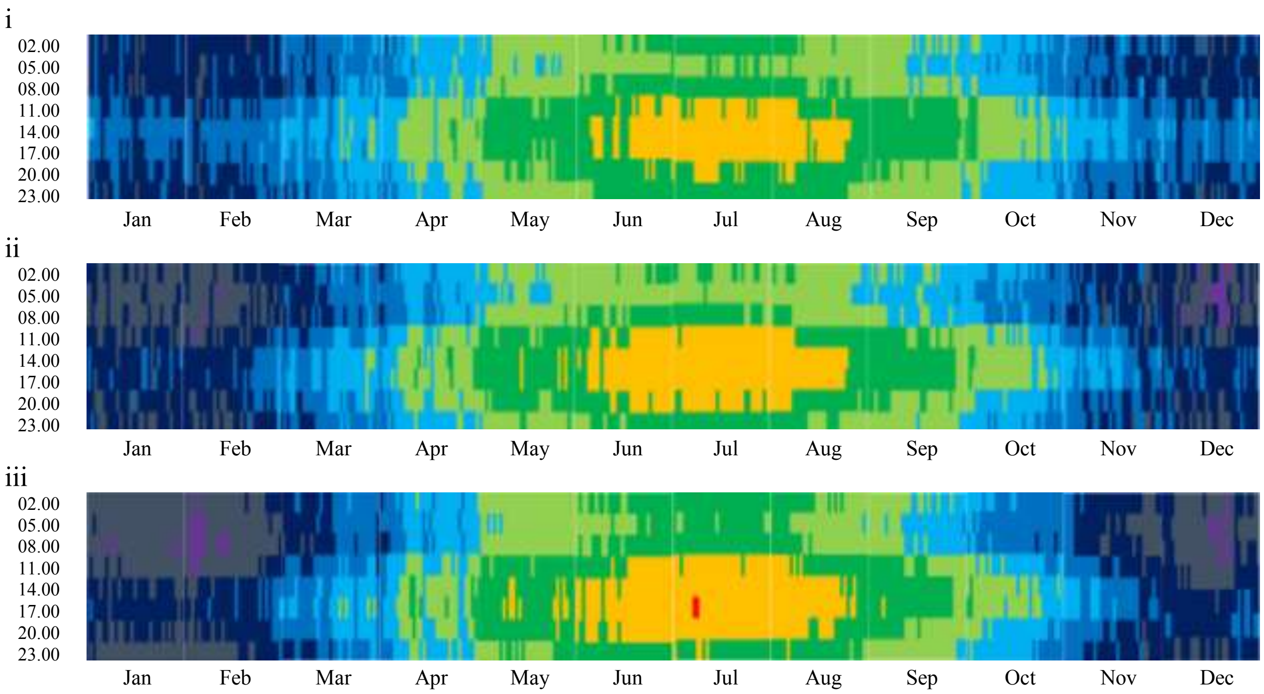


Fig. A2: Long-term average annual distribution of thermal sensation conditions during the day in Samarkand (i), Bukhara (ii), and Khiva (iii) in the period 2011-2020 on the basis of ET

risk of frostbite; very cold; cold; moderately cold; very cool; moderately cool; cool; comfort - moderately warm; comfort - warm; moderate heat load; heavy thermal load

