NATIONAL CLIMATE VULNERABILITY ASSESSMENT: UKRAINE
The overwhelming scientific consensus is that the climate has been changing over the past 150 years, due largely to human activity. Global temperatures are rising, rainfall patterns are becoming more unpredictable, and the sea level is rising, with these trends expected to continue over the coming decades. A warmer climate has also been linked with more frequent and intense climate-related disasters and extreme weather. Records indicate that the number of climate-related disasters has risen significantly over the past century, and these now affect over 250 million people a year.

The humanitarian impacts of climate change and changing patterns of extreme weather are likely to be significant. There is increasing worldwide concern about the negative impacts a changing climate could have on societies and economies, affecting sectors from agriculture to water resources. The most severe effects of climate change are likely to be disproportionately felt by the poorest and most disadvantaged members of societies, who already have very few resources to fall back on in the case of disaster, and are ill-equipped to cope with the new challenges posed by climate change.

While efforts to mitigate the rate of climate change through cutting greenhouse gas emissions are ongoing, the failure to reach a binding international agreement to significantly reduce global emissions means that the planet will continue to experience warming over the coming decades. Mitigation is not enough; societies must take steps to adapt to the projected impacts of climate change, and build their capacity to manage changing risks at every level in the face of an increasingly unpredictable climate.

Civil society and the International Red Cross and Red Crescent Movement have a major role to play in alerting decision makers and the public to the risks of climate change and motivating people to take action based on these risks. Climate Forum East is a project in the six countries of the Eastern Partnership, aimed at building the capacity of civil society to engage with decision makers on these issues, and mobilising youth and communities to respond to the challenges faced by their country in a changing climate. Thus one of the key activities of the project is the assessment by national civil society organisations of the main climate risks and vulnerabilities in each country, and the development of recommendations to civil society and decision makers on possible approaches to take towards climate change adaptation in their country. It is to this end that this National Climate Vulnerability Assessment report is presented.
Scientific data shows that the Ukrainian climate has already started changing (temperature and other meteorological parameters differ from the long-term climate norm). The results of Ukrainian climate modelling show that the air temperature will continue to increase (although the magnitude of change is somewhat different according to the forecast model) and the amount of precipitation will change throughout the year. This may result in a shift of climatic seasons, change in the growing season duration, reduced duration of stable snow cover, changes in local water resources flow, etc.

Major possible adverse effects of climate change, which may occur in Ukrainian cities, include heat stress, flooding, reduced space and deterioration of the species composition of urban green areas, natural meteorological events, reduction and deterioration of potable water, increased incidence of infectious diseases and allergic reactions, and disruption of the normal operation of urban energy systems.

The concentration of a large number of the population in cities, specific features of local microclimate which may aggravate certain adverse effects of climate change, change in prevailing bedding urban surfaces, high-rise buildings, availability of public transport network and well-developed infrastructure (which may suffer from adverse effects of climate change and cause discomfort to the city’s population), make cities much more vulnerable to the climate change compared to other settlements.

To assess urban vulnerability to adverse effects of the climate change we have developed seven groups of indicators to identify effects that can be expected for a given city and determine for which of them an urban adaptation plan is necessary, recommended or unnecessary.

I. ‘Vulnerability to Heat Stress’
II. ‘Vulnerability to Flooding’
III. ‘Vulnerability of City Green Areas’
IV. ‘Vulnerability to Hydrometeorological Events’
V. ‘Vulnerability to Deterioration and Reduction in Potable Water’
VI. ‘Vulnerability to Increased Incidence of Infectious and Allergic Diseases’
VII. ‘Vulnerability of City Energy Systems’

The indicator groups were tested in assessing the vulnerability of the cities of Ternopil, Poltava and Donetsk in the course of the government workshops ‘Supporting Regional Efforts to Develop Regional Climate Change Adaptation Plans’ which took place in the aforementioned cities in September-October 2013, and by individual experts involved in the assessment of these cities’ vulnerability independently from the workshops participants.

To facilitate the development of an urban climate change adaptation plan we have drawn up the list of measures for urban adaptation to adverse effects of climate change and divided the measures in question into 7 groups (based on expected effects). The measures of each indicator group are divided into categories, particularly, engineering and technical measures, construction measures, economic measures, and organizational measures. Recommendations as to the development of an urban adaptation plan are provided for each of the indicator groups.

**Engineering and technical measures** can be used to minimize the risks associated with virtually all the adverse effects of the climate change in the city and therefore they are quite different. They are divided into regular and one-off measures.
Construction and architectural measures will also differ according to the problem. They include, among other things, measures that can be time-consuming while having a sustained positive effect once they are implemented.

Economic measures play a key role in decreasing urban vulnerability to the adverse effects of climate change. They are effective in reducing the consumption of water and electricity, emissions and discharges of pollutants in water and air, and can help quickly eliminate losses and restore damaged assets.

An information campaign aimed at different target groups is an important organizational measure undertaken in the context of urban adaptation measures development.

Urban adaptation to climate change requires a multifaceted approach and the implementation of measures at different levels. In relation to certain adverse effects of climate change, it is important to develop a monitoring / early warning / risk management system to allow for at least partially minimizing losses caused by meteorological factors. When developing a citywide adaptation plan it should be appreciated that there are measures which simultaneously address multiple adverse effects of climate change and which, in case of their implementation, will be more beneficial in the context of city adaptation to climate change.

When planning adaptation measures, it should be remembered that the scale and intensity of the negative effects of the climate change depend on the amount of greenhouse gases generated by human activity. Therefore, at the level of each country and city it is necessary to reduce greenhouse gas emissions for the purpose of mitigating the effects climate change and facilitating adaptation to its unavoidable impacts.
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<td>Nuclear Power Plant</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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<tr>
<td>HW</td>
<td>Heat wave</td>
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<td>SSES</td>
<td>State Service for Emergency Situations</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>MH</td>
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<td>HI</td>
<td>Heat island</td>
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<tr>
<td>MPC</td>
<td>Average daily maximum permissible concentration</td>
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<td>MPD</td>
<td>Maximum permissible discharge</td>
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<td>EWE</td>
<td>Extreme weather events</td>
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<tr>
<td>TPP</td>
<td>Thermal power plant</td>
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<tr>
<td>UHRI</td>
<td>Ukrainian Hydrometeorological Research Institute</td>
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INTRODUCTION

The global climate change which has been observed on our planet today and is expected to continue over the coming decades, raises a number of questions to researchers, politicians, local governments and regular citizens. However, two of these questions are of particular importance: what changes to expect in the future and how to adapt to them. The world’s leading climatologists are trying to find answers to the first question using scientific methods and models. However, even a regular weather forecast for several days is uncertain to some extent, while modelling the manifestations of climate change for specific regions where they will be affected by global and regional factors, both natural and anthropogenic, is also complicated. Therefore, the prediction of climate change is unfortunately uncertain to a significant degree and, when developing adaptation measures, we can take as a starting point rather general statements and forecasts, the accuracy of which can be poor.

Economic sectors such as agriculture, forestry, energy, water resources, and population, especially certain categories of citizens, and inhabitants of individual regions experiencing strong adverse effects of the climate change, are the most vulnerable to the climate change. Several investigations have been already carried out in relation to Ukraine and demonstrated changes that could occur and how such changes could affect the main sectors of the economy [10, 37, 38].

The increase in the Ukrainian urban population (in 2012 - 68.9%), the special vulnerability of cities to extreme weather events (caused both by infrastructure and specific microclimatic conditions and accumulation of a large number of people affected by natural events), the city government’s inability to timely and adequately respond to the effects of extreme weather events, and lack of climate change adaptation measures in general urban plans make investigations of urban vulnerability and adaptation to climate change particularly relevant.

This purpose of this report is to:
1. Develop criteria for assessment of the vulnerability of Ukrainian cities to climate change
2. Provide practical guidelines for the implementation of general adaptation measures that can be used in all or at least most of the cities;
3. Investigate the vulnerability of certain Ukrainian cities to climate change and develop specific recommendations of adaptation measures based on the findings of the investigation.

The report covers the risks posed by climate change and adaptation measures that can minimize their adverse effects on Ukrainian cities. This report is in some degree restricted by the uncertainty incidental to any forecast of climate change for the regions of Ukraine.

Methodology:
1. In the first phase, the report covers an analysis of the results of climate projections for the coming decades in Ukraine (in order to set precisely the starting point for further adaptation).
2. Description of main effects of the climate change for cities.
3. Analysis of physical and geographical conditions of Ukraine and microclimatic features of cities, and the findings of similar previous investigations on the adaptation of European cities to climate change, a comprehensive synthesis of this information and development of indicators to assess the vulnerability of Ukrainian cities to the climate change.
4. Case studies of Ukrainian cities vulnerable to climate change.
CHAPTER 1
Climate Change in Ukraine

Ukraine has a temperate continental climate. In the western and north-western regions of Ukraine the climate is mild with excessive moisture and moderate temperature conditions, while the eastern and south-eastern regions are characterized by a lack of precipitation and slightly elevated temperatures. The climate becomes more continental from west to east. The narrow coastal strip of the southern coast of Crimea is characterized by a subtropical Mediterranean climate.

1.1. HISTORICAL CLIMATE CHANGE

Studies of the Ukrainian climate [5–8] indicate that in recent decades the temperature and some other meteorological parameters differ from the long-term average (average values for the period 1961–1990). According to V.O. Balabuh [6] the average annual air temperature over the past twenty years (1991-2010 years) has increased by 0.8 °C compared to the 1961-1990 average. The Fifth National Communication on Climate Change [56] states that the highest increase in air temperature occurred in January (approximately by 2°C). In the extreme north-east of the territory of Ukraine the standard climatological norm (in 1961-1990s) had an isotherm of -6 °C, while during the period from 1991 to 2010 the isotherm was equal to -4 °C (see Figure 1.1, 1.2). Southwards the values of each isotherm increased by 1°C; in the west the isotherm is equal to -2°C instead of -3°C as before; in the east the isotherm is equal to -4°C instead of -5°C. In Crimea the isotherm is equal to +1°C while before it was about 0°C. Thus, there was an evident increase in air temperature in Ukraine over the period from 1991 to 2010 compared to the period from 1961 to 1990 years.

The climate of a particular territory generally is described using the values of air temperature (average annual temperature and average temperature for different seasons or months - the warmest and the coldest), precipitation, characteristics of wind and other meteorological parameters averaged over a 30-year period (World Meteorological Organization recommended averaging over 1961-1990).
In July the air temperature increased throughout Ukraine by 1.0 – 1.5°C. In the west the isotherm is equal to 19°C instead of 18°C; in the south the isotherm reached the unprecedented value of 22°C as never observed before during the standard climatic period (see Figure 1.3 and 1.4).

Due to global climate change that affects the transformation of the regional climate and some meteorological values, the average monthly air temperature in Ukraine over the past two decades has undergone significant changes as compared with the period 1961-1990s. The air temperature was higher in most months and the whole year, and only in September, November and December did it reduced to somewhat lower values [6]. Also there were observed changes in extreme (maximum and minimum) temperatures. The minimum temperature increased in most months and the whole year. Maximum temperatures in winter months, especially in January, had a tendency to increase. In summer and in the year as a whole the maximum temperature tendency to change is statistically insignificant, but in recent years it has increased [56].

Significant changes have occurred in the onset of spring and autumn (air temperature passing through 0°C) – in spring air temperature passes through 0°C throughout the territory earlier: Crimea - 5-6 days earlier or more, in the south-west - 4-5 days earlier or more, in the west - 3-4 days earlier or more, on the Black and Azov seas coast - 2-4 days earlier, in the rest of the territory - 1-2 days earlier compared to the 1961-1990 average while in the Crimean Mountains the nature of air temperature passing through 0°C remained unchanged, and on the southern coast of Crimea the air temperature never reduced to 0°C and below [56].

Redistribution of precipitation was recorded both in terms of regions of Ukraine and seasons (in winter rainfall in the whole country reduced, in autumn on the contrary a slight increase was recorded, in spring and summer the rainfall amount changed slightly), although the total annual rainfall remained unchanged (Fig. 1.5).

I. Buksha [10] indicates that the total precipitation for the territory of Ukraine has only changed slightly; however significant changes occurred in the intensity and nature of their fall. V. Balabukh [6] also notes that in recent times the number of cases when during a few hours a monthly or half-monthly rainfall amount falls increased. Increased air temperature and uneven distribution of storm precipitation, and localized heavy rainfall in the warm season, which does not provide an effective accumulation of moisture in the soil can cause the increased incidence and intensity of droughts.
1.2. CHANGES IN EXTREME WEATHER AND DISASTERS

Extreme weather events and disasters are the most dangerous impact of climate instability. During the last decade all over the world (including Ukraine) their number has increased. Often they are characterized by considerable intensity causing significant losses to the economy and lead to the loss of life. According to the Fourth Assessment Report on Climate Change [83] Ukraine is not included in the list of regions that are the most vulnerable to global warming of our planet. However, as evidenced by the results of studies, the impacts of climate change in Ukraine have been observed and over the coming decades will continue.

Natural meteorological events include very heavy rain, very heavy snow, large hail, strong winds, storm, tornado, severe dust storm, severe snowstorm, heavy fog, heavy sleet, heavy snow slush build-ups etc. In Ukraine the most common natural meteorological event is very heavy rain resulting in devastating rains, mudflows, earth flows, floods flooding large areas of agricultural land, residential and industrial premises and even leading to a change in the landscape [65]. During 1986-2010 in Ukraine 1355 cases of heavy rain were recorded (44 % of all extreme weather disasters for that period). On the average, in a year more than 53 cases of heavy rains are recorded [45].

The frequency of heavy rain can vary to a significant degree from year to year depending on synoptic processes, but according to data of [65], their number has increased significantly (Fig. 1.6).

In addition, cases of heavy rain are distributed unevenly throughout the territory of Ukraine. Most commonly heavy rains occur in the AR of Crimea (17 cases on the average in annual terms), Transcarpathian (12 cases), Ivano-Frankivsk (7 cases), and Chernivtsi (6 cases) Oblasts. In other Oblasts usually only 1–2 cases of heavy rain are observed each year. Moreover, the number of heavy rains covering large areas is increasing.

Very heavy rains (30 mm or more for 12 hours or more) for the entire territory of Ukraine are common for the summer season – 61% of the total (Fig. 1.7).

\[
\begin{array}{c|c|c|c}
\text{Month} & \text{June} & \text{July} & \text{August} \\
\text{Percentage} & 39\% & 24\% & 17\% \\
\end{array}
\]

Fig. 1.7. Frequency of very heavy rains in Ukraine in different months [65].

Strong wind and events associated with it (storm, tornado, dust storm) are ranked the second among EWEs (19 %). During 1986-2010 in Ukraine 398 cases of strong wind were recorded[45].

In winter heavy snowfall are frequently recorded in Ukraine, which can lead to disruption of the normal functioning of public utilities, road and rail transport, power transmission and communication lines breakdown, disruption of rhythm of work at construction sites. A very heavy snowfall means a snowfall with precipitations amount of 20 mm for 12 hours or less.

In recent years the number of cases of heavy snowfall in Ukraine has increased – in the five year period from 2006 to 2010 51 cases of this natural meteorological event were recorded and 143 in the period from 2006 to 2010. The number of cases of severe snowstorm and other natural meteorological events (large hail, dust storms and squalls) also increased (See fig. 1.8) [45].

Atmospheric phenomena that may cause significant adverse effects include also heat waves. A heat wave (HW) means a period of abnormally hot weather as observed in a particular area. The World Meteorological Organization recommends using the following criteria to determine this phenomenon: HW shall mean a period during which the maximum daily air temperature over 5 consecutive days exceeds the average...
maximum air temperature for those days in 1961-1990 by 5°C. At almost at all surveyed stations in Ukraine the highest incidence of this phenomenon over the past century has been observed during the last decade (2001-2010). (See Fig. 1.9).
Moreover, exactly during the last decade most stations recorded the most powerful heat waves (see Table 1.1). Cumulative T_{MAx} during an individual HW is usually used to evaluate the intensity of HW. Usually during an individual HW this characteristic is calculated as the sum of the differences between maximum daily temperature and a certain threshold that depends on the definition of heat waves used [77, 92].

The heat wave recorded in 2010 was the most powerful and durable recorded during the summer season in the period 1911–2010 for the eastern and southern regions of Ukraine. The abnormal heat was caused by a so-called “blocking anticyclone” that contributed to the preservation of persistent weather conditions.

In Ukraine the HW recorded in late July and August 2010 occurred on July 26 from Lugansk, and from July 30-31 covered all other stations of the eastern and southern Ukraine (with the exception of Odesa – it reached the City only on August 5). The HW ended on August 17–18 and on August 16 in Odesa. A substantially shorter duration of the HW in Odesa (12 days while at other stations 18-23 days) is apparently related to the spatial distance from the epicenter of the HW and mitigating impact of the sea.

Table 1.1. The most powerful HW in Ukraine over the period from 1911 to 2010.

