Vulnerability and Adaptation in the Ukrainian Cities under Climate Change

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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 concentration of a large number of the population in cities and increase in Ukraine urban population (in 2012 – up to 68%), specific features of local microclimate which may aggravate certain adverse effects of climate change in the cities, 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. Despite the importance of this issue and lack of climate change adaptation measures in General urban plans for Ukrainian cities, research of the vulnerability and adaptation of a big cities in Ukraine have been started just few years ago (Shevchenko *et al.*, 2014b).

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.

Studies of the Ukrainian climate indicate that in recent decades the air temperature and some other meteorological parameters differ from the long-term average (average values for the period 1961−1990). According to Balabuch (2013) the average annual air temperature over the past twenty years (1991−2010) has increased by 0.8°C compared to the 1961−1990 average (Table 1). Also there were observed changes in extreme (maximum and minimum) air temperatures.

Table 1. Temperatures anomalies in 1991−2010 years compared to the 1961−1990 (prepared using Balabuch (2013) data) (°C)

Characteristic/Season	Winter	Spring	Summer	Autumn	Year
Mean air temperature	1,0	0,6	1,1	0,3	0,8
Maximum air temperature	0,8	0,7	1,3	0,2	0,8
Minimum air temperature	1,2	0,4	1,0	0,4	0,7

Redistribution of precipitation was recorded both in terms of regions of Ukraine and seasons (Table 2). 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 (Balabuch, 2013).

Table 2. Anomalies of amount precipitation in 1991−2010 years compared to the 1961−1990 (prepared using Balabuch (2013) data) (%)

Characteristic/Season	Winter	Spring	Summer	Autumn	Year
Anomalies of amount precipitation	-9,3	4,8	-2,0	20,5	3,1

Extreme weather events and disasters are the most dangerous impact of climate instability. 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 (Extreme weather events on the territory of Ukraine during last two decades (1985−2005), 2006). During 1986−2010 in Ukraine 1355 cases of heavy rain were recorded (44 % of all extreme weather disasters for that period). The frequency of heavy rain can vary to a significant degree from year to year depending on synoptic processes, but during last 25 years their number has increased significantly – from 216 cases in 1986–1990 to 268 cases in 2006–2010 (Osadchiy and Babichenko, 2012). The number of cases of some other natural meteorological events (heavy fog, severe snowstorm, large hail, stormy winds and squalls) also increased (Osadchiy and Babichenko, 2012).

Atmospheric phenomena that may cause significant adverse effects include also heat waves. At almost at all regions of Ukraine the highest incidence of this phenomenon over the past century has been observed during the last decade (2001−2010). (Shevchenko *et al*., 2014a). The heat wave recorded at the

end of July−August 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.

So, results of researches show 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 modeling show that the air temperature will continue to increase (although the magnitude of change is some what 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. (Snizhko *et al.*, 2012, Shevchenko *et al*., 2014b).

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 Ukraine, a settlement can be assigned the urban status if its population consists of at least 10,000 inhabitants. The largest cities of Ukraine (according to the State Statistics Service of Ukraine, 2013) are Kyiv, Kharkiv, Odesa, Dnipropetrovsk, Donetsk, Zaporizhzhia, Lviv. In most developed countries urban population reaches 75–80% of the total population; in Ukraine this figure 68%.

One of the features of modern urbanization is a significant concentration of the population primarily in large cities and, accordingly, their further growth. Thus, we 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 combination of the negative effects of urbanization and climate change as observed in cities create a unique urban problems that are not incidental to other types of human settlements (Cities and Climate Change, 2011). The main potential adverse effects of climate change in Ukrainian cities include: heat stress, flooding, reduced areas and disturbance of biodiversity in urban green areas, extreme weather events, reduced quantity and quality of potable water, increased incidence of infectious and allergic diseases, disturbance of normal operation of urban electric power systems.

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.

Urban flooding can be caused by fall of a significant amount of precipitation over a short time period, 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) 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.

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 m^2 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 m^2/resident; for cities with population of 100,000 and more it is 10−15 m^2/resident.

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. There are some factors, which can significantly influence on urban green areas vulnerability increasing: change of temperature, amount of water, duration of vegetation period (caused by climate change); new diseases and pests can pose a significant threat to urban plant groups; urban air pollution; the work of municipal services departments engaged in green areas care; lack of the free spaces for the new building and the reduction green area in the city center etc.

Extreme weather events include the phenomena: very heavy rain; very heavy snow; heavy downpour; long-lasting rain; large hailstones; strong wind (including storms, tornadoes); severe snowstorms, severe dust storms; strong ice-slick 20 mm or more in depth; heavy fog; sleet deposits and some other manifestations (Extreme weather events on the territory of Ukraine during last two decades (1985−2005), 2006). Extreme weather events can block the normal functioning of city infrastructure and cause other negative effects.