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# Appendix B

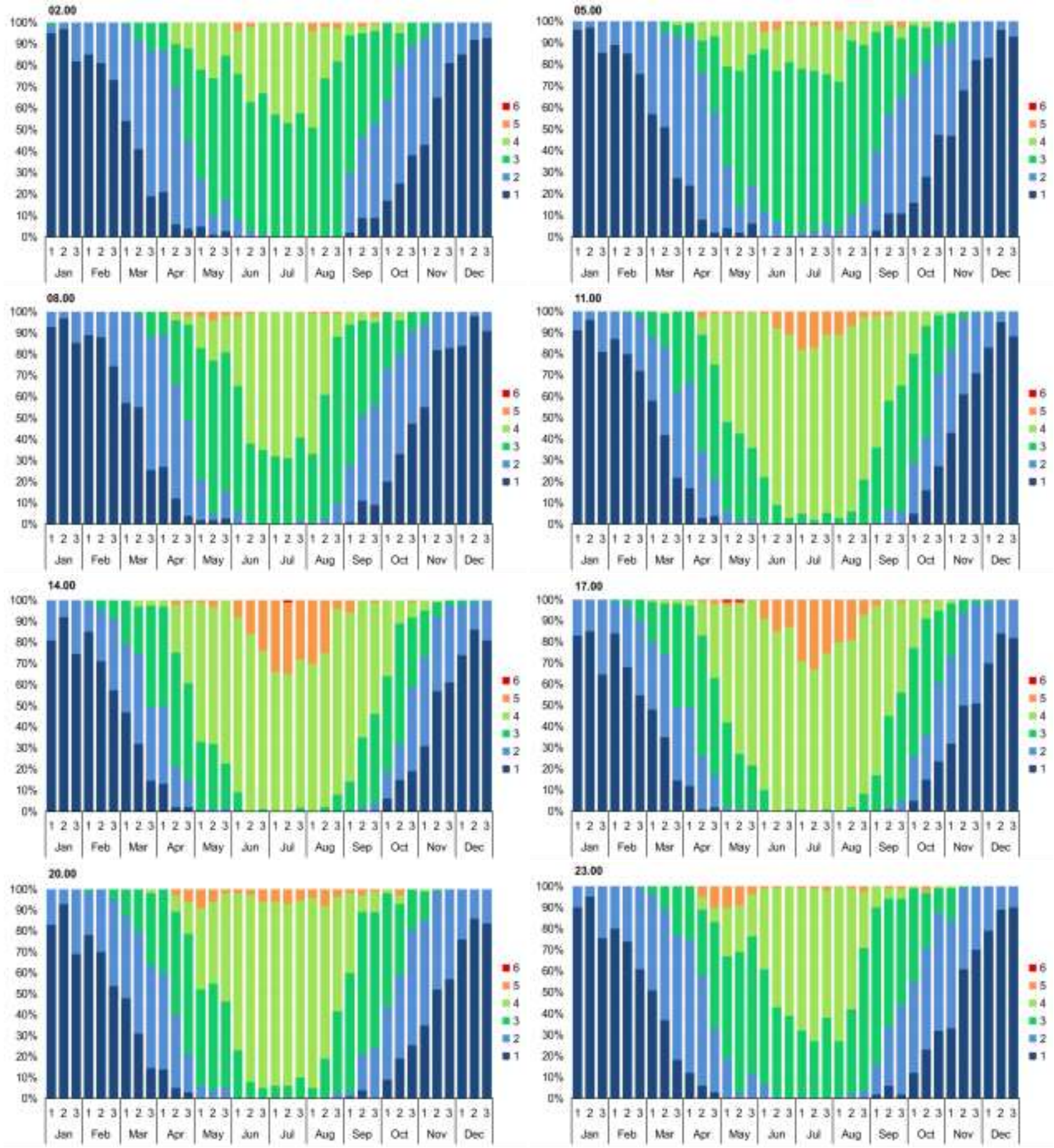


Fig. B1: Repeatability of thermal sensation conditions during the day in Samarkand (2011-2020)
1 – very cold, 2 – cold, 3 – comfort, 4 – relative comfort, 5 – hot, 6 – very hot