<table>
<thead>
<tr>
<th>Station</th>
<th>The highest cumulative T_{MAx}, °C</th>
<th>Date</th>
<th>Duration (days)</th>
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<tr>
<td>Kyiv</td>
<td>108,6</td>
<td>31.07-17.08.2010</td>
<td>18</td>
</tr>
<tr>
<td>Lviv</td>
<td>35,8</td>
<td>28.06-03.07.1938</td>
<td>6</td>
</tr>
<tr>
<td>Lubny</td>
<td>103,2</td>
<td>31.07-17.08.2010</td>
<td>18</td>
</tr>
<tr>
<td>Kharkiv</td>
<td>117,0</td>
<td>30.07-18.08.2010</td>
<td>20</td>
</tr>
<tr>
<td>Lugansk</td>
<td>127,8</td>
<td>26.07-18.08.2010</td>
<td>24</td>
</tr>
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<td>Vinnytsia</td>
<td>75,5</td>
<td>10.08-24.08.1946</td>
<td>15</td>
</tr>
<tr>
<td>Uzhgorod</td>
<td>45,1</td>
<td>22.07-09.09.1994</td>
<td>19</td>
</tr>
<tr>
<td>Chernivtsi</td>
<td>70,1</td>
<td>09.09-22.08.1946</td>
<td>14</td>
</tr>
<tr>
<td>Odesa</td>
<td>46,4</td>
<td>05.08-16.08.2010</td>
<td>12</td>
</tr>
<tr>
<td>Ismail</td>
<td>46,3</td>
<td>16.07-25.07.2007</td>
<td>10</td>
</tr>
<tr>
<td>Genichesk</td>
<td>23,0</td>
<td>24.07-30.07.2001</td>
<td>7</td>
</tr>
<tr>
<td>Kerch</td>
<td>35,3</td>
<td>31.07-18.08.2010</td>
<td>19</td>
</tr>
<tr>
<td>Simferopol</td>
<td>70,7</td>
<td>30.07-18.08.2010</td>
<td>20</td>
</tr>
</tbody>
</table>

The heat wave 2010, the major part of which was observed in Ukraine in August, resulted in the abnormally high difference between the average air temperature in August 2010 and average air temperature in August over the period from 1961 to 1990. At some stations actual temperature value exceeded normal ones by more than 5 °C: for Kiev – 8.3 °C, Kharkov – 6.6 °C, Luben – 6.1 °C.

1.3. CLIMATE CHANGE IN THE FUTURE

Future changes in climate (particularly changes in air temperature) and their impacts directly depend on the scenario under which greenhouse gases emission will occur in the world during the coming decades. If emissions occur under a “business as usual” scenario, which reflects the level of greenhouse gas emissions without introducing additional measures to reduce them, it will strengthen the human pressure on the climate system and aggravate negative consequences that are already occurring. If emissions occur under this scenario, by the end of the century the temperature may rise to 4 °C (with further increase up to 6 °C), leading to catastrophic irreversible consequences for the planet. If actions aiming to reduce emissions are taken and emissions occur under one of the most optimistic scenarios, there is a chance to hold warming at the level of 1.5 °C. Under such a scenario, even if negative consequences increase compared to what we can see now, people will avoid irreversible catastrophic consequences for the planet.

Various forecasts of climate change in Eastern Europe show that main trends of future climate change are associated with an increase in temperature and decrease in rainfall amount, in line with substantial increase in dry climate.

According to data provided by Shvydenko [93] as obtained using HADCM3 model, IPCC Scenario A2A1, by 2020 in Ukraine there will be a possible average annual temperature increase 1

1 More information on http://www.ipcc.ch/ipccreports/tar/wg1/029.htm
by 20% (from 7.5 to 9.0 °C) and likely decrease in the total amount of precipitation in average annual terms and during the growing season - the most significant reduction is expected in the southern regions of the country.

According to forecasts obtained using regional numerical models of atmospheric circulation and semi-empirical models of climate change [36] by 2050 the regional average air temperature near the ground could increase by 1.5-2.0 °C (by 2.0 °C - in January in the south, by 2.8 °C - in the north of the country and on the average for the country by 0.5-1.0 °C in July). The amount of precipitations may slightly increase in winter after 2040; in summer it would remain within the normal range.

According to results of climate modeling for the territory of Ukraine obtained using REMO regional model as performed by climatologists of UHMI [33] anticipated changes in average monthly air temperature and precipitations amount in 2011−2030 compared to 1991−2010 are presented in Tables 1.2, 1.3 and Fig. 1.10.

From the results of climate modeling for the territory of Ukraine obtained using REMO regional model as performed by climatologists of UHMI [33] taking into account global development scenario A1B, one should expect an increase in air temperature and change in rainfall amount (which in different regions will be characterized by different impacts). The precipitation amount will increase in the period 2011−2030 compared to 1991−2010 for Ukraine by 7% a year [33], but by 21% in April and by 17% in January and March. A decline in precipitation is predicted by 12% in August, 7% in October and 1% in July.

An increase in temperature and hydration regime change will lead to changes in river runoff and, accordingly, water supply in certain regions. Based on the results of forecasting climate indicators for the territory of Ukraine using the REMO regional

<table>
<thead>
<tr>
<th>Table 1.2. Anticipated changes in average monthly air temperature (%) in 2011−2030 compared to 1991−2010 for Climatic regions of Ukraine [33].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>North</td>
</tr>
<tr>
<td>West</td>
</tr>
<tr>
<td>Centre</td>
</tr>
<tr>
<td>East</td>
</tr>
<tr>
<td>South</td>
</tr>
<tr>
<td>Ukraine</td>
</tr>
</tbody>
</table>

Fig. 1.10. Anticipated changes in air temperature (°C) in 2011-2030 compared to 1991-2010 [33].
model and water balance model as proposed by experts of the Intergovernmental Panel on Climate Change (IPCC), S. Snizhok et al. [63−64] calculated the projected characteristics of water flow in Ukraine in the XXI century and found that during this century most administrative Oblasts of Ukraine will experience a reduction in surface water runoff due to warming (increase in air temperature near the ground, increased volatility) and a decrease in rainfall amount.

Change in local water runoff resources will occur during the forecast period in the following manner:

- by 2020 – no significant changes are expected in water flows which could significantly disrupt the existing hydroeconomic management scheme; a possible termination of surface water runoff may occur only in Odessa Oblast and only in arid (dry) years;
- in 2021 – 2040 termination of water runoff in dry years (Kherson, Mykolaiv, Dnipropetrovsk and Zaporizhia Oblasts), in water medium and abundant years (Kherson and Odessa Oblasts) (Fig. 1.11).

Therefore, according to all climate change projections the following should be expected:

- increase in air temperature (although the value of change is slightly different for different models);
- changes in seasonal onset;
- change in length of growing period;
- increase in frequency and intensity of heat waves;
- change in the balance of rainfall, snowfall and hail;
- reduction in duration of persistent snow cover;
- change in relative air humidity;
- increase in frequency and intensity of natural hydrometeorological events;
- changes in surface runoff at local level.

Table 1.3. Anticipated changes in average monthly precipitations amount (%) in 2011−2030 compared to 1991−2010 for climatic regions of Ukraine [33].

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>18</td>
<td>6</td>
<td>19</td>
<td>16</td>
<td>6</td>
<td>0</td>
<td>-4</td>
<td>-6</td>
<td>-3</td>
<td>-5</td>
<td>14</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>West</td>
<td>26</td>
<td>12</td>
<td>18</td>
<td>9</td>
<td>12</td>
<td>11</td>
<td>7</td>
<td>-4</td>
<td>1</td>
<td>-5</td>
<td>13</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Centre</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>26</td>
<td>3</td>
<td>1</td>
<td>-3</td>
<td>-15</td>
<td>0</td>
<td>-11</td>
<td>4</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>East</td>
<td>22</td>
<td>9</td>
<td>17</td>
<td>21</td>
<td>-1</td>
<td>16</td>
<td>8</td>
<td>-13</td>
<td>42</td>
<td>1</td>
<td>8</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>South</td>
<td>5</td>
<td>-2</td>
<td>9</td>
<td>32</td>
<td>1</td>
<td>4</td>
<td>-8</td>
<td>-20</td>
<td>5</td>
<td>-13</td>
<td>4</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Ukraine</td>
<td>17</td>
<td>5</td>
<td>17</td>
<td>21</td>
<td>4</td>
<td>6</td>
<td>-1</td>
<td>-12</td>
<td>7</td>
<td>-7</td>
<td>9</td>
<td>13</td>
<td>7</td>
</tr>
</tbody>
</table>

Fig. 1.11. Allocation of forecast water resources in 2021-2040 years in administrative Oblasts of Ukraine (middle depth of runoff for a multi-year period, mm) [63].
CHAPTER 2
Urban Vulnerability to Climate Change

According to the UN recommendations, an urban settlement should exceed 20,000 people. However, in most cases every country uses its own indicators for determining the status of an urban settlement. In Iceland, Sweden and Norway, the urban status is assigned to settlements with population over 200 residents, in Albania - over 400 residents, in Australia - over 1,000 residents, in Columbia – 1,500 residents, in the United States, Mexico and Venezuela - more than 2,500 residents, in Italy, Spain, Portugal - over 10,000 residents [42]. In Ukraine, a settlement can be assigned the urban status if its population consists of at least 10,000 inhabitants.

In most developed countries urban population reaches 75-80% of the total population; in Ukraine this figure 68%. More than a third (33.7%) of all urban residents of Ukraine live in four Oblasts Donetsk, Luhansk, Dnipropetrovsk and Zaporizhzhia. The share of Kyiv residents of total urban population of Ukraine is equal to 7.8% (Table 2.1).

<table>
<thead>
<tr>
<th>City</th>
<th>Number of city residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyiv</td>
<td>2,846,852</td>
</tr>
<tr>
<td>Kharkiv</td>
<td>1,451,372</td>
</tr>
<tr>
<td>Odesa</td>
<td>1,014,563</td>
</tr>
<tr>
<td>Dnipropetrovsk</td>
<td>998,685</td>
</tr>
<tr>
<td>Donetsk</td>
<td>966,205</td>
</tr>
<tr>
<td>Zaporizhzhia</td>
<td>768,949</td>
</tr>
<tr>
<td>Lviv</td>
<td>758,043</td>
</tr>
<tr>
<td>Kryvyi Rih</td>
<td>655,362</td>
</tr>
<tr>
<td>Mykolayiv</td>
<td>495,679</td>
</tr>
<tr>
<td>Mariupol</td>
<td>481,926</td>
</tr>
</tbody>
</table>

One of the features of modern urbanization is a significant concentration of the population primarily in large cities and, accordingly, their further growth. Thus, one can see the formation of an urban environment or urban ecosystem, which is a whole new physical and geographical condition of the environment resulting from the long-term development of a city. This formation provokes changes in all components: atmosphere, climate, vegetation cover, animal life, soils, surface hydrosphere, and the geodynamic condition of the territory. The larger a city is or the longer it exists and the more it is developed, then the most important changes will occur in its natural environment.

A large city is typically characterized by certain microclimatic features [78]:
1. Apparent differences in thermal regime (the formation in the city of a so-called heat island - HI) and decline in the relative humidity of a city (a dry island formation);
2. The presence of specific circulation - rural breeze (generated under calm weather due to the existence of the heat island);
3. The change of a city’s wind regime;
4. Specific features of the formation of clouds over individual parts of a city;
5. An increase in precipitation and fog incidence;
6. The reduction in duration of snow cover occurrence.

2.1. FACTORS AFFECTING URBAN VULNERABILITY TO CLIMATE CHANGE

The combination of the negative effects of urbanization and climate change as observed in cities create a direct threat to the ecological, economic and social stability in the world [14]. Intensified impacts of climate change and the analysis of their adverse effect on urban areas indicate that climate change causes unique urban problems that are not incidental to other types of human settlements.

Climate change may cause direct (physical) impacts such as flooding, abnormal heat which can be intensified by urban
microclimatic features, etc. and indirect impacts, for example, disruption of the normal functioning of a city and some constraints in providing basic public services, particularly water supply, public transport, energy supply etc.

Although local risks related to the climate change, vulnerability and adaptability vary in different cities, there are a number of key insights that are inherent to most cities:

- Climate change affects urban residents differently depending on their gender, age, and economic situation;
- Failure to adjust the planning of an already formed urban territory and non-compliance of building codes and standards with expected changes may constrain the adaptive capacity of infrastructure and endanger people’s lives and their property;
- The effects of climate change can be long-lasting and may be of global importance;
- Fast growing urban districts are the worst adapted to counter the threat caused by the climate change because they usually have insufficient management, infrastructure, etc. [14].

Climate change affects physical urban infrastructure such as buildings, roads, sewer and energy systems, which, in turn, influence the lifestyle of urban residents and their wealth. Destruction and damage of residential and administrative building stock is expected to increase in the event of natural disasters and extreme weather events caused by climate change. From this perspective, floods are considered the most destructive and costly.

High temperatures can also affect not only the residents but also the infrastructure of a city, fostering the destruction of pavement, causing frequent road repairs, which can in turn disrupt the normal operation of public transport. In addition, under the conditions of rising air temperature and the prevalence of artificial surfaces which accumulate heat, the population of cities uses a significant amount of electricity for air-conditioning, which can cause a significant load on the urban energy system.

The increased incidence and intensity of extreme weather events and long-term changes will increase the vulnerability of urban economic assets and accordingly the cost of doing business. Climate change will affect a large variety of business activities, particularly trade, production of certain goods, tourism, insurance services and more. Therefore, climate change will affect the financial position of all levels of urban population. It is well known that people with low incomes are more vulnerable to climate change (poor quality of housing, less capacity to adapt, lower level of medical care, etc.). In addition, this category of population in large cities is usually the most numerous.

Therefore,

- The concentration of large populations in cities,
- specific features of local microclimate which may aggravate certain adverse effects of the climate change, e.g. a heat island may intensify urban heat stress caused by global rise in air temperature,
- changes in urban surfaces (replacing efficiently water absorbing natural surfaces with artificial waterproof surfaces)
- high-rise buildings,
- the availability of a public transport network and well-developed infrastructure (which may suffer from adverse effects of the climate change and cause essential discomfort to the city’s population),

make cities much more vulnerable to the climate change compared to other urban settlements.

Moreover, the amelioration of these adverse effects of the climate change in the city will involve more material and human resources.

As climate change intensifies, many water-related risks will increase. However, the anticipated adverse effects can be mitigated and to some degree minimized due to the development and implementation of a city adaptation plan (with due regard for specific features of a given city) based on the findings of analysis of existing and anticipated changes. That is why urban development master plans of Ukrainian cities should incorporate climate change adaptation measures.

2.2. CHARACTERISTICS OF THE MAIN ADVERSE IMPACTS OF CLIMATE CHANGE ON LARGE CITIES

The main potential adverse effects of climate change on cities include:

1. Heat stress;
2. Flooding;
3. Reduced areas and disturbance of biodiversity in urban green areas;
4. Extreme weather events;
5. Reduced quantity and quality of potable water;
6. Increased incidence of infectious and allergic diseases;
7. Disturbance of normal operation of urban electric power systems.
I. Urban vulnerability to heat stress

The risk of urban heat stress can occur in cities as a result of an increase in air temperature, recurrent heat waves and strengthened heat islands.

The increased number of days with maximum air temperatures above certain thresholds in summer (for instance, 30 °C and 35°C) which occurred, and forecasted increases in temperature (according to climate projections) are indicative of a high risk of occurrence of heat stress affecting the population and worsening the quality of life in cities.

To analyze the number of days with maximum temperatures above 30 ° and 35 ° C, the number of such days over the last two decades should be compared with the number of days in which the maximum temperature exceeded this figure over the period from 1961 to 1990. Necessary information can be obtained from the Climate Cadastre as available on electronic media or from the website of the European Climate Assessment & Dataset (where the information on air temperature at individual meteorological stations gathered for a hundred year period is available), or from the Regional Centers for Hydrometeorology.

The Urban Heat Island (UHI) is a temperature anomaly over the central part of a city that (Fig. 2.1.) is defined by increased air temperature compared to outlying areas.

One of the causes provoking the formation of an urban heat island is the predominance of artificial surfaces, which have a lower albedo than natural ones and therefore absorb, more solar radiation, more heat and cool more slowly. Green areas also reduce local air temperature and contribute to the reduction of heat stress for the urban population. To evaluate changes in green areas in an urban settlement one can use satellite data covering different time periods. According to the Rules of Green Areas Maintenance in Cities of Ukraine [52] green spaces of different structural elements within the city should be accounted for: city parks – landscaping level at 65-80%, squares - 75-80%, residential areas - at least 25%. In cities where green areas do not meet applicable standards and/or are reduced, the vulnerability of urban population to heat stress increases.

To analyze prevailing urban surfaces one can use information about the percentage of the urban territory covered by parks, green areas, and the percentage of the urban territory covered by dense high-rise buildings, industrial plants, roads. The higher the percentage of artificial surfaces is compared to natural surfaces the more urban settlements are exposed to heat stress.

Water is characterized by low albedo values (3-5%) and the highest specific heat among all other liquids existing in nature. Accordingly, it warms up very slowly while its temperature is lower than that of the surface of an urban settlement. Therefore, the water is the coldest surface in urban area in the daytime. Where an urban settlement is situated on the banks of a large water body (lake or sea), the air circulation which occurs between the water body and the shore brings cool air on the shore in the daytime causing a slight decrease in temperature. Large rivers produce a significant impact on urban heat islands. If a river’s linear dimensions are large enough within the limits of the city, the daily heat island formed above it can break down into several parts, depending on the configuration of the water flow [35]. Unfortunately, there is no uniform criterion for the water body size which would be the limit for breaking the heat island in urban settlements since in fact the intensity of the heat island depends on many parameters of the urban settlement.

The presence in the city of large industrial enterprises and a significant number of cars that as a result of their operation release heat into the atmosphere of the city, leads to the city heat island strengthening and increases the likelihood of heat stress. According to VI Globule [13] the calorific value of 10 liters of petrol in a car engine is equal to 100 kW/h. He calculated that the heat production capacity of cars in Moscow for one
A Heat Wave (as defined by WHO) means a period during which the maximum daily temperature over 5 consecutive days exceeds the average maximum air temperature recorded for this day for the period from 1961 to 1990 by 5° C. To evaluate changes in the frequency of HW for a particular urban settlement one may use the data on the maximum air temperature gathered at the nearest meteorological station, which is available in the Archives of the Central Geophysical Observatory or information about the frequency of heat waves in the recent hundred years in different regions of Ukraine by the example of 13 meteorological stations that presented in [77].

An important factor for evaluation of urban vulnerability to heat stress is a city's population structure: vulnerable groups include elderly citizens and children, and people suffering from chronic diseases (primarily cardiovascular diseases) according to physiological indicators and the poor according to socio-economic indicator. On the UN scale a population is considered old if the share of people aged over 65 exceeds 7%. [50]. According to the State Statistics Service of Ukraine as of January 1, 2013 the share of population aged 65 years and over in relation to the total permanent population of Ukraine constituted 15.2% [26], although in different regions ageing levels vary considerably. The higher the percentage of vulnerable groups is, the more a city is vulnerable to heat stress.