Vulnerability to poor quality potable water and reduction of potable water stock. There are some factors, which can significantly influence on water supply of city inhabitants. They include: a lack of sufficient sources of water supply in the city and the use of imported water; using water from surface sources increases the probability of a degradation in its quality and/or a decrease of water resources as result of changes river flow; negative trends in river flow and its forecasted further decline; large industrial facilities (which use significant amounts of water and discharge of wastewater in cities water bodies); bad state of water supply network.

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.

Extreme weather events 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.

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.

2. Electricity generation and supply to consumers.

Abnormal precipitations and certain extreme weather events can lead to damage of electric lines and electric power supply disruption, as well as destruction of electric power substations.

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.

Thus, climate change vulnerability of cities is determined not only by climate change manifestations on certain territory, but is determined by number of factors, including:

- Social factors – as city's population structure and not adequate health care;
- Urban infrastructure (for example, lack of or poorly maintained storm drainage is the reason of increasing of vulnerability to flood);
- The prevalence of artificial surfaces in a city (the high risk of flooding and additional heat in the city);
- Urban air pollution (negative impact on the plants and humans, so higher vulnerability of urban green spaces and the causes of increasing of allergic diseases and others.

Climate vulnerability assessment of Ukrainian cities. Because of the influence a lot of different factors on cities vulnerability to climate change, it would therefore be wrong to expect for all the big cities of Ukraine the same climate change consequences. To determine the degree of urban vulnerability to the adverse effects of climate change, we used methodology, specially developed for this.

According this methodology there are 7 groups of indicators. Every group intended for assessment to city's vulnerability to certain adverse effects of the climate change (for example, Group I − for vulnerability assessment to heat stress, Group II − for flooding etc.). To determine the most dangerous effects of climate change for a city it is necessary to analyze each indicator in every group, fill in the special assessment form, 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. More detail about methodology see in Shevchenko *et al.* (2014b).

For climate vulnerability assessment we have chosen 7 Ukrainian cities – Donetsk, Khmelnytskyi, Lviv, Odesa, Poltava, Ternopil, Uzhgorod, which situated in different part of the territory of Ukraine (Figure 1, Table 3). Few of these cities situated on the west of the country, but it is because quite different conditions in this region caused by Carpathian Mountains.

Figure 1. Location of the cities in Ukraine used in this investigation.

Table 3. Characteristics of the Ukrainian cities used in this investigation.

The city name	Latitude	Longitude	Region	Elevation (m a.s.l.)	Area (sq.km.)	Population (thousand people)
Donetsk	48°00´32´´N	37°48´15´´E	East	169	385	968
Khmelnytsky	49°25´10´´N	26°58´46´´E	West	295	93,1	266
Lviv	49°49´48´´N	24°00´51´´E	West	289	182	729
Odesa	46°28´18´´N	30°42´37´´E	South	50	162,4	1015
Poltava	49°00´36´´N	34°00´33´´E	Central	155	112,5	289
Ternopil	49°33´12´´N	25°35´41´´E	West	320	59	217
Uzhgorod	48°37´26´´N	22°17´42´´E	West	120	40	116

The vulnerability to climate change was evaluated using a lot of different dates for every cities – climatology data (air temperature, precipitation, vegetation period duration, heat waves, manifestation frequency of extreme weather events), characteristics of water bodies and green area, which situated in the city of near it, information about industrial enterprises and motor transport (including it dynamics), population structure, quality of health care (especially, emergency medical care), information about flooding and it reasons, air quality, invasive species in city green areas, urban infrastructure, sources of water supply of the city, statistics about incidence of infectious and allergic diseases etc. The results of the evaluation are given in Table 4.

Table 4. The results of climate change vulnerability assessment of Ukrainian cities

City	Donetsk	Khmelnytsky	Lviv	Odesa	Poltava	Ternopil	Uzhgorod
Vulnerability to heat stress	***16***	11	***15***	***16***	10	7	13
Vulnerability to flooding	8	6	6	***17***	9	***16***	7
Vulnerability of urban green spaces	12	14	10	***22***	***16***	6	***17***
Vulnerability to extreme weather events	10	8	8	14	8	14	8
Vulnerability to deterioration and reduction in potable water	***16***	6	7	10	10	8	12
Vulnerability to increased incidence of infectious and allergic diseases	10	10	10	14	12	10	12
Vulnerability of the city's energy systems	8	10	8	14	12	10	12
Σ	80	65	64	107	77	71	81

On the basis of the results of climate change vulnerability of Ukrainian cities, in seven cities in three is extremely vulnerable green areas (Odesa, Poltava and Uzhgorod) − they scored more than 14 points, three very vulnerable to heat stress (Donetsk, Odesa and Lviv), two – to flooding (Odesa and Ternopil) and Donetsk is vulnerable not only to heat stress, but also to deterioration and reduction in potable water.