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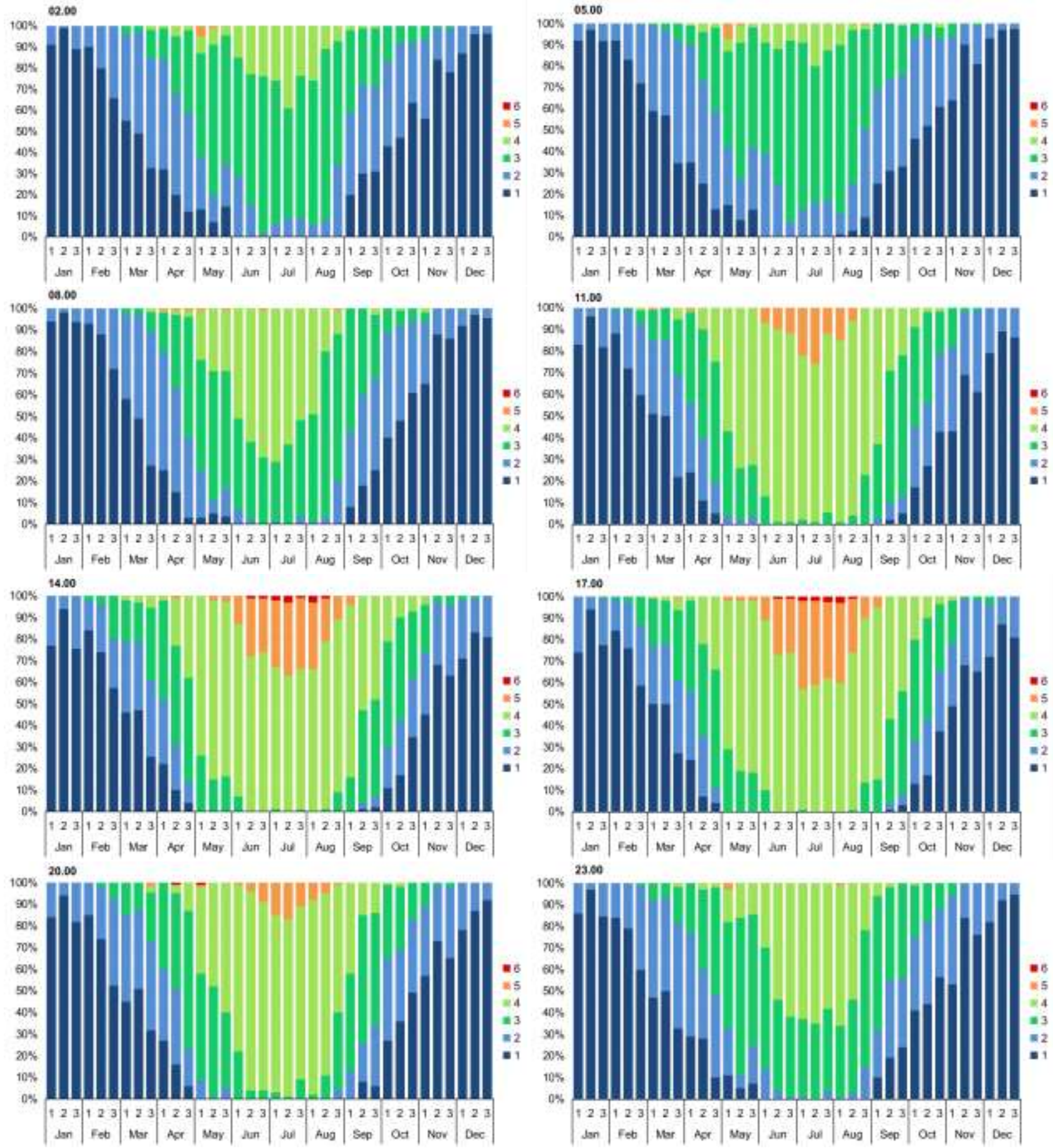


Fig. B2: Repeatability of thermal sensation conditions during the day in Bukhara (2011-2020)
1 – very cold, 2 – cold, 3 – comfort, 4 – relative comfort, 5 – hot, 6 – very hot