Adequate health care and public access to reliable sources of information about the weather reduce urban vulnerability to heat stress. The availability of cooling centres and air-conditioned spaces for people to seek refuge during a heat wave are also important. The quality of medical care can be easily evaluated on the basis of the number of beds, hospitals and primary care establishments (per 10,000 people). In this sphere Ukraine is ahead of the European average half as much and twice as much accordingly [53]. However, the number of primary care establishments in Ukraine is 4 times less than in the EU [53]. A result first aid is not always provided efficiently and at the appropriate level. Long-lasting high air temperature increases the number of complaints of patients suffering from cardiovascular diseases and causes the exacerbation of chronic diseases affecting various body systems, with the result that the population requires quality first aid.

When analyzing public access to sources of information on the weather, it should be remembered that the older generation continue to consider radio and television as their main information source. It is important for raising awareness to conduct a massive public information campaign about the issue of heat waves and how to behave during these periods, and include these issues in the school curriculum.

II. Urban Vulnerability to Flooding

Urban flooding can be caused by fall of a significant amount of precipitation over a short time period (Fig. 2.2.), the fast melting of a large amount of snow, water rising in urban water bodies, river floods, and for urban settlements located on riversides (seashores) a violent storm with high waves or sea level rise. According to IPCC, 2007 [86] global deglaciation can lead to sea level rise. Different authors estimate differently the rise level and time at which a critical limit after which flooding of low-lying coastal areas will commence will be reached. However in any case the low-lying areas are those with high risk.

According to the National Hydrometeorological Center of Ukraine, the amount of precipitation that fell in Cherkasy in the night of June 28-29, 2011 was equal to 38.4 mm and exceeds the monthly rate twofold. In the span of just a few hours, most roads were flooded, so in the morning most inhabitants of Cherkasy failed to arrive at work because of the constrained operation of municipal transport. As a result of the flood caused by heavy rains hundreds of people (mostly residents and car owners whose households and cars were flooded) appealed to the rescue service. The heavy rains flooded not only houses, but also the basement of Polyclinic No. 5, and caused damage to the dam across the Dnipro River, which resulted in a partial restriction of traffic on it for the period of its repair. Certain roads in the city were also flooded. To avoid the equipment flooding, Power Substation RP-28 supplying electricity to the south-west part of the city was deactivated [76].
The increased incidence of storm precipitation combined with improper operation of urban infrastructure (lack of or poorly-maintained storm drainage), the physical and geographical features of a city (altitude above sea level, hydrography) increase the risk of a city flooding. In addition, the prevalence of artificial waterproof surfaces in a city also increases the risk of flooding in some areas, because the moisture drains quickly from such surfaces and enters the storm sewer as opposed to moisture that is trapped on the surface of the soil is infiltrated in its deeper layers, thus reducing the risk of flooding.

Large areas of a city being part of a potential flooding area, the presence of people living in this area (e.g., number of children and the elderly needing primary evacuation in case of flooding) increases urban vulnerability to flooding, and the existence of strategic facilities (hospitals, post offices, etc.) in areas where the risk of flooding is minimal on the contrary, reduces urban vulnerability to this adverse effect of the climate change.

Analysis of floods (destructions they have caused, victims, damages, flooded areas; material, human and financial resources involved for emergency response) will help to develop a plan of measures required to avoid them (if possible) or minimize their negative effects and a detailed plan of providing aid to the population.

III. Vulnerability of urban green spaces

In this study we have classified as urban green spaces a combination of trees, shrubs and herbaceous plants in certain areas (trees, shrubs, lawns, flower beds, parks, gardens, woodlands, tree plantings along streets and roads, as well as on the land of private houses, enterprises, educational and health care institutions, military units). In Ukraine, one local resident accounts for, on the average, 16.3 m² of greenery. According to the Official Document # 105 from 10.04.2006 of the Ukrainian Municipal Ministry for cities with a population of 50,000 inhabitants, the norm of green areas is 7-11 m²/resident; for cities with population of 100,000 and more it is 10-15 m²/resident [41].

Each plant has its own required ecological conditions (heat, humidity, solar access, etc.). Certain values of each of the environmental factors are optimal; when a factor value is beyond the growth optimum, the development of a plant is at first suppressed and further vulnerability can lead to its death. Plants that grow in temperate climate are adapted to summer and winter temperatures observed in these latitudes. An increase in extreme summer temperatures (strengthened additionally by urban heat island) can lead to the extinction of some species which may result in reduction of urban green areas.

The vegetative period means the time required for the full cycle of plant development. In temperate climate the beginning of the vegetative season coincides with the average daily temperature passing through +5° C in spring, and its duration is limited by the stable temperature passing through +5 °C in spring and autumn. Increased temperature can result in extended vegetative seasons and its bias. According to forecast models temperatures are expected to further increase and vegetative season features are expected to change in the future. It may result in disruptions of the development cycle of some plants and creation of conditions favorable for growth in a given area of new (invasive) species. The emergence of such species can produce adverse effect on native plant groups.

Providing plants with sufficient humidity during the vegetative season is as important as the optimal temperature conditions. Moreover, it is necessary that precipitation is regular and of average intensity. Changing the features of the vegetative period can cause the migration of certain species of plants which may result both in the reduction of green areas and partial change in species composition.

The emergence of new species of plants within green areas is an indicator that may evince a change in environmental conditions meaning that not only the conditions have become optimal for new species, but also native species may gradually become extinct.

Increased temperatures (e.g. in winter) can cause the expansion of the range of certain pests and pathogens of plant diseases. New diseases and pests can pose a significant threat to urban plant groups.

To maintain urban green areas in proper condition not only climate conditions but also the work of municipal services departments engaged in green areas care is important (planting of new trees, timely removal of dead branches, treatment of pests and diseases if any, etc.). Quite often the condition of agricultural equipment used for urban plant care is poor, which does not improve the condition of plants within green areas and even causes them harm [34].

The poor air quality in large cities - high air dustiness, presence in the air of sulfur dioxide and nitrogen oxides (which in interaction with atmospheric moisture are converted into acid and cause the formation of acid rain), ozone and a number of atmospheric pollutants causing considerable harm to urban
IV. Urban Vulnerability to Extreme Weather Events

Extreme weather events include phenomena which by their intensity, extent (more than 1/3 of the territory) and duration reach and exceed the below criteria:

- very heavy rain, very heavy precipitation - precipitation of the amount of 50 mm or more over 12 hours or less;
- very heavy snow - precipitation of the amount of 20 mm or more over 12 hours or less;
- heavy downpour - precipitation of the amount of 30 mm or more over 1 hour or less;
- long-lasting rain - precipitation of the amount of 100 mm or more over 12 hours or less;
- large hailstones - hailstones 20 mm or more in diameter;
- strong wind (including storms, tornadoes) - maximum wind speed of 25 m/s or more;
- severe snowstorms, severe dust storms with wind speed of 15 m/s or more and lasting for 12 hours or more;
- strong ice-slick 20 mm or more in depth;
- heavy fog - visibility less than 100 meters for 12 hours or more;
- sleet deposits, complex deposits of glaze ice and frost-mist 35 mm or more in depth and some other manifestations.

Extreme weather events can block the normal functioning of city infrastructure and cause other negative effects. Heavy rains and high winds may result in the destruction of, or damage to, industrial facilities that could cause accidental emissions or discharges of pollutants into the environment, human losses, and disruption to the operation of urban infrastructure. The closer enterprises are located to densely populated areas of an urban settlement, the more potentially dangerous are the consequences of their destruction or damage as a result of natural meteorological events. Moreover, strong wind can cause damage to electricity lines and power supply disruptions, and damage trees in the city.

V. Vulnerability to Poor Quality Potable Water and Reduction of Potable Water Stock

A lack of sufficient local water sources or inadequate water quality of available supplies requires an urban population to use imported water for their needs. According to L.A. Napadovska et al. [43] as of 2009, 1,228 Ukrainian cities and towns used imported drinking water. A lack of sufficient sources of water supply and the use of imported water make urban settlements more exposed to the degradation of drinking water quality and stock.

80% of potable water in Ukraine is supplied from surface sources unprotected against technological pollution, and in some regions up to 100% [4]. Using water from surface sources increases the likelihood of a deterioration in its quality (discharging waste water of enterprises, spread of infections) and/or a decrease of such water stock as a result of changes in air thermal regime, reduction in precipitation quantities and, accordingly, river flow.

Negative trends in river flow and its forecasted further decline significantly increase urban vulnerability, especially if in cities reliant on surface water supply.

Drought is a complex phenomenon caused by a lengthy and significant deficit of precipitation accompanied by elevated air temperatures during the warm period of the year resulting in the depletion of water stock through evaporation and transpiration [79]. Accordingly, long-term droughts reduce flow of rivers and surface water supply. In addition, droughts result in increased water consumption in urban settlements.

If in an urban settlement there are large industrial facilities that use significant amounts of water, this leads to an increase in water consumption. Moreover, wastewater discharged by enterprises located in an urban settlement increases the risk of deterioration in surface water quality. Even if such water is subject to proper water treatment it is difficult to ensure that no negative impact is produced on water bodies (for example, in the result of an accidental discharge). This factor significantly affects those urban settlements which rely on water supply from surface sources.

Maintaining the water supply network in a good condition will provide consumers with water supply and sewerage services without losses which may cause network failure.

VI. Urban vulnerability to infectious and allergic diseases

Elevated air temperatures in winter will result in improved wintering conditions for infectious pathogens and parasites and consequently potential expansion of their ranges. Moreover, increased temperatures can result in a more active expansion of infectious pathogens in their natural environment. The urban heat island phenomenon further increases the temperature and accordingly cities create even more favorable conditions for the wintering of pests.

EWEs and disasters may also facilitate the expansion of infectious diseases. For example, heavy rains can lead to flooding areas and consequently more rapid spread of water-borne infectious diseases.
The decreased immunity of some urban dwellers (as a result of air pollution, consumption of poor quality water, daily stress at work, etc.) causes increased susceptibility to allergies and the percentage of highly allergic individuals in cities is increasing more significantly compared to rural areas. For low-income populations, factors weakening immunity also include poor nutrition, working and living conditions, lack of proper rest etc.

**VII. Vulnerability of urban electric power systems**
The negative effect of climate change on the urban energy system can be manifested in two essential ways:

1. **Increased demand for electricity.**
The increased frequency of heat waves and rise in air temperature intensified by the existence of a heat island in the city will lead to heavy electricity consumption and load on the city's electrical systems in summer (increased energy consumption for air conditioning). Heavy electricity consumption for additional heating is observed also during the periods of extremely low winter temperatures.

2. **Electricity generation and supply to consumers** [84].
   - The frequency and intensity of strong winds and some other EWEs is expected to increase, which may lead to power lines breaks and disruption of the normal energy supply to consumers (Fig. 2.3). Moreover, EWEs can cause flooding or destruction of distribution substations or other facilities in the city's energy system. Therefore, to determine whether there is a real threat of flooding or destruction of a station or its elements, it is necessary to carefully analyze the frequency of hazardous weather events, the height at which the substation is located, the distance from large water bodies etc.,
   - The rise in air temperature, precipitation redistribution, increase evaporation from the surface of water bodies may reduce the volumes of river flow and affect hydroelectric power production,
   - Increased air temperature can adversely affect the operation of thermal power plants and nuclear power plants (e.g., as a result of the increase of temperature in cooling water systems), which could lead to emergency stopping of the stations (as in Europe during the heat waves in 2003 and 2006).

Abnormal precipitations and certain EWEs can lead to damage of electric lines and electric power supply disruption, as well as destruction of electric power substations. One should carefully analyze the frequency of hazardous events, the altitude of a station location, distance to large water bodies etc. in order to determine the real threat of flooding or destruction of a station or its individual parts.

The availability of multiple sources of electric power (or the possibility to use alternative energy sources) may ensure uninterrupted power supply in case of failure of one or more stations of a city, or at least two independent energy sources for strategic facilities in the event of emergency.

The rapid growth of urban population and increased electricity consumption against the background of elevated summer temperatures as expected may cause overloading and breakdown of the electric power system. Taking into account the increased load of the electric power system it is important that its technical condition is satisfactory. Therefore, all worn parts shall be replaced, maintenance operations and inspections should be performed regularly and thoroughly.
To assess the vulnerability of a city to climate change a team consisting of representatives of different organizational units of the municipal council of a given city should be created, and representatives of other organizations (experts representing departments of the Ministry of Health, State Emergencies Service, in particular, Hydrometeorology Department of the State Emergencies Service, non-governmental organizations, etc.) should be involved.

Having reviewed the background information on climate change, factors that intensify the adverse effects of the climate change in cities, having analyzed changes in climatic conditions that already occurred and anticipated future changes, the expert team should proceed with the assessment of the city vulnerability.

Assessment of urban vulnerability to the climate change (or vulnerability monitoring) is carried out using vulnerability indicators, which can be divided into groups according to different principles. In our opinion, the most logical and easy to use is the principle providing for grouping indicators to establish the city’s vulnerability to certain adverse effects of the climate change. All indicators used in this methodology are divided into 7 groups according to this principle.

To determine the most dangerous effects of climate change for a city it is necessary to analyze each indicator (for getting a better understanding of the role of individual indicators, see Section 2), fill in the assessment form (Table 3.1), calculate the number of points for each group of indicators and rank the groups on the basis of the number of points scored.

If an indicators group ultimately scores more than 14 points (which score exceeds 60% of the maximum possible score), it indicates that the city is extremely vulnerable to some of the adverse effects of the climate change and is indicative of the need to develop adaptation measures, incorporate them into relevant plan and implement.

In case of indicator groups that scored fewer points (from 8 to 14) it is also recommended to provide for urban adaptation measures notwithstanding that the city’s vulnerability to these adverse effects is not too high.

Groups that scored less than 8 points at this stage do not require the development of adaptation measures. However, fast changes in the city’s social structure, energy system, and green area development dynamics, may drive new climate modeling results etc., so it is recommended that at least every few years all necessary information is reanalyzed and vulnerability reassessed.
Table 3.1. Form for Evaluating Urban Impacts of Climate Change.

### Group I. Urban vulnerability to heat stress

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (1 score)</th>
<th>Very relevant (2 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increased number of days with upper temperature limit above 30 °C and 35 °C during the last decade compared to the 1961-1990 average.</td>
<td></td>
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<tr>
<td>2. Increased average daily and average monthly temperatures in summer months over the last decade compared to the 1961-1990 average.</td>
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<tr>
<td>3. Projected increase in air temperature for the region in which the city is located.</td>
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<tr>
<td>4. Increased frequency of heat waves in the recent years.</td>
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<tr>
<td>5. Existence of heat island.</td>
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<tr>
<td>6. Absence of water bodies in the city.</td>
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<tr>
<td>7. Small areas of green spaces in the city, tendency of their reduction, uneven distribution in different parts of the city.</td>
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<tr>
<td>9. The existence of urban anthropogenic sources of heat (factories, power plants etc.).</td>
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<tr>
<td>10. Significant percentage of urban population exposed to HW (older people, children, people with chronic disease).</td>
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<tr>
<td>11. Limited access to quality health care (primarily emergency medical services, number of beds in the hospital, etc.).</td>
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</tr>
<tr>
<td>12. Limited public access to information on weather and climate, the rules of conduct during the periods of heat waves (e.g. number of government information campaigns on behavior during heat waves, presence of this on school curriculum).</td>
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</tbody>
</table>

**Total score:**

### Group II. Urban Vulnerability to Flooding

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (1 score)</th>
<th>Very relevant (2 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increased number of days with abnormal season precipitations over the last decade compared to 1961-1990 average.</td>
<td></td>
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<tr>
<td>2. Increased incidence of flooding of individual districts of an urban settlement over the last few years.</td>
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<tr>
<td>3. Projected increase in precipitation quantity in general for the year and in particular for certain seasons, as well as increased frequency of significant torrential precipitation over a short period.</td>
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<tr>
<td>4. Absence of storm drainage system, or, if available, its poor technical condition, irregular cleaning.</td>
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<tr>
<td>5. Urban settlements located on the banks of a large water body.</td>
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</tbody>
</table>
6. Location of a city or its individual parts below sea level or at small heights.

7. People living and strategic facilities located in possible flooding zones.

8. Significant number of artificial waterproof surfaces compared to natural ones in the city.

9. Lack of sufficient technical and human resources for prompt evacuation of the population from possible flooding zones.

10. Destroyed infrastructure due to climate change in the recent years (length, area, and type of road destroyed by acts of nature within a year).

