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COMPARATIVE ANALYSIS OF STRATEGIES FOR ADAPTATION OF URBAN AREAS TO CLIMATE CHANGES

ABSTRACT. **Purpose.** Managing complex systems, especially those related to environmental balance, is among the most complicated tasks. Climate changes raise challenges for the safety and well being of urban population. Successful solutions to these challenges can be found provided that thorough analysis of the system interactions is conducted. The aim of the paper is to define the most efficient approaches to adapting urban areas to climate changes. **Methodology/approach.** The system analysis was based on the conceptual modeling. The three-step procedure included system description, cause-effect analysis, factors weighting and utility calculation. The last step was multi-criteria evaluation, defining most efficient approach to adaptation. **Findings.** The "city-climate-population" system has multiple components able to amplify the effects of climate changes, but most of them are manageable. The comparison of three alternative approaches - nature-based, organizational and engineering solutions, using multi-criteria evaluation, showed that the complex of nature-based solutions will provide the best result, but the engineering solutions and organizational ones proved to be competitive options. **Research limitations/implications.** The results of the modeling provide useful background for planning adaptation in cities and efficient use of available resources; however, it doesn't give ready solutions. **Originality/value.** The research results demonstrates feasibility of all alternatives, therefore, stakeholders are able to make informative decision, which approach they will pursue, depending on the target issues and finance reserves of a community

Key words: Climate change adaptation, Urban Environment, Decision making, Multi-criteria evaluation, State of environment

ПОРІВНЯЛЬНИЙ АНАЛІЗ СТРАТЕГІЙ АДАПТАЦІЇ МІСЬКИХ ТЕРИТОРІЙ ДО ЗМІН КЛІМАТУ

АНОТАЦІЯ. В статті розглядаються стратегії адаптації міських територій до кліматичних змін. Чинник клімату натепер є одним з основним модифікаторів рівня екологічної безпеки міста. Зважаючи на зміни клімату та наслідки, які вони несуть, необхідність адаптуватись до нових кліматичних умов постає у кожному місті у тій чи іншій мірі. Методичну основу даного дослідження складає концептуальне моделювання, яке включало такі кроки: опис системи, в якій відбувається взаємодія жителів міста, клімату та якості довкілля загалом; побудова концептуальної моделі, опис взаємодії між складовими систем; визначення чинників, що визначають успішність адаптації та їх ранжування за важливістю з призначенням вагових коефіцієнтів; багатокритеріальна оцінка запропонованих стратегій адаптації. В якості основи для роботи був використаний Оболонський район міста Києва. До розгляду були запропоновані стратегії, що будуються на основі центральної концепції – природничі рішення, організаційні рішення та інженерні рішення. За результатами порівняння стратегія адаптації, побудована на використанні природничих рішень отримала найвищий рейтинг. Дана стратегія може забезпечити не лише прямі вигоди у формі адаптації, а й додаткові переваги. Разом з цим, впровадження проєктів з розширення зеленої та блакитної мережі міста потребуватиме серйозного перепланування території та перегляду транспортних маршрутів. Важливо відмітити, що інші розглянуті стратегії отримали високі бали в ході оцінки, а отже стейкхолдери при прийняті рішення щодо вибору стратегії адаптації можуть обрати іншу стратегію, але вже цілком свідомо щодо її недоліків та очікуваної ефективності.

Ключові слова: адаптація до зміни клімату, міське середовище, прийняття рішень, багатокритеріальне оцінювання, стан довкілля.

1. Introduction. Adaptation to climate changes is an important issue for consideration in most of development projects of settlements. In particular, cities turn to be hotspots of climate changes due to both high concentration of population and factors contributing to aggravation of thermal pressure. At the same time urbanization is ongoing trend for most countries and expansion of residential areas must be done in a way, which reduces possible health threats and ensures safe living conditions.

A wide variety of similar projects have been already developed, but adaptation is always in need for some original ideas and thorough considerations, since there is no single solution that fits all cities.

2. Literature Review. Ukraine has adopted the Strategy for environmental safety and adaptation to climate change to 2030, stating that there is a range of cross-sectoral problems for development and implementation of efficient responses to climate changes [1]. In particular, there is a problem with a range of fundamental problems, like lack of the existing trends analysis and risks assessments for cities [2]. Without the appropriate risk assessment and vulnerability assessment of each city the risk of maladaptations increases, leading to even more severe problems [3]. Furthermore, adaptation to climate changes intends the development of full-scale strategy, which covers all components of urban ecosystem and municipal infrastructure [4]. But it should not end up in only plan and description, the implementation plan and milestones must be embedded into any strategy to guarantee its efficiency. Adaptation to climate changes has also been recognized as one of Sustainable Development Goals and as such it turned to be strongly interacting with all other goals, which wasn’t obvious at the beginning of this trend [5]. In particular, equality is an important issue, since not only countries, but neighbourhoods within a single city have very different possibilities and potential for adaptation [6].