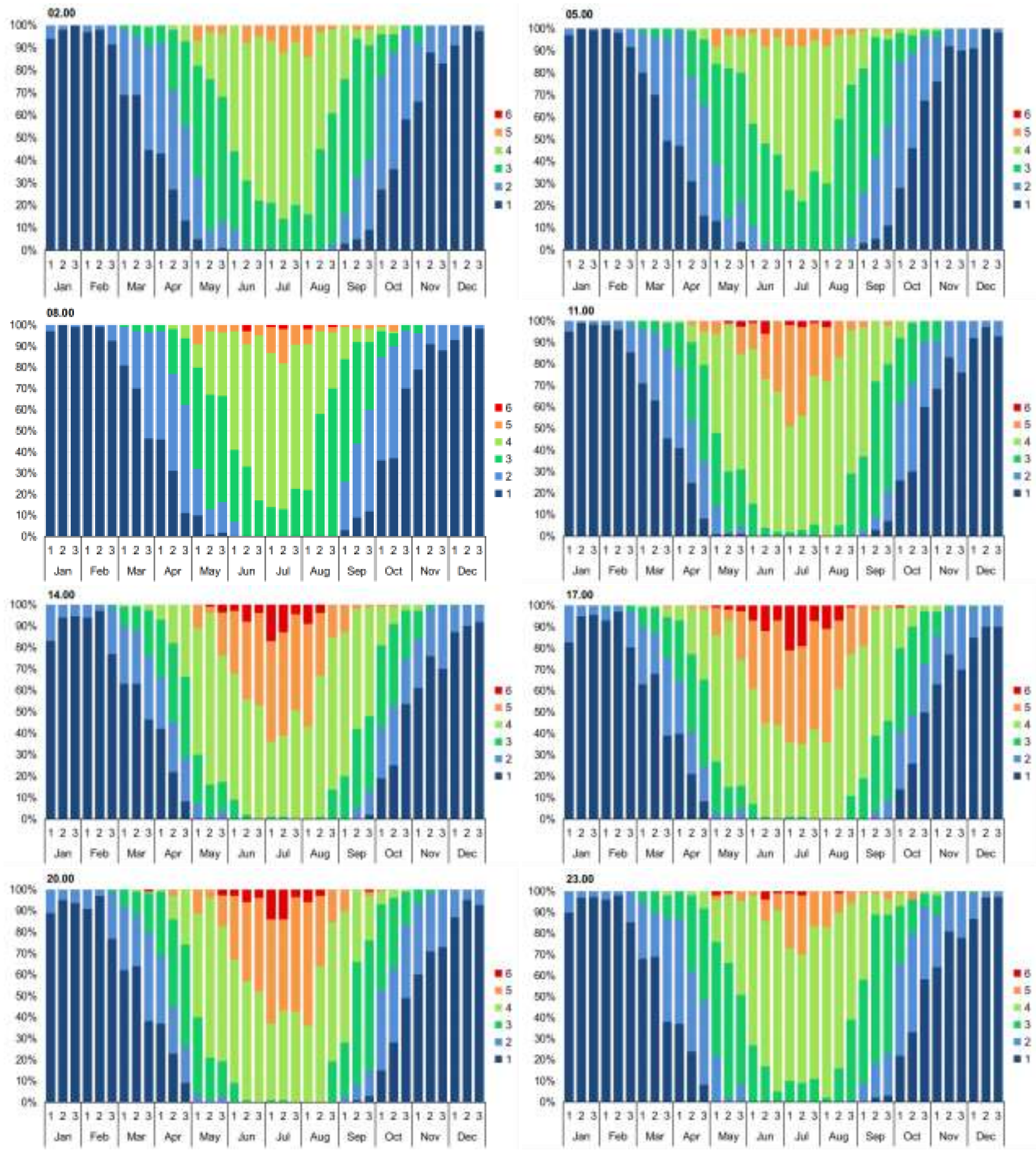

Fig. B3: Repeatability of thermal sensation conditions during the day in Khiva (2011-2020)
1 – very cold, 2 – cold, 3 – comfort, 4 – relative comfort, 5 – hot, 6 – very hot

# Appendix C

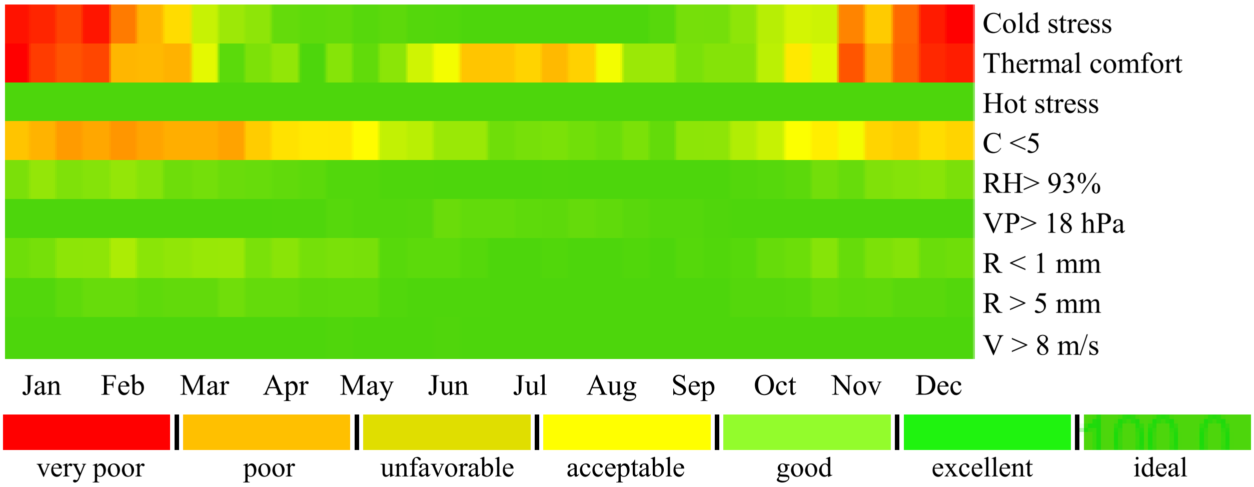


Fig. C1: CTIS for Samarkand by degree of favorability (2011-2020)