11. Limited public access to information on weather and climate, the rules of conduct during the periods of floods.

12. Absence of infrastructure in certain parts of an urban settlement that can be separated by water from other areas.

Total score:

**Group III. Vulnerability of Urban Green Areas**

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (1 score)</th>
<th>Very relevant (2 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increased number of days with upper temperature limits above 30 ° C and 35° C and higher during the last decade compared to 1961-1990 average.</td>
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<tr>
<td>2. Displacement in time and change in growing period duration.</td>
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<tr>
<td>3. Change in the amount and intensity of precipitation falling during the vegetative season.</td>
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<tr>
<td>4. Area of green zones per 1 inhabitant is less than regulatory value.</td>
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<tr>
<td>5. Reduction of green areas (as a percentage of the total area of the city).</td>
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<tr>
<td>6. The ratio between the area of protected territories and the total area of the city.</td>
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<tr>
<td>7. Emergence of invasive species within green areas.</td>
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<tr>
<td>8. Emergence of new plant pests/diseases within green areas.</td>
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<tr>
<td>10. Lack of human and technical resources for green areas maintenance. Poor maintenance of agricultural equipment used for urban plants care.</td>
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<tr>
<td>11. Lack of funding for greener planting in the city and maintaining the existing green areas in proper condition.</td>
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<tr>
<td>12. High level of urban atmospheric air pollution.</td>
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</table>

Total score:
### Group IV. Urban Vulnerability to Extreme Weather Events

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (2 scores)</th>
<th>Very relevant (4 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increased frequency of extreme weather events that caused damage and losses in recent years.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Availability of infrastructure destroyed as a result of extreme weather events in the recent years (length, area, and type of road destroyed by acts of nature within a year) and industrial enterprises in the city or near the city that can be damaged as a result of natural events.</td>
<td></td>
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<tr>
<td>3. Limited public access to information on weather and climate (e.g. presence/absence of early warning system, measurement of effectiveness).</td>
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<tr>
<td>4. Absence of storm drainage system, or, if available, its poor technical condition, irregular repairs.</td>
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</tr>
<tr>
<td>5. Lack of sufficient technical, human and financial resources for prompt evacuation of the population from zones affected by natural meteorological event.</td>
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<tr>
<td>6. Limited access to quality health care (primarily emergency medical services).</td>
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<td><strong>Total score:</strong></td>
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</tbody>
</table>

### Group V. Vulnerability to Poor Quality Potable Water and Reduction of Potable Water Stock

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (1 score)</th>
<th>Very relevant (2 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lack of city sources for public water supply or use of imported water.</td>
<td></td>
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</tr>
<tr>
<td>2. Prevalence of surface sources of water supply over subsurface ones.</td>
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<tr>
<td>3. Negative trend in river flow in the region.</td>
<td></td>
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<tr>
<td>4. Increased frequency of drought events over the past 10 years.</td>
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<tr>
<td>5. Presence in an urban settlement of industrial enterprises consuming large water volumes.</td>
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<tr>
<td>6. Presence of enterprises discharging waste waters into water bodies.</td>
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<tr>
<td>7. Improper condition of water supply network in urban areas.</td>
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<tr>
<td>8. Improper condition of water treatment facilities used to purify water consumed by the population.</td>
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<tr>
<td>9. Lack of standardized urban water management.</td>
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<tr>
<td>10. Increased urban population.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>11. Lack of water consumption culture in urban areas.</td>
<td></td>
<td></td>
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<tr>
<td>12. Large percentage of low-income families among urban population.</td>
<td></td>
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<tr>
<td><strong>Total score:</strong></td>
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</tbody>
</table>
### Group VI. Vulnerability to Increased Incidence of Infectious and Allergic Diseases

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (2 scores)</th>
<th>Very relevant (4 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Large percentage of people vulnerable to infectious and allergic diseases.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Increased frequency of extreme weather events that may contribute to the spread of infectious diseases (such as heavy rains).</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3. Increased average air temperature as forecasted.</td>
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</tr>
<tr>
<td>4. Large percentage of population prone to allergic diseases.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5. The presence of natural focus of infectious and parasitic diseases in urban areas or nearby them.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. The presence of urban heat island.</td>
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</tbody>
</table>

Total score:

### Group VII. Vulnerability of Urban Electric Power Systems

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Irrelevant (0 score)</th>
<th>Relevant (2 scores)</th>
<th>Very relevant (4 scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Elevated air temperature, frequency of heat waves, the presence of urban heat island and extreme low temperatures.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Increased number of days with abnormal precipitations amount and frequency of natural meteorological events.</td>
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<td></td>
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</tr>
<tr>
<td>3. Low absolute height of the station, distance from water bodies, station or adjacent territories flooding incidents.</td>
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<tr>
<td>4. Lack of energy sources (traditional or alternative) in the city for the population (or at least strategic facilities) in the event of emergency.</td>
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<tr>
<td>5. Increase urban electricity consumption per capita because of population raising and increasing power demand for cooling (according to the forecast rise in temperatures).</td>
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</tr>
<tr>
<td>6. Depreciation of fixed assets, improper technical condition of the urban electric power system equipment.</td>
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</tbody>
</table>

Total score:
CHAPTER 4
Recommendations for the Development of Urban Adaptation Measures

The next step after the assessment of urban vulnerability to climate change and evaluation of consequences that could produce the most adverse effect on the city and its inhabitants should be the development of a Climate Change Urban Adaptation Plan. It is advisable that the plan should incorporate “finished” adaptation measures which are already being implemented in other cities, and “individual” ones that can be used only for a given city and developed with due regard for its specific features.

The action plan should be developed by a working group consisting of representatives of the city administration, experts of relevant agencies and NGOs. Most measures should be aimed at minimizing the adverse effects of climate change the city is the most vulnerable to. In relation to each item of the adaptation plan it is necessary to specify the responsible person selected among members of the working group (who implements the relevant action, arranges for its implementation or controls it) and organization, which, whenever required, should be involved in the cooperation (organizational units of the State Meteorological Service, health care institutions, utility service providers, rescue service of the Ministry of Emergency Situations, organizational units of the State Agency for Water Resources of Ukraine etc.) subject to specifying a relevant official acting as their authorized representative.

The plan should also provide for the relative cost of the measure (low, medium, high) which will be further transformed into the absolute cost (finalized cost estimate of the measure implementation) by a person in charge of the implementation of such measure.

Below are the sets of measures of urban adaptation to key adverse effects of climate change with explanations regarding the implementation of some of them, specifying the relative cost and additional information to facilitate their implementation).

Heat Stress
1. Development and implementation of a warning system notifying of hot weather which can cause harm to health (Heat Health Warning System – HHWS).

According to R.S. Kovats and L.E. Kristie HHWS is a system using meteorological forecasts in order to take measures aimed at reducing the adverse effect of hot weather on public health [87]. Heat public warning systems can be of a national (as, for instance, in France, the USA, etc.) or local type (used locally in certain regions or cities).

Such systems should allow the notification of all categories of consumers using a variety of information transmission methods: for enterprises and organizations – over the Internet and by facsimile, for citizens – via mass texting, radio and television. The establishment and effective operation of a similar system can be achieved only due to well-coordinated cooperation between the city government and organizational units of the State Hydrometeorological Service. Meteorologists provide advanced and reliable information about the expected heat and the city government notifies the population thereof. Some outreach activities must be carried out first so that the information received can be used in the most efficient way: how to act during heat waves, protect oneself and provide assistance to the most vulnerable population. Local NGOs can play a major role in spreading HHWS information among population. In particular, this information can be disseminated through holding topical workshops in schools, higher educational institutions,
2. Organizational Measures

- Place emergency aid and fire fighting system on high alert during hot weather periods. If necessary (having analyzed the situation in hospitals during previous HWs) increase the number of beds in hospitals and doctors on duty.
- Make changes to the working hours of companies providing services to the population (post offices, banks, etc.) taking into account the periods of extreme heat during the day [37].
- Ensure ongoing reminders of key rules of conduct in case of heat and fire safety rules are transmitted on all radio stations and television channels for the duration of a HW.
- Implement a well-planned awareness-raising campaign on climate change, factors that cause it, heat stress as one of its effects and how it can be avoided. Such a campaign should cover all social groups regardless their age and occupation and involve the use of all possible means, the Internet, social advertising on radio and television, brochures, handout flyers, presentations in schools, etc.
- Ensure comfortable temperature conditions during heat waves in crowded places attended by people belonging to vulnerable social groups (kindergartens, hospitals, nursing homes), through construction of additional shaded areas for people in parks, squares, near water bodies during hot weather periods.
- Construct drinking fountains and pump rooms in different districts of the city.
- Map cool areas (parks, squares, lakes) in the city, where people can stay on a hot day, and disseminate this information [95].
- Implement effective transport management in order to reduce traffic congestions and, accordingly, heat and pollutant emissions by vehicles.

For example, France has put in place a so-called “Blue Plan” which involves the arrangement of cool air-conditioned rooms in nursing homes and health care institutions. Purchase of air conditioners maintaining air temperature in such rooms below 25 °C is funded from the state budget [95].

3. Construction and Architectural Measures

- Build sidewalks and parking lots using low thermal conductivity materials. Creating ‘porous’ sidewalks and parking lots (Figure 4.1) has two direct advantages: first, they are less heated than commonly used ones, and, secondly, they perform precipitation infiltration function thereby reducing the risk of flooding and evaporation of moisture penetrated in the soil through the holes also causes a decrease in the temperature over such surface.
- Create as many green areas within the city as possible. The positive effect will be ensured by both green spaces with tree plantings shading the area and preventing additional heating of underlying surface and buildings, and by lawns and flower beds in building surrounding areas (since any unpaved area provides additional evaporation and therefore air cooling).
- Use so-called ‘blue areas’ - water fronts and water bodies [95] Construct fountains, ponds, restoration and proper maintenance of natural water bodies - rivers, lakes.
- Construct roofs and facades of buildings using materials that reflect the maximum possible amount of solar radiation. It is well known that light colours absorb less solar radiation, and, therefore, even repainting exterior walls in light colours will slightly reduce their heating.

Fig. 4.1. Surface of a ‘porous’ parking lot.
• Control the solar radiation penetration inside the premises by specific features of their structure (e.g., using canopies over windows, roller blinds, wooden blinds, etc.) or adjacent tree plantings. The advantages of special orientation of streets and proximity of buildings to produce a shading effect and reduce solar radiation penetrating into the walls and windows are quite contradictory since buildings are operated not only in summer but also in winter when daylight illumination and penetration of solar radiation inside the premises is necessary.

• Provide the highest performing thermal insulation of buildings, which will be useful both in summer, to reduce premises heating, and in winter, to reduce premises heat loss.

• Construct new buildings with structures providing natural ventilation indoor and air movement between buildings.

Flooding

1. Development of flood hazards management strategy

• Identify potential causes of flooding in the city (falling of a significant amount of precipitation in a short span of time, rapid melting of a large volume of snow, rising of water level in urban water bodies, river floods, sea level rise or a severe storm for coastal cities), evaluate its magnitude and map potential flooding zones.

• Evaluate flooding predictability (including accuracy and timeliness of such forecasts).

• Develop in collaboration with the organizational units of the State Emergency Service a plan of action to be undertaken in case of flooding and notify the population thereof.

• Control the flood movement (water path) to cope with the effects of heavy rainfall or rapid snow melt. A pre-built system of protective dykes and ponds that will partially reduce the water flow can be used [95].

• Develop early warning systems to notify the population living in flood risk areas and increase public awareness of the likelihood of flood, its causes, consequences, actions to take during flooding, evacuation means, a list of things to have in one’s possession for a faster evacuation and providing assistance in a more efficient way during a flooding event [95].

2. Organizational Measures

• Ensure strategic planning in river basins: the prohibition of construction in flood plains and coastal areas classified as flood risk areas and evacuating industrial facilities from such areas [37].

• Plan the development of new city districts with due regard for possible flooding of certain territories.

• Develop measures for redistributing the risk of flooding certain territory through increasing the risk of flooding of another territory which is economically less important for the city.
• Arrange for, and ensure proper operation of (if any), meteorological and hydrological stations or posts that will provide necessary information for river flood forecasting.
• Exercise control over spontaneous development of coastal areas. Notify the population living in flood risk areas of changing flood risk due to sea level rise, take appropriate administrative measures.

3. Engineering and Technical Measures
• Modernize and, if necessary, extend the city sewer system to allow for the accumulation of considerable quantities of water during storms [37]. Monitor the regularity of cleaning and maintenance of sewer systems to increase the conveyance capacity of public water supply [95].
• Develop a rainwater management system for the entire city, creating reservoirs for rainwater accumulation and use for commercial purposes [95].
• Protect river banks and banks of other large urban water bodies.
• Restore nearby wetlands that can accumulate large amounts of water in case of flooding [95].
• Reduce water resistant surface and maintain / increase the amount of green plantings in urban areas in order to increase the surface of areas ensuring water infiltration into the soil and reduce the pressure on the drainage system during heavy rains.

This can be achieved by raising public awareness of the positive impact of green space or through encouragements and incentives, allocating land for the creation of new green areas in the city, using “porous” surfaces (see Fig 4.1) to create parking lots near stores and shopping malls. Infiltration ponds can be created in urban parks and green areas.

• Create controlled flood areas in sea coast cities in the event of high tide and the construction of dams and breakwaters in hazardous locations [37].
• For cities that could be potentially flooded as a result of sea level rise the relevant measures should include, first, fighting direct land flooding, second, erosion control measures.

4. Construction and Architectural Measures
• Provide recommendations to construction professionals as to the need to take into account climate change and reduce flood hazards through the development of large-scale infrastructure.
• Design new buildings and infrastructure using appropriate structures and materials resistant to flooding [95].

Materials that can, over a certain time period and without significant damage, withstand direct contact with floodwater include concrete, vinyl and ceramic tiles, glass blocks, metal doors, etc.

• Recommend appropriate precautions to take (raising the floor, electrical fittings and electrical equipment (Fig. 4.3) when carrying out construction in flood hazard areas

Fig. 4.3. Layout of a building in a flood hazard area [91].

• Use removable household appliances that are easily dismantled and do not store on the underground floor any items that can be irreparably damaged by flood.
• Provide for temporary blocking of pipes, drains and toilet bowls using expansion / bag plugs to prevent back flow in case of flooding.
• Use innovations, in particular, green roofs or walls, which can absorb a certain amount of water in case of storm precipitations and thereby reduce flood hazard, tanks for temporary storage of rainwater serving the same function, moreover, rainwater can be used for technical purposes by households, e.g. lawns watering etc., when designing buildings [95].

5. Economic Measures
• Insurance against losses that can be caused by flooding [95].
• Preferential taxation in case of gardening urban building adjacent territory and building surfaces.
Potable Water Quantity and Quality Deterioration

1. Organizational measures
- Raise public (target business, industry and agriculture) awareness as a method to build water saving capacity [95]. Implement educational and training programs on effective water management, far-reaching information campaigns involving radio, television, information leaflets and flyers, social advertising [37].
- Create an emergency water supply system for population and strategic facilities
  A minimum requirement should be developing procedures for providing population with bottled water and water in tanks in hospitals, kindergartens, etc. under similar circumstances [95].
- Develop a strategic action plan in the event of drought and water distribution among consumers in case of limited quantity thereof [95].
- Ensure that plants adapted to arid conditions (according to forecasts) are planted in urban areas to reduce the consumption of water required for their watering. Change irrigation methods, including water amount, regularity, technology, etc. in case of plants that need extra watering [63].
- Develop a rainwater management system for the entire city, creation of reservoirs for rainwater accumulation and use for commercial purposes [95]. Increase volumes of collected rainwater [63] and promoting increased use of rainwater by households (Fig. 4.4)

2. Engineering and Technical Measures
- Explore and develop new underground water sources in the city and the surrounding areas [63].
  In the light of deteriorated quality of surface water the increased use of groundwater from depth horizons will help to ensure the effective functioning of the potable water supply system.
- Improve the efficiency of water use via water recycling. Actively develop of water treatment plants for reverse water supply cycle [63].
- Increase water recycling rate for industrial purposes.
- Introduce additional waste water treatment methods.
  After chemical or physical treatment (micro-filtration) waste water can be used for irrigation or for flushing the toilet.
- Use devices that allow a reduction water consumption at work, at home, in public places [95].
  For example, at home - use of the latest-generation dishwashers and washing machines which consume insignificant amount of water; in public places - use of water taps that respond to human presence and once you remove your hands from it the water ceases to be supplied etc.

Fig. 4.4. Methods for accumulating and using rainwater by private households.
• Take measures to reduce water loss from drainage and irrigation channels, prevent them from being polluted and improperly used.

For example, afforestation to reduce evaporation [63].

• Remove of invasive non-native species of plants from coastal area of water bodies to reduce the risk of their rapid growth or water logging [63].
• Maintain the water supply network in good operational condition to avoid accidents and reduce water loss on the way to the consumer. Carry out periodic maintenance inspections and routine repairs.
• Introducing new technologies for the treatment of water supplied to consumers, and thorough treatment of waste water.
• Improve the potable water quality control system.

3. Economic Measures
• Promote the reduction of water consumption in the industry, energy and everyday life through subsidies, taxes, and penalties.
• Raise penalties for the overconsumption of water during certain (dry weather) periods.

Additional Information
1. Проект руководства по адаптации водных ресурсов и климата. Материалы семинара по адаптации водных ресурсов и климату: Амстердам (Нидерланды), 1–2 июля 2008 г. ЕЭК ООН. – 53 с.

Urban Power Systems

1. Organizational Measures
• Evaluate the impact of climate change on the energy sector, identifying the most vulnerable components thereof in urban areas (e.g., anticipated reduction in electric power production by a hydroelectric power station), simulating future demand for energy, particularly, during its peak periods [37].
• Develop an action plan that will help to reduce energy consumption during peak periods of extremely high summer or extremely low winter air temperatures when a large volume of energy is consumed for air conditioning and additional heating of premises in order to reduce the load on urban energy systems.

The aforesaid action plan may include both measures that can be implemented at the local government level and methods that can be used to encourage measures that can be implemented by individuals, families, apartment building co-owners associations (e.g. heat insulation of apartment walls, doors, installation of new windows, heat insulation of doors and windows in entrances of multistory apartment buildings, etc.).

• Promote measures that will allow a slightly lower air temperature inside premises without using air conditioners (shading with canopies over windows (Fig. 4.5), planting trees for shading low-rise buildings - in summer trees covered with leaves create shadow, and in winter trees stripped of their leaves do not impede the penetration of sunlight into premises).
• Draw up a list of institutions, organizations, and enterprises that require autonomous alternative energy sources in the event of an emergency or interruption of electricity supply (this list shall incorporate hospitals, stations, etc.). Developing a plan to provide them with autonomous energy sources.
• Develop new rules for selecting locations for the construction of electrical power plants or distribution substations in urban area in order to avoid flooding as a result of floods or natural meteorological events.
• Promote the development in the city of alternative energy sources (wind, solar or other), paying special attention to the use of alternative energy sources in private households. To do this, it is necessary first to conduct an information campaign and show the public the benefits of using alternative energy sources (such as cost savings due to water heating in summer using solar energy, etc.). Prior to the construction of wind or solar power plants which will produce energy for the city it is necessary to carry out a thorough study of meteorological conditions of the area with due regard for their expected changes.
• Promote the use of energy-saving technologies by industry and private households, urban population (energy saving lamps, household appliances of energy efficiency class “A”, etc.).
• Engage in targeted business and industry outreach to explain the negative effects of traditional energy sources on the environment as well as possible negative effects climate change may have on the energy sector; encourage the development of an energy conservation culture among population, recognizing the need for energy savings.
• Ensure development of, and strict control over, the compliance with building regulations ensuring high energy efficiency of buildings [90].
• Development and implementation of the overall river basin management system based on human activity carried out within it in order to ensure the most efficient operation of hydroelectric power plants.