Among all researched cities Odesa is the most vulnerable to climate change – it scored 107 points. Odesa is located on the northwestern shore of the Black sea (Figure 1). This is the third largest city in Ukraine with population 1015 thousand people. The city currently covers a territory of 163 km^2. The city is a major seaport and transportation hub. The average elevation at which the city is located is around 50 meters above sea level, whilst the maximum is 65 m a.s.l. and minimum (on the coast) amounts to 4.2 m below sea level. Near the city situated three big estuaries − Kuialnyk, Khadzhybeysky and Dry Estuary.

The climate of Odesa is temperate continental with mild winter, relatively protracted spring, warm and long (often − very hot) summer and long and warm autumn. During last few decades climate of Odesa has already started changing, for example, during 2003−2013 mean annual air temperature has increased by 1.4°C compared to the 1961−1990 average and reached value of 11.5°C. The increasing was mainly due to a significant warming in July and August − by 1.9 and 2.0°C respectively. As well, was observed a significant increasing in the average number of hot days (with a maximum daily air temperatures +30,0°C and above) during the year (Table 5) and increasing of heat wave cases (Shevchenko *et al.*, 2014a).

Table 5. Mean number of hot days in Odesa

	May	June	July	August	September	Year
1961–1990	0,03	1,1	2,9	3,6	0,2	7,8
2003–2013	0,7	3,2	7,9	8,1	0,2	20,1

According to the climate vulnerability assessment results, in Odessa most vulnerable is urban green zones (this negative effects of climate change scored 22 points out of 24 possible). Very high vulnerability of Odesa green areas is caused by number of factors − primarily air temperature increasing, changes in amount of precipitation during the vegetation period, increasing frequency of droughts, which lead to significant changes in ecological conditions for plants. Also increases the vulnerability of green areas is appearance of aggressive invasive species, new pests and plant diseases, poor air quality in city, insufficient funding of organizations which care for municipal green areas in Odesa. The situation is complicated also due to the fact that the area of green zones in Odessa is much more smaller than that provided appropriate Ukrainian standards and its areas continue to decline under the pressure of developers (they try to build new buildings everywhere, often instead of a green areas).

Very high is Odesa vulnerability to flooding (17 points out of 24). The cause of this is increasing torrential rains frequency, poor technical condition and functioning of urban drainage system for rainwater which is not able to take during a short time a big volume of water, large asphalted territories (and, consequently, poor water filtration in the soil). Moreover, features of some areas location (for example, Peresyp, which located between the Black Sea and Khadzhibei and Kuialnyk estuaries) besides the risk of flooding due to heavy rains add additional risk of sea water flooding due to heavy storms or sea levels raising.

Also, quite high vulnerability of Odesa to heat stress (vulnerability to this negative climate change effects was estimate in 16 points). Of course, the first reason of this is rising of air temperature, which is observed in Odesa now and, according to the climate modeling results, will be continue in the future. In addition, the urban heat island, which has been fixed in the city and characterizes intensity 2.8°C (Marinin and Dranicher, 2013) has negative impact on Odesa vulnerability to heat stress. An important factor influences on 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. In Odessa, a high percentage of categories of population vulnerable to excessive heat (for example, only the elderly people 24% of the total population), there is no premature informing the public about the periods of hot weather and do not carry out information campaigns on how to protect themselves during the heat.

Analyzing in detail the factors that effect on the vulnerability of other cities, which have been studied, one can conclude that an important role in determining of their vulnerability to heat stress, floods and reduced space and deterioration of the species composition of urban green areas play a socio-economic factors and urban infrastructure. Of course, every city has individual features, but the main factors that increase vulnerability in Ukrainian cities is very similar − city's population structure (a big percentage of vulnerable categories of population), lack of premature informing the public about heat period/flooding etc., poor state of urban infrastructure, prevalence artificial surfaces in the city (they are almost completely prevent water infiltration into the soil, as well have a lower albedo than natural ones and therefore absorb, more solar radiation, more heat and cool more slowly), in cities areas of green zones do not meet applicable standards and/or continue reducing and others.

Thorough vulnerability assessment of the city to climate change is the first step to development effective city adaptation strategy and it is very important to define factors which cause the rises of vulnerability for directing adaptation measures to minimize their negative impact on the stability of the city to

climate change. Because of this, after climate change vulnerability assessment of these seven cities, have been prepared the lists of adaptation measures for every cities, depends on the most possible adverse effects of climate change, which may occur in particular city. The all measures can be divided into categories, particularly, engineering and technical measures, construction and architectural measures, economic measures and organizational measures.

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.

Organizational measures, typically, require significantly less time and money for their implementation, compared to the two aforementioned groups, but often can provide a visible decreasing of vulnerability to negative impacts of climate change. This group of measures, primarily, includes planning, monitoring, control, etc. An information campaign aimed at different target groups is an important organizational measure undertaken in the context of urban adaptation measures development.

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.

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.

Urban adaptation to climate change requires a multifaceted approach and the implementation of measures at different levels. 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.

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