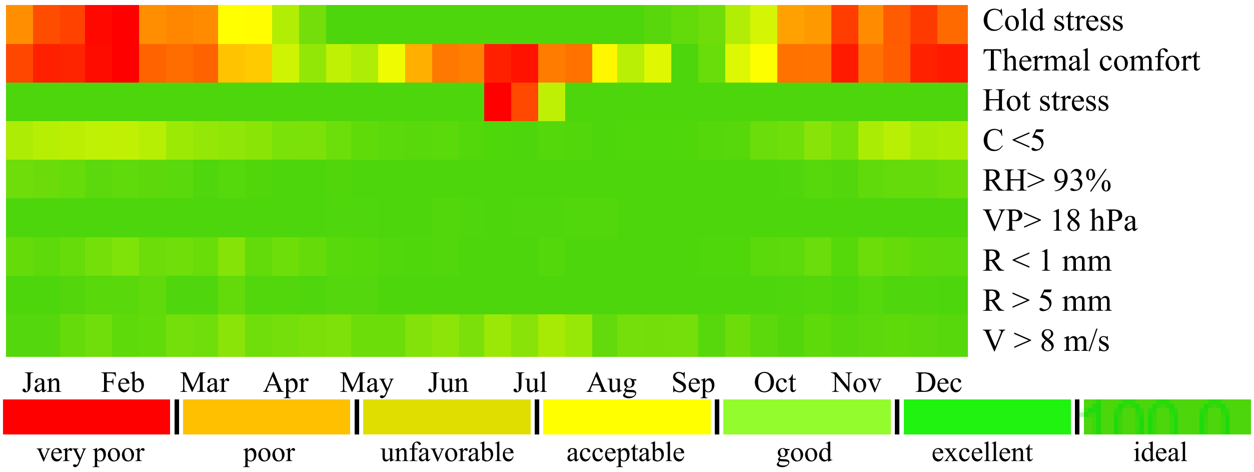


Fig. C2: CTIS for Bukhara by degree of favorability (2011-2020)

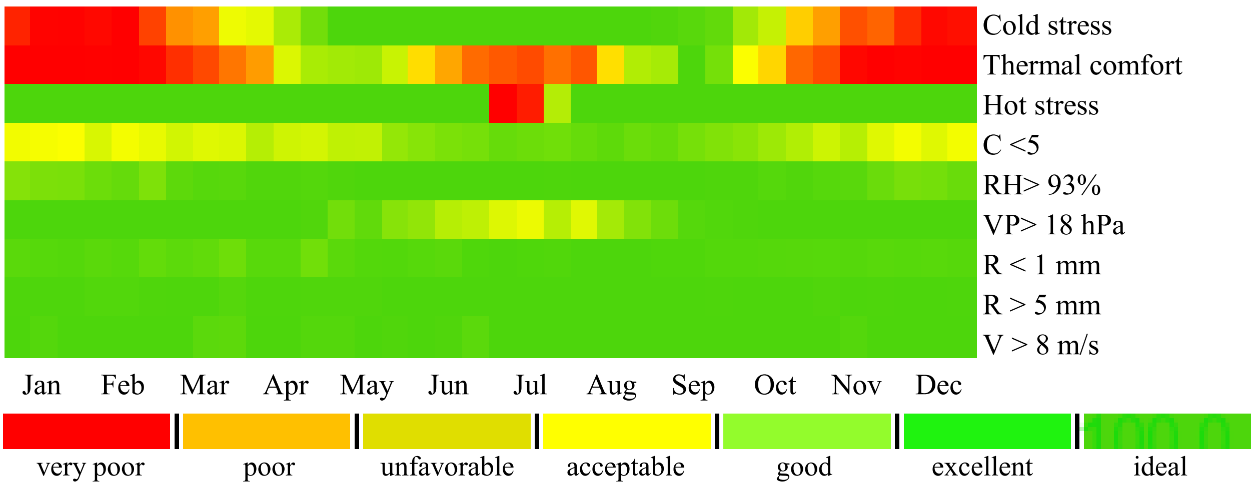


Fig. C3: CTIS for Khiva by degree of favorability (2011-2020)