2. Engineering and Technical Measures
• Replace fixed assets and equipment of the urban energy system. Ensure that electric power lines are maintained in proper operational condition (carrying out regular maintenance inspections and repairs) since they may suffer negative impacts produced by disasters and extreme weather more often as their frequency increases.
• Create additional highly flexible thermal power plants running on organic fuel to secure service of peak loads in winter [66].
• Temperature, air humidity, and the temperature of the water used to cool condensers affect the efficiency of boilers and turbines of thermal power plants, therefore, in case of a projected increase in summer temperatures it is necessary adopt new technologies that will allow the operation of thermal power plants under such conditions. As an option, where modernization at a given phase is impossible from a financial point of view, use chillers (industrial refrigeration units) for cooling circulating water [66].
• Increase the volume of reservoirs used for producing urban electricity in order to reduce the risk of energy underproduction by a hydroelectric power plant due to decrease in water runoff [82]. Periodic removal of sediment within and around a hydroelectric power plant will ensure smooth water flow [37].

According to [66], global warming will lead to changes in average annual water content of the Dnipro River and, therefore, an estimated reduction in hydroelectric power production by 1–4%.

• Intensively develop and implement all possible measures for conserving energy and energy carriers and implement the policy of maximum possible energy and resources saving in the energy and other sectors.
• If electric power plants are located in an area that could be flooded as a result of climate change, create special protective dams [89]. In addition to electric power stations, sites where coal for thermal power plants is stored should be also protected from flooding.

3. Economic Measures
• Promote the reduction of energy consumption in the industry and everyday life through subsidies, taxes, and penalties.
• Raise prices for overconsumption of energy during peak periods.
• Apply financial incentive plans to companies using energy generated by alternative power sources.

Fig. 4.5. Shading with canopies over windows [81].
Public Health

1. Organizational Measures

- Conduct an information campaign aimed at raising public awareness of the impact of climate change on the emergence of new allergens and spread of certain diseases (including their symptoms and medical aid methods). Develop and publish information and educational materials for different target groups (citizens, journalists, management and staff of health care institutions) on the impact of climate change on public health (for more details regarding the effects of climate change on public health in Ukraine please see Annex B).

- Improve the system of monitoring diseases and pathogens that are affected by climate change and planning relevant disease prevention measures in collaboration with representatives of health care institutions.

- Develop and implement anti-epidemic measures to protect urban populations under the conditions of climate change in collaboration with representatives of health care institutions [21].

- Create a system allowing objective monitoring of the condition of natural objects within the city, primarily water bodies that may provoke poor sanitary and epidemiological situation.

- Analyze the number of health care institutions, evaluate their work, and analyze the possibility of health care infrastructure training on the effects produced by climate change on public health; develop an appropriate action plan and identify possible bottlenecks in the plan implementation. Improve the infrastructure of the health care system since it will experience a greater load as a result of anticipated climate change and spread of new diseases.

- Invite leading experts and conduct topical workshops for health care professionals on diseases that can occur in urban area. These workshops aim to allow experts gaining knowledge necessary for early diagnosis of diseases to increase their chances of successful treatment and prevention of further rapid spread.

- Facilitate effective cooperation between organizational units of the health care system and Hydrometeorological Service in order to establish effective work aimed at preventing the spread of infectious diseases.

- Cooperate with scientific institutions investigating effects of climate change on human health, incorporating the findings obtained into the action plan on urban adaptation to climate change, providing assistance as may be necessary to attract additional funding for research institutions.

In particular, encouraging epidemiological studies concerned with the issue of disease vectors migration and transmission of diseases, cases of tropical diseases and relevant potential impacts for endemic pathogens [37].

- Develop and implement an action plan aimed at reduction of pollutant emissions into urban atmospheric air.

- Promote healthy lifestyles; inform the public about methods that can be used to strengthen their immune system. Create sports area within building surrounding territory and in parks and squares, and hold contests and sports competitions for schoolchildren and students.

- Plan and hold events aimed at improving the sustainability of buildings where health care institutions are located. Providing uninterrupted power supply to such buildings in order to ensure that adequate health care is delivered to the population in cases of natural hydrometeorological events or floods is crucial.

- Provide public access to safe potable water; exercise control over compliance with water disinfection and purification technology [39].

- Put in place additional filters, reserve tanks of fresh water, and replace pipes used to supply water to consumers [29].
The incidence of infectious diarrheal diseases can increase significantly in summer driven by temperature and humidity conditions fostering their spread. The risk of their spread increases significantly in dry periods due to increased concentration of pathogens in reservoirs where raw water is stored. Moreover, the shortage of water can result in forced use of fresh water of inferior quality (for example, rivers that can be contaminated). Using water of poor quality causes many infections (cholera, typhoid, hepatitis A, dysentery, salmonellosis, leptospirosis, etc.) and even non-infectious (digestive system, cardiovascular system, endocrine system, etc.) diseases, often with bad after-effects.

- Relevant public services should have a clear plan for rapid response to floods, and the population should be aware of the need to adhere strictly to the rules of hygiene during such periods (avoid using raw water, wash hands, etc.). Develop and implement a water supply sanitary and epidemiological supervision system in the event of floods [21].

- Improve control over the quality and safety of food products.

- Increase control over quality of urban recreational water (water bodies), which is used for recreation purposes and can serve as a source of infection.

- Identify and control natural foci of disease spread (if any located near the city).

- Install of tablets in parks and gardens and conduct public outreach concerned with Lyme disease (borreliosis).
The first mention of Lyme disease (tick-borne borreliosis) is dated back to 1975, when there was an epidemic of this disease in Lyme, Connecticut, the U.S.A., and the first cases of the disease were reported in 1962 in the United States. Today the disease has spread all over the world (USA, Japan, Sweden, England, Australia, Egypt, Belarus, Moldova, Russia). Climate change has caused the spread of the disease also in Ukraine. As of today the cases of the disease were reported in 23 regions and the Autonomous Republic of Crimea, including the City of Kyiv (in 2006 there were reported 43 cases of the disease, in 2008 - 106 cases, and over 6 months of the year 2009 - 59 cases) [55].

2. Engineering and Technical Measures

- For the purpose of urban greening it is necessary to take into account the allergenic properties of plants and their adaptation to the conditions of urban environment (the list of plants recommended for planting in urban areas is enclosed in Annex B).

3. Economic Measures

- Ensure proper financing for health care institutions in urban areas.
- Improve material and technical base of laboratories [29] and their technical equipment used to identify pathogens sensitive to climate change for the purpose of effective diagnosis of infected people, infected blood components, and infected organs.

### Additional Information


### Urban Green Spaces

The presence of green spaces and individual trees in cities is one of the factors that help to make urban microclimate more comfortable, however they are the most vulnerable to climate change and need the implementation of certain adaptation measures.

1. **Organizational Measures**
   - Develop a green spaces monitoring system to identify ‘dangerous areas’ where fires can occur, plant diseases and pests monitoring systems [37].
   - Conduct far-reaching public outreach concerned with the vulnerability of urban green spaces and methods that can be used to reduce it.
   - Make an inventory of urban green spaces, developing green spaces certificates;
   - Assign certain urban green spaces to organizations, institutions, schools, and higher educational institutions.
   - General urban plans should provide for extending the area and increasing the number of green spaces in cities.
   - Consult experts to identify the types of trees that are better adapted to expected climate changes in a given region and promote their expansion (replacing diseased trees with trees of those types in urban park area) [37].
   - Ensure prompt cutting and removal of trees damaged by wind or any extreme weather [24].
   - Develop and implement an action plan aimed at reducing pollutant emissions into urban atmospheric air in order to minimize the adverse effect of polluted atmospheric air on urban green spaces.
   - Urban green spaces should be maintained only by professionals with relevant education who are able to provide proper care for plants.
   - Create seed plantations near urban areas for a better delivery of local reproductive material [38].

2. **Engineering and Technical Measures**
   - Include water bodies in new green spaces or rehabilitation of old ones as a measure of cooling.
   - Create artificial irrigation systems to ensure optimal conditions for soil moisturizing in dry and hot summer periods (preferably using rainwater).
   - Ensure an appropriate level of agricultural technology, complying with pruning planting technology, tree care technologies.
   - Conduct periodic cleaning and cutting out dead wood to minimize the fire risk [38].
• Recycle trees or branches affected by pests or diseases in order to prevent their further spread to healthy urban trees.
• When planting new parks and squares it is necessary to take into account that the most stable ecosystems are those with high biodiversity.

Such biodiversity can be achieved due to, among other things, stratification of natural grouping. An original "multistory structure", where the upper story is dominated by trees, the medium story consists of shrubs, and the lower story incorporates grass, is observed in natural plant groupings and ensures their stability (Fig. 4.7) [29]. This principle should be followed to ensure a greater stability when designing and planting parks and gardens.

Fig. 4.7. – Storied vegetation structure of a natural grouping [29].

1. Organizational Measures

• Draw up a list of natural meteorological events which are highly probable in a given urban area in collaboration with meteorologists.
• Map territories and draw up a list of important public buildings (hospitals, post office etc.) that may suffer flooding due to heavy precipitation and developing an action plan to mitigate potential negative impacts.
• Develop in collaboration with organizational units of the State Emergency Service a plan of action to be undertaken to overcome disaster impacts and provide aid to affected population.
• Conduct public outreach to notify residents of possible EWEs in the city, their anticipated effects, rules of evacuation in the event of flooding, a list of necessary items to have in one's possession in such a situation, etc.
• Create mobile teams in different districts of the city to provide aid (including first aid measures) to affected people. Arrange workshops involving doctors and representatives of the State Emergency Service to provide training how to render right assistance in different situations.

One of major activities of the Ukrainian Red Cross Society involves providing aid to people who suffered from emergencies. To this end, the National Committee and all regional organizations have entered into agreements with the Ministry of Emergencies of Ukraine and its territorial bodies. The National Committee has a centralized emergency response service, all regional, city and district bodies have warehouses and emergency stock as may be required to provide aid to population affected, and formed 308 first intervention teams. Since the number of people affected as a result of emergency situations is usually high, in December 2011 the Ukrainian Red Cross Society adopted the Resolution of the Presidium of the Board «On the Readiness of Organizations of the Ukrainian Red Cross Society to Provide Aid to People in Emergency Situations», binding its subordinate organizations to, among other things, continue working upon the creation of the Red Cross training centers to teach first aid skills [26].

• Improve and exercise control over the operation of the public warning system used to notify population of possible EWEs and disasters, their scope and anticipated effects.
• Establish close cooperation with other departments of the State Hydrometeorological Service (e.g. a timely forecast of heavy snowfall as delivered to public utilities and taken into consideration by them will allow avoiding transport collapse in the city or at least minimize its scale).
• Develop a plan for providing affected population with potable water and foods in case of emergency.

Measures of Urban Adaptation to extreme weather events

As noted above, extreme weather events (EWEs) include heavy or lengthy precipitation, large hail, strong winds, etc. Key adverse effects of EWEs in urban areas include floods in certain districts of the city or the city as a whole and the destruction of buildings, power lines, broken trees, snow drifts leading to disruptions in electricity supply, disruption of normal operation of urban transport infrastructure, communications failures, disruptions to health care institutions due to damage / flooding / lack of power, failure of food deliveries to some of the city's districts, physical injuries, increased incidence of cold-related and diarrheal diseases due to high concentrations of evacuated residents, increased spread of water related diseases as a result of water supply and sewage failure.
2. Economic Measures

- Develop insurance against losses that can be caused by natural meteorological events (EEA report).

Measures of adapting urban area to, and minimizing the effects of EWEs in cities (floodings and power supply disruptions in cities) are described in details above.

**SUMMARY OF THE CHAPTER**

Thus, adaptation to climate change is possible only subject to concerted action of the city government and residents; therefore, one of the important tasks in the development of urban adaptation strategies consists in holding a far-reaching information campaign focused on different target audiences (from the youngest to the oldest residents). Communications should take place using various means of information transmission to different target groups, but it is important to achieve the main goal: namely, to convince every resident of the city that he/she must play a key role in successful adaptation of the community to climate change and provide information that will help people minimize adverse effects thereof specifically on them (for example, disseminating the Rules of Conduct in the event of hot weather / flood, etc.). It would be expedient to create a web-page on the city’s administration website dedicated to the city adaptation to climate change, where all relevant information will be posted.

In relation to certain adverse effects of climate change it is important to develop a monitoring/early population warning/risk management system to allow at least partially minimizing losses caused by meteorological factors.

Today, when climate change is becoming an ever more important problem, any issue in the city (planning the development of new districts, transport infrastructure development, selecting location for construction of a shopping mall, selecting plants for a new park, etc.) should be resolved taking into account anticipated climate change so that at least these new facilities will be resistant to changes taking place in urban ecosystems.

When developing a municipal adaptation plan it should be appreciated that there are measures which allow dealing at once with multiple negative effects of climate change (e.g., increasing the area and the number of urban green spaces, using porous surfaces for parking lots and sidewalks, etc.) and which, in case of their implementation, will be more beneficial in the context of urban adaptation to the climate change. If the plan is developed on an industry or adverse effect basis, it should be thoroughly evaluated for any actions that could be mutually contradictory. This issue becomes even more important if each section of the plan is supervised by another person.

Moreover, it should be remembered that there are no one-size-fits-all measures, and before developing an urban adaptation plan and implementing it one should consult experts in the relevant field, who know the city well, because only joint teamwork of experts in different fields will help develop a plan which implementation will yield positive results.
CHAPTER 5
Urban Climate Vulnerability Assessment: Case Studies

Three cases studies were worked out using the methodology of climate vulnerability assessment for cities presented in previous chapters. The CVAs and the recommendations for developing an urban climate change adaptation plan were provided below for their approbation with the example of three Ukrainian cities, which are located in different parts of Ukraine and predictably will suffer from different adverse effects of climate change. These are Ternopil, Poltava, and Donetsk. The assessment was carried out experts (V. Vakolyuk – case of Ternopil; O. Illiash – case of Poltava; O. Shevchenko – case of Donetsk) using the results of the national workshops “Supporting regional efforts to develop regional action plans on climate change adaptation” which took place during September and October 2013 in the cities mentioned above.

Representatives of relevant regional state administrations, regional departments of water resources, agriculture, forestry and hunting, regional centers for hydrometeorology, research institutions were involved in discussing the indicators of vulnerability of Ternopil, Poltava and Donetsk to climate change and carrying out the preliminary assessment. Despite the participation of relevant experts, the assessment results can serve as a pilot demonstration showing the procedure of applying the methods and cannot be regarded as the sole basis for developing an action plan on these cities adaptation. A comprehensive assessment of urban vulnerability to climate change using the proposed methodology requires the involvement a working group of experts and a thorough preliminary treatment of necessary statistical information by its members. However, even an expert assessment review of seven groups of indicators allows identifying vulnerable elements of urban ecosystem and can provide the basis for priority adaptation measures.

5.1. CLIMATE CHANGE VULNERABILITY ASSESSMENT OF TERNOPIL

Ternopil, the administrative centre of Ternopil Oblast, is located in the western part of the Right-Bank Ukraine within the Podolia Upland (fig. 5.1). The geographical location of the city fosters temperate continental climate within its territory. Ternopil covers an area of 59 km² and has a population of 217,000 people. In the center of the city there is a large artificial pond, the Ternopil Pond, located on the Seret River.

Studies [6, 7] indicate that the climate of Ternopil and Ukraine as a whole have started changing and this trend is expected to continue in the future, which may lead to material adverse effects on the environment, population and infrastructure of the City.

The vulnerability of the city to climate change was evaluated using the developed methodology with the results of the regional workshop “Supporting Regional Efforts Aimed at the Development of Regional Plans for Adaptation to the Climate Change” held in Ternopil on 12-13th of September 2013. The results of the evaluation in question are given in Table 5.1. The description of risk groups to which the city is exposed to the greatest extent is provided in descending order, from the most vulnerable to the least vulnerable group. Recommendations as to improving the city’s resilience to the climate change have been also provided.

Ternopil is the most vulnerable to flooding (16 points) and hydrometeorological events (14 points). The reason for this is the presence of large water bodies in the city, shallow groundwater, as well as the deterioration of the sewerage and storm water systems. Thus, the abnormal downpour that occurred in June 2013 led to flooding of streets, constrained traffic in the city, caused the de-energizing in certain districts of the city, and people had to wait for improved weather conditions to
leave the premises [27, 54, 74]. This was due to the failure of the city’s sewerage system to deal with large volumes of water. Floods are especially dangerous for the city. There are signs of water erosion, landslides are observed on the slopes of the Seret River. Sudden changes in temperature lead to deterioration of the urban roadway covering.

The second ranked group is the vulnerability of the city’s energy systems (10 points). In particular, the absence in the city of independent sources of energy (conventional and alternative) could provoke a critical situation in the event of emergencies (abnormal downpours, wind gusts). The increased number of days with ice-slick leads to increased frequency of accidents due to power lines icing, resulting in buildings and districts of the city losing power. Depreciation of fixed assets, the increased number of days with abnormal precipitations and temperature rise all cause an increased load on energy systems. For instance, in the night of November 26, 2013 adverse weather conditions (wind gusts, rain and sleet) triggered the power lines protection systems and caused 266 urban settlements to lose power (133 10 Kw power lines, 1130 transformer substations lost power, 17 transmission towers were damaged) in Ternopil Oblast [69, 75].

Table 5.1. Climate Change Vulnerability Assessment of Ternopil City by 7 Indicator Groups.

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<th>Group I.</th>
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<td>The City's Vulnerability to Heat Stress.</td>
<td>The City's Vulnerability to Flooding.</td>
<td>Vulnerability of the City's Green Area</td>
<td>Vulnerability to Hydro-meteorological Events</td>
<td>Vulnerability to Deterioration and Reduction in Potable Water</td>
<td>Vulnerability to Increased Incidence of Infectious and Allergic Diseases</td>
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Groups V and VI — increased incidence of infectious and allergic diseases and vulnerability to deterioration of quality and reduction in the number of potable water scored the same number of points (8 points). In terms of age the city’s population is dominated by residents of working age - 65.7%, who are not especially vulnerable to climate change; however, another significant number of residents is sensitive to sudden temperature drops and high temperatures. In general, the city has a sufficient number of health care institutions (there are 47 beds per 10,000 people in Ternopil, at the same time there are 85.3 beds per 10,000 people in Ternopil oblast; the norm for Ukraine is 75 beds per 10,000 people [40]). UAH 141.4 mln were allocated from the municipal budget for their needs in 2012 [30]. Expenditures of the municipal budget per resident in 2012 amounted to UAH 609.6.

As part of the local environmental program, poplar trees (the pollen of which is an allergen), which have reached their age limit are gradually being replaced with decorative flowered trees of common catalpa (Catalpa bignonioides Walt) ([11, 32, 60]).

Knowledge of response to the impact of natural disasters remain low. The culture of water consumption in the city is also unimposing. Obsolete water treatment facilities being operated since the 1970s (chlorination) deliver poorly-purified potable water. The positive is that the City carries out a scheduled flushing of the municipal pipelines twice a year in spring and autumn [28]. Most enterprises of the City use closed cycling water.

The second to last group is the vulnerability of the city to heat stress (7 points). The Ternopil Pond located within the territory of the city performs not only recreational but also ecological functions; in particular, it has a significant cooling effect on the climate of the city. Its functioning as a “cooler” of the city’s micro-climate will be of greater importance with the rise of temperature in the city which according to the results of forecasting change in monthly average maximum and minimum air temperatures in Ternopil Oblast for the period from 2021 to 2050 compared to the period from 1981 to 2010 shows the rise of the average annual minimum air temperature by 1.1˚C, and the average annual maximum air temperature by 1˚C for the period from 2021 to 2050. [7]

The last vulnerability group relates to the green areas (6 points). This is due to the availability in the city of a large number of objects of the nature reserve fund and a significant amount of green areas. The city’s administration have adopted a program of increasing the number of green areas by replacing asphalt surface of classic parking lots with eco-grass surfaced lots [60].

"For many years the drainage system has been worn out, so now we have set ourselves the task of upgrading it, making all efforts to ensure its efficient operation. The load on the city’s aged water system is also caused by rainwater from new buildings. The developers did not provide for the construction of sewage collectors for them. Therefore, the existing storm sewage system in certain micro-districts is physically unable to drain a large amount of water accumulated during downpours because the existing networks are designed for a much lower capacity”, - Serhiy Nadal, the Mayor, August 2011 [54]

Measures the City Government is Recommended to Take to Reduce the City Vulnerability to Flooding

- investigate and analyse the types and causes of flooding and inundations in the city, their magnitude (area, duration, speed) and develop forecast maps of risk areas based on the findings these assessments.
- develop a system of early warning of the population residing in the flood risk areas.
- improve public awareness of flood probability, causes, consequences, and actions to be taken in case of flood occurrence, and evacuation methods.
- perform proper planning of new districts development taking into account forecasts of possible floods.
- upgrade and where necessary extend the city sewer system for accumulating considerable quantities of water during storm precipitation.
- make sure that the city’s sewer system is regularly cleaned and maintained to increase the conveyance capacity of public water supply.
- Develop a rainwater management system for the entire city, create reservoirs for rainwater accumulation and use for commercial purposes.
- Take measures aimed at protecting banks of large water bodies and streams in the city.
- Reduce the area of water resistant surfaces and maintain / increase the number of green areas in the city (to increase the area of surfaces through which water can infiltrate into the soil, and reduce the load on the drainage system during heavy downpours).
- Design new buildings and infrastructure using appropriate flooding resistant structures and materials;
- Develop measures of redistributing the risk of flooding certain territory by increasing the risk of flooding of another territory which is economically less important for the city.
- Carry out full technical and technological modernization of the existing ground hydrometeorological network (meteorological stations and hydrological stations) to conduct continuous measurements of hydrometeorological parameters that are the factors driving the river flow.
- Place new and resume operation of closed meteorological stations and hydrological stations equipped with devices automatically measuring hydro-meteorological parameters, especially in the areas of the river flow formation;
- Create natural buffer zones, biological shields to mitigate the risk of flooding.

Recommendations Aimed at Reducing the City’s Vulnerability to Natural Hydrometeorological Events

- Draw up a list of natural disasters and extreme weather events which are highly probable in the city.
- Create a map of city territories and draw up the list of important public buildings (hospitals, post office etc.) that may be affected by flooding caused by disasters and EWEs, and develop an action plan to mitigate the negative effects thereof.
- Develop a plan of action for the mitigation of consequences of, and providing aid to people affected by, natural disasters (in cooperation with departments of the State Emergency Service of Ukraine)
- Develop procedures for the population to respond to adverse natural and climatic events, and conduct appropriate trainings.
- Improve the system used to inform the public of hazardous events, for example, transferring information in the form of short text messages by mobile operators.
- Conduct public outreach to notify the city residents of possible EWEs in the city, their possible effects, rules of evacuation in the event of flooding, a list of necessary items to have in their possession in such a situation, etc.
- Improve the efficiency of awareness education in schools and universities on possible climate changes and actions to be taken in the event of adverse climatic (hydrometeorological) events.
- Create mobile teams in different districts of the city to provide aid (including first aid measures) to affected people.
- Develop a plan for providing affected population with potable water and foods.

Some Other Recommendations which Implementation Would Minimize the Adverse Effects of the Climate Change on the City

- Begin keeping statistical records of heat waves in the city and place meteorological stations outside the city to monitor the intensity and nature of the heat island phenomenon in Ternopil.
- Carry out major repairs of sewerage networks and upgrade water treatment facilities.
- Maintain the pond in proper hydraulic condition, strengthen control over the pond balanced use; take measures necessary to avoid the bloom of blue-green algae and prevent the pond shoaling.
- Make an inventory of green space in the city, develop certificates and assign all plantings to the holder.
- Increase the number of green areas in accordance with the general plan of the city, city planning documentation;
- Develop a set of measures designed to increase alternative sources of home heating, replace gradually public transport with those means of transport that produce no air emissions (e.g., electrically driven cars).
- Provide proper financing for health care institutions.
- Continue replacing allergenic trees and plants with crops that provoke no allergic reactions.
- Exercise control over the use of ground water to prevent the subsidence of soils, walkways and automobile roads in the city.

Additional information about the city of Ternopil

Ternopil (49°30’ of north latitude and 25°35’ of eastern longitude), the administrative centre of Ternopil Oblast, is located in western part of the Right-Bank Ukraine. The highest point of the City is 374 m, the lowest point is 298 m, with an average height of the city above sea level of 320 m. As of 2011 Ternopil covers an area of 5,852 hectares (approximately 59 km²), of which 12.4% are objects of the nature reserve fund (Fig. 5.3).
The terrain of the city is predominantly flat, but in some places dissected by ravines, gullets.

The city has sufficient water resources due to the widespread occurrence within the city of underground waters, which are major sources of water for population and enterprises. The capacity of water-bearing strata in Ternopil is equal to 60m, and sometimes it reaches 96m. The horizon is subartesian, and the groundwater surface is located at a depth of 4.5-76m. Mineralized water occurs in deeper soil horizons.

The Seret River valley and an artificial water body, the pond, are located within the territory of the city. Ternopil Pond is an internal artificial water body in the urban environment that has become a self-recovering and self-regulating natural ecosystem. Currently the Ternopil Pond makes part of the regional landscape park “Zagrebellya” and covers an area of 289 hectares.

The climate of Ternopil is temperate continental with warm summers, mild winters and plenty of rainfall (to the extent of 550 mm). Most precipitation fall in summers (about 75%) and least precipitation fall in winters. Downpours, thunderstorms and sometimes hail occur often in summer. Winds are typical for all seasons, especially for the summer. Snow cover is widespread in the city from the second half of December to early March, its thickness varies from 8 to 10cm. Annual precipitation ratio = 0.92. The thermal regime is characterized by continental features (change in large amplitude of temperature fluctuations between winter and summer, which for Ternopil is equal to 23-24 °C). The average temperature of the warmest month (July) is equal to +18 ... +19 °C and the coldest month (January) - 4.5 ... -5°С. The intrusion of continental air leads to significant temperature fluctuations: up to +37°C in summer and -34°C in winter. The duration of the frost-free period is 150-165 days. The plant growing season is equal to 205-209 days, the period of active vegetation development lasts from the first decade of April to the end of October.

According to O.Sofinska, the Head of Ternopil Regional Center for Hydrometeorology of the State Hydrometeorological Service UMNSU, over the past 20 years there was no a single year during which the average temperature in January, February, July and August was within the climatic norm.

According to the presentation at [7] by the Head of the Department of Synoptic Meteorology of the Ukrainian Hydrometeorological Institute of the State Emergency Service of Ukraine and NAS of Ukraine, VA Balabukh, the average annual air temperature for Ternopil Oblast has been higher compared to the average value of 7.2 °C since 1997. Moreover, the number of days with air temperature above 25°C in Ternopil Oblast continuously increased during the period from 1981 to 2009 (Fig. 5.4) [7]. Trends of the city and Oblast air temperature change are indicative of the air temperature rise.

Within the territory of Ternopil there is a variety of parks, gardens, avenues, boulevards. The total space of green areas in the city is equal roughly to 1,888 hectares (32% of the total
area of the city), the area of street green areas (including lawns) is accounted for 60 hectares, house green areas - 13.9 hectares, and flower gardens - 0.34 hectares. The city has ten objects of the nature reserve fund of the city with a total area of 724.91 hectares corresponding to 12% of the city's territory. The regional landscape park “Zagrebellya” counts about 600 species of flora, including five plant species entered to the Red Book of Ukraine (large masterworth, early marsh orchid, snowdrop, turk’s cap lily, whale scutifolious), and six species entered to the List of Rare Wild Endemic Plants of the Oblast that need special protection (Arum Besser, Jugs Yellow, Gray Alder, Daphne, Verbena Officinalis, Common Bladderwort) [60].

The arboretum of Ternopil V. Hnatiuk National Teaching University deserves a special attention in terms of importance and variety of green areas. Unique introduced species occur within the city's territory: 2 white poplars (Populus alba), whose age is more than 200 years, common maple (Acer platanoides) aged over 110-120 years. Botanical natural monuments of local importance include common oak (Quercus robur L.) - 200 years and small-lived lime (Tilia cordata Mill.) - 225 years [60]. As of the end of May 2013 no technical inventory of green space has been carried out in the City [68]. Media and official documents provide different figures ranging from 39.5 to 80 m² per capita (while the recommended WHO value is equal to 50 m² per capita in cities).

Within the City there are no large enterprises causing air pollution with emissions. The economy of the City is based on food, light industries, manufacture of electric and electronic equipment, rubber and plastic products and other non-metallic products (Fig. 5.5) [30].

Heating and hot water supply in the City is ensured by automated individual heat substations for kindergartens and schools, boiler plants, and individual heating systems. Ternopilmiskoteplocomunenergo, a utility company, has created an emergency and monitoring service that automatically controls the operation of heating stations, monitors 22 automatic boiler plants and 34 central heating units [73].

The population of the City counts 216,816 inhabitants (as of 1 October 2013), of which men consist of 46.3% and women of 53.7%. In terms of age the population is dominated by inhabitants of working age (65.7%); the number of inhabitants aged below the working age (below 16 years) accounts for 16.6%, and inhabitants aged above the working age (60 years for women and 65 years for men) for 17.7% [12, 30].

5.2. CLIMATE CHANGE VULNERABILITY ASSESSMENT OF POLTAVA

Poltava, the administrative center of Poltava Oblast, is located in the central part of Ukraine on both banks of the Vorskla River (Fig. 5.6). Poltava covers an area of 112.52 km². The form of the city's territory is orbicular, and the city's population is 296 million people. The location of Poltava within the temperate climate zone causes the formation within the city of a moderate continental climate characterized by mostly cold winters and warm (sometimes - hot) summers, but current Poltava climate research [5−6, 15] indicate that the climate of the city has already started changing as the overall climate of Ukraine and this trend is expected to continue in the future, which may cause significant negative effects.
The assessment of the vulnerability of Poltava to climate change was carried out following the developed methodology. This assessment takes into account the results of national workshop "Supporting regional efforts to develop regional action plans on adaptation to climate change" held on 24-25th of October 2013 in Poltava. Representatives of the regional state administration, regional department for water resources, regional department of agriculture, regional forestry and hunting departments, regional hydrometeorological center, research institutions and experts in relevant fields took part in discussing the indicators of Poltava's vulnerability to climate change and carrying out the preliminary assessment. Table 5.2 incorporates the results of assessment of Poltava vulnerability to climate change.

The results of the assessment carried out show that urban green area is the most vulnerable to climate change (group III. “Vulnerability of the City’s Green Area” scored 16 points) (see Figure 5.7). It is no surprise in case of Poltava which historically has the status of one of the greenest cities in Ukraine, and the population of the city is committed to keep this status. Therefore, these indicators of the city vulnerability are subject to high requirements.

The second rank is shared by VI and VII groups of indicators “Assessment of Vulnerability to Increased Incidence of Infectious and Allergic Diseases” and “Assessment of Vulnerability of the City’s Energy Systems” belonging to the below two groups:

The city’s high vulnerability to the increased incidence of diseases clearly indicates the trends in the sanitary and epidemiological situation in Poltava (and probably other cities of Ukraine), which are observed in the recent years, especially during hot weather periods - meteorological factors (especially rise in the air temperature) is a “catalyst” of amplification and spread of hotbeds of infectious diseases and allergic reactions given the existence of a number of hazards, both natural and production induced.
Energy is one of the most vulnerable sectors of Ukraine's economy as a whole (and, particularly, Poltava) and, therefore, it impacts administrative structures at any level especially in case of additional adverse effect caused by external factors (such as climate).

It is necessary also to give accent to group V “Assessment of Vulnerability to Deterioration and Reduction in Potable Water” ranked third as a result of the CVA. If the trends observed in hydrogeological field in the area of the city location persist against the background of increased exposure to climatic factors and absence of proper monitoring of this issue, this group will become the “leader” for Poltava.

**Recommendations for the City Administration to Reduce the Climate Change Effects.**

The recommendations can be divided into groups according to the indicators that became determinative as a result of assessment of Poltava:

**Recommendations to reduce the vulnerability of the City's green area to climate change and the vulnerability of the City to heat stress:**

1) Give due consideration to proposals in the Poltava strategic development plan (for the period until 2025) regarding the planning of new green areas in the city and reconstruction of the existing ones following the principles that take into account environmental, climatic, recreational and aesthetic norms (particularly by choosing the types of green space on the basis of their capacity to assimilate air pollutants, resistance to climate, in particular, humidity, resistance to pests, etc.);
2) Begin a step-by-step implementation of complete reconstruction and renewal of the City’s dendrological park in the Poltava Battlefield subject to making and taking into account in the existing project current and future climate change, including prolonged growing season and cold period mitigation;
3) Undertake the recovery (subject to appropriate funding) and modern organization of work and interaction between public services of the city in the area of creation and maintenance of garden and park facilities, providing certain budget items to finance the maintenance of the city’s green area during hot weather period and looking for effective means of controlling pests and plant diseases within the city’s green areas;
4) Create (subject to appropriate funding) additional “cool zones” through the construction of artificial lakes and fountain complexes and also the reconstruction and repair of the existing ones;
5) Develop and implement drip irrigation systems for the city’s green areas during hot weather periods;
6) Provide additional shelters (tents) for people in the city’s recreation areas to improve recreation safety during hot weather periods;
7) Develop and organize infrastructure for green tourism facilities in Poltava, including in the green area between Polovky and Sady neighborhoods with cascading natural ponds;
8) Conduct a more extensive public outreach through the city’s media, internet, social advertising, brochures, and topical flyers on the security and health effects of high air temperatures on the people health.
9) Develop a heat wave early warning system.

**Recommendations to reduce the city’s vulnerability to increased incidence of infections and allergic diseases:**

1) Carry out an objective monitoring of the condition of natural water bodies within the city (which have become centers of unsatisfactory sanitary and epidemiological situation in the vicinity) with the involvement of independent experts to determine the reasons for the deterioration of their condition and develop a set of appropriate measures;
2) Implement a set of measures aimed at restoring water bodies and improving the sanitary and epidemiological situation;
3) Plan the city’s greening activities taking into account the allergenic properties of plants and synergy effect in relation to growth of air temperatures;
4) Control allergenic plants using appropriate methods and in a timely manner (especially during the period from June to September), providing for this purpose a special annual item in the city’s budget;
5) Reconstruct the existing city storm water sewer system;
6) Solve the issue of separate collection, sorting and recycling of municipal solid waste (MSW) of the City (which is not directly taken into account in the assessment form, but the issue of MSW is an important technological factor affecting the sanitary condition of the City, especially during the warm season when the air temperature rises), in particular:
   - proper arrangement of container platforms (allowing surface layer draining into storm sewers);
   - disinfecting containers in compliance with applicable regulations;
   - conducting public outreach on the pathogenic risks of waste accumulation places especially during the warm season;
   - fundamental reorganization of the City’s container pool and waste collection machines fleet (this requires significant funding);
– allow interested investors to take part in building a waste processing complex near Poltava (suspended since in 2003).

**Recommendations to reduce the vulnerability of the city energy system**

1) Allocate necessary funding (or working out an investment decision) aimed at updating and modernizing the city’s energy system;
2) Look for alternative energy sources for the city, developing an incentive scheme at the city level to promote the use of alternative energy sources at the local level, especially for socially important facilities.

**Recommendations to reduce the vulnerability of the city to deterioration and reduction in potable water:**

1) Carry out comprehensive monitoring of hydrogeological situation in the area of Poltava’s water supply wells characterized by the creation of cone of depression in recent years. It is expected that the development of this depression cone will result in the loss of potable water resources of appropriate quality by the city; relevant update of forecasts with due regard for climate changes;
2) Carry out further reconstruction and repair of water supply network of the City;
3) Establish an appropriate water management system in the city;
4) Conduct an extensive public outreach among the population, especially among children, pupils, and students, with the involvement of experts, civil society experts, and scientists on the importance of water resources and the need to improve the culture of water use among residents of the city.

**Additional Information on Poltava**

The city of Poltava (49°00’36” of north latitude and 34°00’33” of eastern longitude) is located in the eastern part of Ukraine on both banks of the Vorskla River and is one of the largest industrial and cultural centers of the left-bank Dnipro region. Poltava is located within the East European Plain, Poltava plateau plain and its riverside steep slope. The larger western part of the city is located on a relatively high (150-159 m above sea level) watershed plateau near the Vorskla River valley dissected deep enough gulches into a number of flat-topped outshots. The smaller, eastern part of the city (Podil, Levada, Dublyanschina) is located at the floodplain and, partially, at the first terrace of Vorskla. This territory is dominated by absolute heights from 78 m to 100 m above sea level. The highest City’s peak is located at 161 meters above sea level. From the east the city’s territory is limited by the valley of the Kolomak River near its mouth.

Poltava covers the area of 112.52 km². The form of the city is quite ideal in terms of compactness, i.e. orbicular (Fig. 5.8.). This impacts positively the specific features of the city planning structure, transport junctions, climate particularities and natural halo around the city [46].

![Poltava satellite image](image)

The city is based on a part of the East European platform, the Dnipro-Donetsk Basin with the basement depth of 12 km. The basement sedimentary cover contains rock salt, which lays under the city at a depth of 2 km, building sand, and loess loam.

On the western outskirts the city is dominated by dark gray forest soils and black soils, and turf and meadow soils on the eastern outskirts. 20% of the city area consists of green areas. The city counts more than 30 objects of the nature reserve fund.

The eastern part of the city is dissected by deep gulches. Most gulches and ravines open into the valley of the Vorskla River. The lowland part of the city, the Vorskla river floodplain, accounts for less than a third of the city territory.

As a result of the urbanization process the city’s territory relief is constantly changing to meet the needs of the city development. The main trend in the city’s terrain change relates to its alignment associated with the territory planning during the process of preparation of sites for building [22].

Poltava counts more than 100 water bodies, including 76 ponds with the total area of more than 1,500 m² (total area - 846,700 m²) and 3 rivers: Vorskla, Kolomak and Tarapunka. Vorskla is the major waterway of the City [22, 57].
The major flooding risks in the area of floodplains of Vorskla and Kolomak and their side streams are associated with:

- construction of dams on the Vorskla river that, apart from direct back water effect in the river bed and rise in the groundwater level in the stream part of the valley, reduce the rate of annual runoff and lead to reduced drainage capacity of the stream;
- in aggradation areas, aggradation operations are carried out using fine-grained materials with low filtration capacity or even without removing the natural soil cover consisting of loamy or clay soils;
- patrolling groundwater flow on foundation basis;
- ploughing of the slopes of the river valley and its floodplain, leading to siltation of soil.

Poltava has four fountain complexes, but in recent years they do not operate consistently due to disruptions in water supply. The dispersion of these fountains is large enough so they do not create a “cold belt” to improve the microclimate of the city in the warm season.

City’s Climate. The geographical position of Poltava within the temperate climate zone conditions moderates the continental climate of the city, characterized by mostly cold winters and warm (sometimes hot) summers [62].

The average annual air temperature is equal to 7.6 °C, the lowest indicator is accounted for January (-6.6 °C), and the highest one for July (+20.1°C) [2, 15].

Over the past 100-120 years the average annual temperature in Poltava has increased by about 1.5 °C. 2010 was the warmest year since the records began. The most significant temperature rise has been recorded in the first half of the year.

The dates on which average daily temperature becomes constantly above 0° come earlier (more than a decade) and take place in the middle of the first half of March. Crossing 5° (commencement of active vegetation season) and 10° takes place almost five days earlier – crossing 5° - in late May and 10° in mid–April. The average multi-year date of the last frost in the air falls on mid-April, on the ground - on the first decade of May.

The total average annual rainfall in Poltava in the last decade remains almost unchanged (on average 569 mm). However, we observe their redistribution throughout the year. The amount of precipitation in winter (especially during the period from December to January) has reduced by 25 mm, but is increasing on average in autumn (September-October) for the same value. April is characterized by significant shortfall of precipitations (15-20 mm) creating arid conditions already in spring. Precipitation in summer become increasingly convective and are followed by dangerous events: hail, tornadoes, heavy rains (June-July) and arid weather in August (over the past 7 years the amount of precipitation was only 10-25 mm).

Due to the fact that winter precipitation increasingly falls in the form of rain and sleet, in recent years we observe a trend of dry winters, with unstable snow cover, such as winters 2006-2007, 2003-2004, 2000-2001, increasing the risk of freezing plants, winter crops in case of sudden decline in air temperature. An exception to the aforesaid trend was winter 2010, when snow depth in some places reached 45 cm (the maximum value since the records began).

Therefore, over the past years the climate of the City underwent certain changes which can be characterized by the below main trends:

- increase in the average annual temperature, which during the period from 1991 to 2010 resulted in the air temperature increase by 0.7˚C;
- prompt temperature increase is observed in winter, and in March – April; air temperature in summer months also increase in general but much slower;
- against the background of winter months warming sudden cold waves become especially dangerous as in 2006, 2010 and 2012, as well as unusually hot periods in summer months (1999, 2007, 2010 and 2012);
- average annual amount of precipitations remains unchanged; however, their nature and intensity is changed against the background of increased incidence of hazardous events: hail, tornadoes, heavy rains.

Poltava contains 20 parks, 28 squares, 12 boulevards. In total 360.77 hectares of public green area [46, 22, 23, 17]. While the urban greening norm for urban settlements (with population exceeding 100,000 residents) Poltava refers to is equal to 11 m² per capita (according to Order N 105 of the Ministry of Regional Development, Construction and Housing of Ukraine dated 10 April 2006) the actual level of greening in the city was 12.47 m² per capita (calculated on the basis of 289,325 people permanently residing in the city as of November 1, 2013). Poltava’s green space fund counts 33 natural protected objects, including 32 of local importance, and the Poltava City Park, a natural protected object of the national importance.

Poltava’s phenomenon is first due to the fact that green spaces are tight enough to create a so-called green belt over the City passing through the whole city in several areas.
The natural resources potential, favourable economic and geographical location of Poltava, proximity to large industrial centers of Ukraine such as Kyiv, Kharkiv, and Dnipropetrovsk, have promoted the development of mechanical engineering, chemical, oil and gas, timber, food industries and building materials manufacture. The city counts more than 100 industrial enterprises manufacturing a fifth of the region’s industrial output [46, 23, 57].

The key industry sectors of the city include:
• metallurgical production and manufacture of finished metal products;
• chemical and petrochemical industry;
• mechanical engineering, repairing and mounting machinery and equipment;
• oil, gas and gas condensate industry;
• production of food products;
• light industry;
• production of other nonmetal (mineral) products;
• energy industry.

The food industry and mechanical engineering are predominant.

The population density of Poltava is over 3,000 people / km². As of November 1, 2013 the population of Poltava was 296,346 people of whom permanent residents were accounted for 289,325 people [16].

5.3. CLIMATE CHANGE VULNERABILITY ASSESSMENT OF DONETSK

Donetsk, the administrative center of Donetsk region, is located in the east of Ukraine, to the south of Donetsk ridge. The city lies on the River Kalmius at a distance of 95 km from the Sea of Azov (Fig. 5.9). The geographical location of the City contributes to the formation of temperate continental climate within its territory with cold winters and hot dry summers. Donetsk covers an area of 385 km² and together with neighboring towns constitute Donetsk agglomeration. Its population is 968,000 inhabitants.

Studies [8] show that Donetsk climate, as well as Ukraine’s climate in general, has started changing and this trend is expected to persist in the future, which may lead to serious adverse effects for the environment, population, and infrastructure of the City.

The assessment of the vulnerability of Donetsk to climate change takes into account the results of the national workshop “Supporting regional efforts to develop regional action plans on adaptation to climate change” held on 30 September 2013 in Donetsk. Representatives of the regional state administration, regional department for water resources, regional department of agriculture, regional forestry and hunting department, regional hydrometeorological center, research institutions and experts in relevant fields took part in discussing the criteria for the vulnerability of Donetsk to climate change and carrying out the preliminary assessment. The results of the aforementioned assessment are set forth in Table 5.3 below. The description of criteria groups Donetsk is the most vulnerable to is presented in descending order.
CLIMATE VULNERABILITY ASSESSMENT

Table 5.3. Climate Change Vulnerability Assessment of Donetsk.

<table>
<thead>
<tr>
<th>Group I.</th>
<th>Group II.</th>
<th>Group III.</th>
<th>Group IV.</th>
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<tbody>
<tr>
<td>Vulnerability to heat stress.</td>
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<td>Vulnerability of urban green spaces</td>
<td>Vulnerability to extreme weather events</td>
<td>Vulnerability to Deterioration and Reduction in Potable Water</td>
<td>Vulnerability to Increased Incidence of Infectious and Allergic Diseases</td>
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- from the most to least vulnerable. In addition, this document provides for recommendations for the city government to improve the city’s resistance to climatic events.

Thus, the results of the assessment (see Table 5.3) show that Donetsk is the most vulnerable to Heat Stress (Group I) and Deterioration and Reduction in Potable Water (Group V) each of which scored 16 points.

The city’s high vulnerability to heat stress and quantitative and qualitative properties of potable water is due to the city’s incidental dry summers with high air temperature values that seem likely to continue rising in the future. The overall population structure is dominated by people vulnerable to heat, senior people and people suffering from chronic diseases (the highly polluted air of the industrial region is one of the main reasons for the incidence and development of chronic diseases). In addition, the developed industry of the City, which consists mainly of energy-intensive sectors, is a source of additional heat supplied to the urban atmosphere amplifying the risk of heat stress. Under the conditions of rising air temperature and decreased amount of precipitation in summer [8], and increased frequency of droughts, the river water flow will predictably decrease, evaporation from water reservoirs will intensify and their water levels will reduce accordingly. In Donetsk, where the problem of population water supply is already severe enough, this can lead to an aggravation of the situation. Moreover, the activities of industrial enterprises located in Donetsk require a significant amount of water, releasing considerable amount of poorly treated waste in the city’s water bodies. Another important factor amplifying the city’s vulnerability to water reduction relates to the lack of water management that has been implemented at the city’s government level, and water consumption culture among population. The solution to these two problems would help to save a significant amount of water city-wide.

Donetsk city green areas (group III) are also vulnerable to the climate change (this group scored 12 points). The city’s green area suffers from the change of traditional climate conditions for plants - temperature rise and redistribution of precipitations between seasons, and increased length of the growing season. This has led to the emergence of certain plants, causing the condition of green spaces generally to deteriorate. Furthermore, this creates favorable conditions for the emergence of invasive species of plants and insects, some of which are allergens, adapted to higher temperatures. Poor quality atmospheric air of this industrial city strengthens the adverse effect of climate change on Donetsk green area hindering normal growth and development of green area and causing plant diseases.
The level of contamination in the city according to the atmosphere contamination index (ISA = 14.1) is considered to be very high. Donetsk is entered in the priority list of cities with the highest levels of air pollution in Ukraine. In 2010, the city's air was defined by a very high average annual level of nitrogen dioxide - 4.0 a.d.MPC, formaldehyde - 3.3 a.d.MPC, high average annual level of suspended substances - 1.9 a.d.MPC, ammonia and benzo (a) pyrene - 1.5 a.d.MPC, phenol - 1.3 a.d.MPC, nitric oxide - 1.2 a.d.MPC. The maximum monthly average concentration of benzo (a) pyrene was 6.1 a.d.MPC. The trend of changes in average contamination levels over the past 5 years was defined by increased levels of all agents except suspended substances, phenol, benzo (a) pyrene and some metals. High air contamination level is to a significant degree due to the location of the Donetsk Metallurgical Plant and 3 sites of the coking plant in the central districts of the city and the lack of sanitary protection zones for these enterprises [80].

The city is much less vulnerable to natural hydrometeorological events (group IV) and the increased incidence of infectious and allergic diseases (group VI) each of which scored 10 points. Although meteorologists [8] report an increased recurrence of certain hazardous weather events in Donetsk region (thunderstorms, hail, hail larger than 6 mm, number of squally weather days), the effects on the population and economy in most cases are not very severe due to the peculiarities of physical and geographical location of the City and its structure.

Changing temperature conditions of the territory can cause the emergence of new pathogens and insects conveying infectious diseases or whose bites can cause allergic reactions in allergy-prone people. Donetsk inhabitants living in adverse environmental conditions and having occasional access to proper medical care represent population vulnerable to allergic manifestations.

The City is the least vulnerable to flooding (group II) and the disruption of normal operation of its energy systems (group VII) - 8 points for each of these two groups.

Recommendations to reduce the city’s vulnerability to heat stress

- During hot periods ensure an ongoing reminder in all media of the essential rules of conduct during hot weather, fire safety rules, and awareness raising campaigns on heat wave risks.
- Create as many green areas in the city as possible. Arrange for additional shaded areas for the population in parks, squares, near water bodies during hot periods.
- Create drinking fountains and pump rooms in different parts of the City.
- Create maps of cool zones (parks, squares, lakes) in the City, where people can stay on a hot day, and disseminate this information.
- Build fountains, create ponds, ensure proper care for the natural water bodies, rivers, lakes.

Recommendations to reduce the City’s vulnerability to deterioration and reduction in potable water:

- Develop and implement educational and training programs on efficient water use. Organize workshops on sustainable use of water and the possibility of saving for local businesses, industry and farmers.
- Develop a strategic action plan in the event of drought and water distribution among consumers in case of limited availability.
- When planting trees, a priority should be given to the use of species adapted to arid conditions. Change irrigation methods, taking into account the amount of water, regularity, technology, etc. in case of plants that need extra watering.
- Develop a plan aimed at improving the city’s water resources management.
- Reduce pollutant discharges by public utility companies by setting stricter standards for pollutants levels.
- Improve water use efficiency due to water recycling. Implement water treatment plants for reverse water supply cycle.
- Use technologies that allow reducing water consumption at work, at home, in public places.
- Ensure regular technical checks and maintenance of water supply network to keep it in proper operational condition to avoid accidents and reduce water loss on the way to the consumer.
- Introduce new technologies in treating water supplied to consumers and wastewater.

Recommendations to reduce the City’s Green Area Climate Change Vulnerability

1. In developing the city’s general plan, provide for additional space to increase green area in the city.
2. In consultation with experts, compile a list of tree species that are better adapted to expected climate changes in the region and use these species for the creation of new green areas.

3. Create dendrology centers near the city for a better supply of local reproductive material.

4. Develop a system for monitoring the city’s green areas to identify “problem places” where fire may occur and systems of monitoring plant diseases and pests. Ensure proper disposal of trees or branches affected by pests or diseases in order to prevent further spread to other trees of the city.

5. Make an inventory of the city’s green spaces.

6. Exercise control over prompt cutting and harvesting of trees damaged by wind or as a result of natural hydrometeorological events.

Some other recommendations the implementation of which will help minimize the impact of climate change

- In collaboration with meteorologists make an inventory of natural meteorological events which occurrence is highly probable in the City and create a public warning system of possible EWEs and disasters, their extent and anticipated effects.
- In cooperation with civil society organizations, monitor vulnerable groups (identify them, and their location in the city) and coordinate them in case of hot weather, flooding, natural disasters, etc.
- Undertake timely planning of river basins to reduce the risk of flooding certain areas (prohibition of construction in flood plains and coastal areas classified as flood hazard zones, and removal of industrial facilities from such areas).
- Undertake the modernization of the city’s sewage system to enable the intake of large quantities of water in case of storm precipitations and ensuring control over the regularity of cleaning and maintenance thereof.
- To increase the area of surfaces through which water can infiltrate into the soil and reduce the pressure on the drainage system during heavy rains – reduce water resistant surface and maintain / increase the number of green area in the City.
- Develop an action plan that will help to reduce energy consumption during peak periods of extremely high summer or extremely low winter air temperatures when huge volume of energy is consumed for air conditioning and additional heating of premises in order to reduce the load on the City’s energy system.
- Develop an incentive scheme encouraging measures that allow slightly lower temperature in the premises without using air conditioners.
- Draw up a list of institutions, organizations, and enterprises that require autonomous alternative energy sources in the event of an emergency or interruption of electricity supply (this list shall incorporate hospitals, stations, etc.). Develop a plan to provide them with autonomous energy sources.
- Promote the use of energy saving technologies by industry and private households, residents of the city (energy saving lamps, household appliances of energy efficiency class “A”, etc.).
- Ensure the replacement of fixed assets, equipment of the city’s energy system. Ensure that power lines are maintained in proper operational condition (through regular technical checks and repairs).
- Conduct a public outreach campaign aimed at raising the awareness of the population of the impact of climate change on the emergence of new allergens and spread of certain diseases (including their symptoms and methods of health care delivery).
- In collaboration with representatives of health care institutions develop and implement antiepidemic measures to protect the population from the adverse effect of the climate change.
- Provide the population with access to safe potable water in case of EWEs and disasters.

Additional Information on Donetsk

Donetsk (48°00'32" of north latitude and 37°48'15" of eastern longitude), is the administrative center of Donetsk region. The city is located in the steppe zone in the east of Ukraine, south of Donetsk ridge. The city’s average height above sea level is 169 m. Donetsk territory consists of a hilly upland strongly rugged by ravines and gulches with altitude difference within the territory of Donetsk of 120 m. In the city there coal mines operate and 125 spoil heaps. The total area of Donetsk is 385 km². The city is oriented from west to east. In this direction its length is equal to 55 km (while from north to south - 28 km). The city’s shape looks like an isosceles triangle. The city, together with neighboring towns, constitutes Donetsk agglomeration, the largest industrial hub of Ukraine.

In the city there are four small rivers running from north to south, the Asmolovka (13 km), the Cherepankyna (23 km), the Smoroshka, the Bahmutka, and the Kalmius rivers which serve the basis for the construction of Nyzhnikalmiuske water reservoir, which is located in the city center, and is actually a cascade of two reservoirs separated by a dam (62 + 38 hectares). All together, 18 small artificial ponds were built on the basis of the city rivers. The largest water reservoir in the
city, is an artificial water body with the water surface area of
206 hectares and maximum depth of 17 m, is located on the
southern outskirts of the city. Nevertheless, in recent years [19]
a decrease in the water level by approximately 4 m has been
reported, along with a shoreline retreat of 20 - 30 m.

The city’s location on the watershed of the basins of the Siverskyi
Donets River and the Sea of Azov geographically conditions
the low water level of this territory and makes the issue of the
city water supply especially sensitive. Coal extraction as carried
out in the region for nearly two centuries has resulted in the
dehydration of the territory, being an inevitable consequence
of large-scale mining industry development. However, many
enterprises operating in Donetsk agglomeration use water in a
very irrational manner. Large amounts of untreated and poorly
treated wastewater re discharged into the rivers. This water
could be multiply reused in reverse water supply systems [20].

Donetsk is subject to a temperate continental climate with cold
winters and hot dry summers. The average air temperature in
January - 4 °C, in July - +25 °C. The maximum air temperature
since the records began was reported during a strong heat
wave in summer 2010 and reached +39.1 °C. North-east and
east winds prevail in winter and north-west and west winds
prevail in summer. Annual amount of precipitations is equal
to 492 mm and their major part falls in June and July (65 and
51 mm accordingly). Precipitation falling during the hot and
dry summer period falls during intense, severe thunderstorms.
The temperate continental climate is defined by low humidity
the whole year around. The duration of the frostproof period is
190 – 200 days on average.

Climatic summer comes in Donetsk usually in early May and
lasts until the end of September (130-140 days). However, in
hot weather years summer could last almost six months from
mid-April to mid-October. According to V.O. Balabukh [8] the
average, maximum and minimum air temperatures are con-
tinuously rising in recent years in Donetsk and Donetsk region
(Fig. 5.10). The number of frost days is decreasing and accord-
ingly the number of days with air temperature below -10 °C
is being reduced. The trend of winter mitigation in Donetsk
region has been observed since the beginning of the XXI cen-
tury. The length of the growing season is being increased and
the number of days with maximum air temperatures above
+25 °C has risen (Fig. 5.11).

In recent years, we observe the redistribution of the precipita-
tions amount during the year – quantities decrease in summer
(amplifying the drought incidental to this season) and increase
in transitional seasons. Increased incidence of certain hazardous
natural events in Donetsk region, such as thunderstorms,
hail, hail larger than 6 mm, number of days with squalls have
also been observed [8].

Donetsk is a green city with a significant number of parks
and gardens (12 and 94 respectively). The total space of the
city’s green area is equal to 18423.2 hectares. Many parks are
the property of local companies. Donetsk Botanical Garden,
located in the eastern part of the City along Bohodukhivska
Gulch, is one of the largest in Europe in terms of its territory
- 262.2 hectares. Just in 2013, 9042 new trees were planted in
Donetsk [72]. In the 1970s the City was called as “the city of
roses”, and in the early XXI century Donetsk regained the status
of a city with one rosebush per inhabitant. In 2010 the City
counted 1,096,000 rosebushes (Fig. 5.12).
Donetsk contains more than 220 enterprises, including Donetsk Metallurgical Plant (approximately 9% of steel production in Ukraine) and coal mining enterprises (mines). Furthermore, Donetsk is the center of the chemical industry in Ukraine. Large chemical plants, such as Donetsk Chemical Reagents Plant and Donplastavtomat, are located in the city. Generally speaking, the city industry incorporates almost all sectors. However, in terms of the quantity of sold products, the city industry is dominated by metallurgical production and manufacture of finished metal products - 25%, manufacturing and distribution of electrical power, gas, and water - 24.8%, and coal sector - 20.4% [47] (Fig. 5.13).

DonetskMiskteploerezha, a Donetsk City Council Public Utility Company manufactures, transports, and supplies heat energy and hot water to different categories of consumers using boiler plants, heat stations, boiler and heat supply networks. The company covers approximately 85% of the City demand for heating supply [48].

The city has 968,000 inhabitants (of whom women consist of 55%). The life expectancy of women in Donetsk region is equal to 73 years, which is 13 years longer than the men’s life expectancy in the region. Negative demographic processes affect changes in the age structure of the population. Over the past three decades, the share of people of old age increased by 35% while the percentage of working population reduced twice as small as [9]. Changes in the age structure of the population of Donetsk region are marked by the ongoing increase in the percentage of people of old age against the background of a significant decrease in the percentage of children of the total population.

Outcome of case studies

The territory of Ukraine is defined by a variety of geographical and physical conditions. Accordingly, climate change in different regions also varies significantly. With an approach dividing the territory of Ukraine into five regions, particularly, western, southern, eastern, northern, and central regions, we have focused on three cities representing different regions of Ukraine: Ternopil, a city located in Western Ukraine; Poltava, Central Ukraine; Donetsk, Eastern Ukraine. The findings of the three cities assessment show that the cities differ not only in terms of their geographical conditions, but also in terms of the negative impacts of climate change that the cities are most vulnerable to. All this indicates the necessity for taking into account individual features and needs of the cities in developing climate change adaptation measures.

Therefore, according to the findings of the vulnerability assessments of Ukrainian cities as carried out in the form of the case studies of Donetsk, Poltava, and Ternopil, Donetsk has proven to be the most vulnerable to the climate change among them. The city’s scores in total (for all groups) was 80 points (cf. 168 worst possible score as provided for by the assessment) or 48%. Each of Poltava and Ternopil scored 71 points or 42%. There is no surprise that none of the cities has hit the maximum possible score according to the findings of its vulnerability assessment (and 100% accordingly) because criteria groups include all major adverse effects of climate change (which can be observed in cities located in different geographic regions) and it is obvious that some of them usually do not manifest simultaneously. However, in respect of each of the cities we have identified a vulnerability criteria that hit the same high score indicating the most hazardous climate change effect for a given city: in case of Ternopil this was flooding; in Poltava, the vulnerability of the city’s green spaces; while in Donetsk, the main vulnerability was to heat waves and lack of potable water.

The assessment of the vulnerability of other Ukrainian cities would allow the development of opinions as to regional
trends in urban climate change and the identification of which Ukrainian cities are the most and the least vulnerable to climate change. This information would facilitate the development of measures aimed at urban adaptation to climate change and assist local governments in carrying out effective public outreach in case of adverse effects of climate change and preventing their occurrence as much as possible.
Conclusions

The Ukrainian climate investigations show that in recent decades the temperature and some other meteorological parameters differ from the climate norm (1960-1990). The average annual air temperature over the past twenty years (1991-2010) with respect to this indicator has increased by 0.8°C. Precipitation redistribution occurred between regions of Ukraine and seasons (although total annual amount of precipitation remained virtually unchanged) and the incidence of certain EWEs such as very heavy rain, strong winds, very heavy snowfall, dense fog, etc., and heat waves increased.

Forecast climate projections for Ukraine indicate that the air temperature in general will continue to increase. Further change in the amount of precipitation within a year will result in a shift of climatic seasons, change in the growing season duration, reduced duration of stable snow cover, changes in local water resources flow, etc.

The effects of climate change frequently have an adverse impact on the urban environment. The concentration of a large population in cities, specific features of local microclimatic which may aggravate certain adverse effects of the climate change, change in prevailing bedding urban surfaces, high-rise buildings, availability of public transport network and well developed infrastructure (which may suffer from adverse effects of the climate change and cause essential discomfort to the city’s population), make cities much more vulnerable to the climate change compared to other urban settlements.

Major possible adverse effects of climate change, which may occur in cities, include heat stress, flooding, reduced space and deterioration of the species composition of urban green area, increase in frequency and intensity of extreme weather and disasters, reduction and deterioration of potable water, increased incidence of infectious diseases and allergic manifestations, disruption of the normal operation of urban energy systems.

To assess urban vulnerability to adverse effects of the climate change we have developed seven groups of indicators to identify the most risky effects of the climate change for a given city and determine for which of them an urban adaptation plan is necessary, recommended or unnecessary.

The indicator groups were tested in assessing the vulnerability of the cities of Ternopil, Poltava and Donetsk, located in three climatic regions of Ukraine - Western, Central and Eastern. First results of the investigations were obtained in the course the government workshops “Supporting Regional Efforts to Develop Regional Climate Change Adaptation Plans” which took place in the aforementioned cities in September-October 2013, and by individual experts involved in the assessment of these cities vulnerability independently from the workshops participants.

To facilitate the development of an urban adaptation plan we have drawn up the list of adaptation measures (based on individual effects) and worked out the essential guidelines for the development thereof:

1. Urban adaptation to the climate change requires a multifaceted approach and the implementation of measures at different levels.
2. When developing an urban adaptation plan it should be appreciated that there are measures which simultaneously address multiple adverse effects of the climate change and which, in case of their implementation, will be more beneficial in the context of the city adaptation to the climate change.
3. If the plan is developed on an industry or adverse effect basis, it should be thoroughly evaluated for any actions that could be mutually contradictory.
4. In relation to certain adverse effects of the climate change, it is important to develop a monitoring / early warning / risk management system to allow for at least partial minimization of losses caused by meteorological factors.
5. Thus, holding a far-reaching information campaign focused on different target groups (from the youngest to the oldest residents) is one of important organizational tasks in the development of urban adaptation measures.
6. Today, when the climate change is becoming ever more important problem, any issue in the city (planning the development of new districts, transport infrastructure development, selecting location for construction of a shopping mall, etc.) should be resolved taking into account the anticipated climate change so that at least these new facilities will be resistant to changes that occur in urban ecosystems.
As the climate change intensifies, many water related risks will aggravate. However, the anticipated adverse effects can be mitigated and to some degree minimized due to the development and proper implementation of the city adaptation plan (with due regard for specific features of a given city and the anticipated climate change). It is therefore important to consider the results of the assessment of urban vulnerability to the climate change in urban development master plans for Ukrainian cities and local climate change adaptation plans.
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Annexes

ANNEX A

Rules of Conduct During Heat Waves

• Consume at least 2.5-3 liters of water per day (mineral water, green tea, compotes). Drink fresh but not cold beverages. Avoid drinking carbonated and soft drinks, alcoholic and low-alcoholic beverages.

• Avoid prolonged stay in direct sunlight, especially if belonging to vulnerable social groups, for example, children should avoid staying in direct sunlight for more than 10-15 minutes. Clothes should not be excessively revealing and should help to avoid sunburn and reduce water evaporation from skin surface. Use sunblocks, wear Panama hats, head scarves. Use visors and sunglasses to protect your eyes.

• Stay at home without needing much going outside (if this can not be avoided wear light and airy clothes made of natural fibers that do not pinch vessels). Wear headdress if going outside. This applies especially to persons aged over 55 years and children.

• Avoid acute exercises from 12:00 p.m. to 5:00 p.m. because heat creates significant heart load without physical activities.

• Eat more fruits and vegetables to compensate the loss of potassium.

• Avoid energy food.

• Avoid taking exercises because physical load increases the thermal exchange fivefold, which can lead to body dehydration. Go to the swimming pool in the event of hot weather.

• Swimming in water bodies allows efficient body cooling. Follow swimming rules and avoid consuming alcoholic beverages. Avoid staying on the beach from 10 a.m. to 4 p.m.

• To escape from the heat and refresh the body you may undergo other water procedures, in particular, often rinse your hands and face during the day, sponge your body with a towel wet with cold water and take a shower twice a day (these are compulsory procedures in the event of hot weather in summer), walk along water bodies which create a more comfortable microclimate.

• During hot periods change your routine day regimen, go to bed and wake up earlier, when it’s still cold outside, and at least manage your chores during the hours of morning coolness.

• If possible, minimize your use of urban land transport, walk in case of short distances and take the subway in case of long distances.

• Minimize or avoid smoking.

• Avoid prolonged driving because heat seriously affects vigilance and concentration of drivers, reactions, and, accordingly, increases the number of accidents.

• At night, when the temperature decreases slightly, open windows and air the room. To keep comfortable temperature in the room close and cover windows apart from periodic airing only.

• Carry out daily wet cleaning.

• Arrange for fresh air access (extensive aeration) to premises where children stay including during the daytime and nighttime sleep, but avoid drafts.

• If using air conditioners please remember that the difference between the indoor and outdoor temperatures should not exceed 10° C. In addition, periodically turn off the air conditioner and air the room.

• To create more comfortable conditions indoors during hot periods provide additional air humidification. To do this put a container with water on the table (in this case, you may use an aquarium).

• To avoid acute intestinal diseases and food intoxication follow safe food regulations:

  - in hot weather avoid purchasing convenience foods, confectionery, cream products and ready-to-eat salads and other perishable food products;
  - avoid buying products on unregulated ‘spontaneous’ markets and points of sale;
  - check the expiry date and storage conditions of food products when buying them;
  - when cooking adhere to personal hygiene rules, cooking technology, avoid cooking ‘in reserve’;
  - when camping or gipsying avoid eating junk foods, especially perishable ones, keep food products in cool boxes etc.
ANNEX B

Possible Impacts of Climate Change on Public Health in Ukraine

- Sudden warming can cause drying of peat bogs in the north of Ukraine and Polissia entailing frequent fires and, consequently, increased incidence of allergic and asthmatic diseases.
- Frequent downpours and coastal cities flooding can cause a deterioration of potable water quality entailing increased incidence of intestinal and infectious diseases rarely or never reported in Ukraine (leptospirosis, cholera, hepatitis A, salmonella, etc.).
- The rise in air temperature can result in the invasion of insects from Africa, Middle East and Mediterranean, the bite of which cause allergic reactions; in the south and in the east - invasion of venomous spiders which bites are dangerous (sometimes fatal) for humans.
- Increased air temperature and humidity in the south can lead to the invasion of ‘malaria’ mosquito carrying malaria, Rift Valley fever and other infectious diseases.
- The number of ticks is increasing across the country resulting in the increased incidence of tick-borne borreliosis (Lyme disease) and tick-borne encephalitis.
- As a result of climate change living conditions in Ukraine will be better compared to those in other (southern) countries; we expect an increased steam of climate refugees and, consequently, the appearance of infectious diseases that are atypical for Ukraine, and increased incidence of already known infectious diseases (HIV/AIDS, hemorrhagic fever with renal syndrome, hepatitis C, atypical pneumonia, etc.).
- Mold/dampness caused by flooding provoke the development of cough, phlegm, or breathing troubles and can cause allergic reactions.

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2 According to [71]
ANNEX C

List of Plants Recommended for Planting in Urban Areas

<table>
<thead>
<tr>
<th>Specie name in Latin</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armeniaca vulgaris L.</td>
<td>Ornamental (early flowering)</td>
</tr>
<tr>
<td>Betula pendula</td>
<td>Requires watering, fertile soil</td>
</tr>
<tr>
<td>Ginkgo biloba</td>
<td>Gas pollution resistant, does not require special soil, resistant to fungus and virus diseases, hardly damaged by insects.</td>
</tr>
<tr>
<td>Crataegus</td>
<td>Good topiary characteristics</td>
</tr>
<tr>
<td>Juglans regia L.</td>
<td>Quick shoot of wood</td>
</tr>
<tr>
<td>Juglans mandshurica</td>
<td>High dust catching rate</td>
</tr>
<tr>
<td>Sorbus aucuparia</td>
<td>Shadow sustainable, frost resistant, ornamental</td>
</tr>
<tr>
<td>Carpinus betulus L.</td>
<td>Non-demanding, easy crown formation (live fences, bowers)</td>
</tr>
<tr>
<td>Quercus robur</td>
<td>Light demanding, used for slope stabilization. Phytoncides of oak leaves kill stable germs — dysentery bacillus</td>
</tr>
<tr>
<td>Quercus rubra L.</td>
<td>Wind stable, not demanding as to soil fertility, sustains acid soils, does not sustain limy and aqueous soils</td>
</tr>
<tr>
<td>Acer platanoides L.</td>
<td>Shadow sustainable, frost resistant</td>
</tr>
<tr>
<td>Acer negundo</td>
<td>Frost resistant, non-demanding, up to 95% establishment rate</td>
</tr>
<tr>
<td>Tilia cordata Mil.</td>
<td>Valued as a soil shade tree, prevents dust pollution</td>
</tr>
<tr>
<td>Platanus orientalis</td>
<td>Fast growing, long term plant. Light demanding and moisture loving</td>
</tr>
<tr>
<td>Robinia pseudoacacia L</td>
<td>Draught resistant, salt resistant, soil demanding. For slope stabilization purposes.</td>
</tr>
<tr>
<td>Populus alba L.</td>
<td>Fast growing, light demanding</td>
</tr>
<tr>
<td>Populus nigra L.</td>
<td>Light demanding, moisture loving</td>
</tr>
<tr>
<td>Malus</td>
<td>Ornamental</td>
</tr>
<tr>
<td>Picea glauca4</td>
<td>Evergreen, phytoncide. Lateral root system, requires watering.</td>
</tr>
<tr>
<td>Juniperus sabina L.</td>
<td>Evergreen, ornamental, draught resistant, frost resistant. Used for sand binding, border tree. Easy establishing.</td>
</tr>
</tbody>
</table>

3 Prepared by WWF Ukraine with the participation of experts from Hryshko Botanic Garden
4 Alien species