Ukrainian approach to climate adaptation is under active development now. The rate of the downscaling National strategy to local needs is stimulated by the need to plan post-war reconstruction of cities, which opens a new room for integration of climate change into municipal planning and design strategy. There is a range of successful programs implemented in Vinnytsia, Zhytomyr, Khmelnytskyi, Kamianets-Podilskyi. But there is one very important issue, typical for all these cities and their strategies: they work mostly towards reduction of GHGs emissions and mostly via energy efficiency improvement. Undoubtedly, this is a task of highest priority, but this is not about adaptation, rather it deals with mitigation of climate changes. Thus, there is a need to understand the complex interactions within urban system at the interface of climate, infrastructure, human health and environment quality in order to build a clear picture of adaptation approaches able to provide high efficiency at lower costs.

3. Problem Statement. Climate adaptation is only efficient when it addresses local issues, created by climate change effects and is tailored to local environmental, social and economic conditions [7]. Given that the idea of the research was to consider perspectives of different adaptation strategies on the example of urban areas with the highest urgency for mitigation and adaptation efforts. The choice was made through the focus of heat island intensification, since it is the most profound manifestation of climate changes in cities. Based on thermal maps of Kyiv city, produced by satellite imagery [8], the areas with the highest land surface temperature were defined. These are Obolon district (eastern part) and Darnytsky district (Kharkiv massif and Osokorky massif). Of these areas Obolon district possesses the most unfavourable combination of factors.

Thus, the Obolon district of the city of Kyiv borders the right (western) bank of the Dnieper River, which provides a general cooling affect for its eastern part. But closest to the river, this cooling is considerably reduced due to a dense row of high-rise buildings along the river. As a result, this area is characterized by high density of buildings, intensive air pollution, small areas of water bodies and green spaces, and a comparatively intense heat island.

So, the main research question was formulated as follows: How to reduce the intensity of climate changes effect on the residents of Obolonsky district?

The tasks included development of the conceptual model for the system, analysis of impacts, formulation of alternative adaptation scenarios and their comparison, using the modelling apparatus of Multi-Criteria Evaluation. The expected result is not the exact plan of action, but the focus of adaptation measures, which has potential to shift the balance in the ecosystem toward more comfortable and safe living condition even under growing thermal pressure.

This preliminary modelling also provides a critical perspective on uncertainties that need attention for actual management decisions.

4. Methods and Materials. The interactions in the system “residents-climate-living conditions” form a very complex system, which need transdisciplinary efforts for their solution. To facilitate this task it is necessary to understand the structure and dynamics of such systems, which can be achieved with the help of conceptual modelling, avoiding complicated math work.

The interest to conceptual modeling has grown considerably over the last decade, and as a result a variety of approaches is available now, producing certain confusion [9]. The given research generally follows the framework, suggested by R. Steavens, based on earlier publications by Keeny (1976) and Saaty (2008) [10]. The general procedure in this case includes three major steps:

1) System characterization. This includes description of the environment or conditions associated with the problem, factors and processes defining the system under investigation. The results of the initial data collection are formed into so called System Sketch, which is used to determine the parameters most appropriate for further modeling.

2) System structural analysis. This step intends to identify and study in details parameter relationships in the system. The central part of this step is the development of the impact matrix, which reflects the intensity of impact of each parameter on others is rated by the scale from 0 to 4. The accumulated sums of rows and columns represent the combined impact and effect of parameters on each other, and these sums are used as coordinates to plot a “Cause and Effect” diagram. The diagram analysis helps in defining those parameters, whose manipulation can help manage the problem towards the desired solution.

3) Synthesis modeling (using Multi-Criteria Evaluation, MCE). MCE is a very useful tool for combining the impact of different parameters within a system on its final status. This is the moment when the conceptual modeling shifts from the internal relationships in the problem to its solutions. The MCE has been proved to be efficient for the solution of various environmental tasks [11] and for urban sustainable development planning in particular [12]. It is also the step at which

computation techniques are used and qualitative parameters are given specific numerical values. The overall structure of a MCE is described with the equation:

$$R = w_i \cdot u_i , \qquad (1)$$

where R is the rank of each solution, wi – weight of each parameter of the system, ui – level of each parameter in the given solution.

Since parameters are given in different units, they are transferred into the values from 0 to 1, using specially constructed utility diagrams.

Complex systems like the one discussed in the given paper are The Multi-Criteria Analysis represents a group of methods applied to support decision making process in cases of preliminary site and situation assessment and when the necessary data are partially lacking or absent.

5. Results. System Sketch: Extreme hot periods increase the risk of heatstroke and negatively affect people's health in general. Indoor cooling in buildings leads to an increase in electricity consumption.

Climate change can also have an impact on the vegetation and green spaces in the area. High temperatures and insufficient moisture can lead to plant death, affecting the aesthetic appearance of the area and air quality. At the same time, changing precipitation patterns cause increased precipitation over shorter periods time of time, which, in turn, lead to inefficient runoff collection and flooding. All together these factors lead to degradation of water quality.

As a result, urban residents are under the combined pressure of environmental, social and economic effects due to climate change. Moreover, factors from these groups further amplify each other, with environmental effects causing the most intensive feedbacks.

However, most of these effects are manageable (Fig. 1) and thus an efficient strategy for city adaptation should be able to mitigate most of consequences.

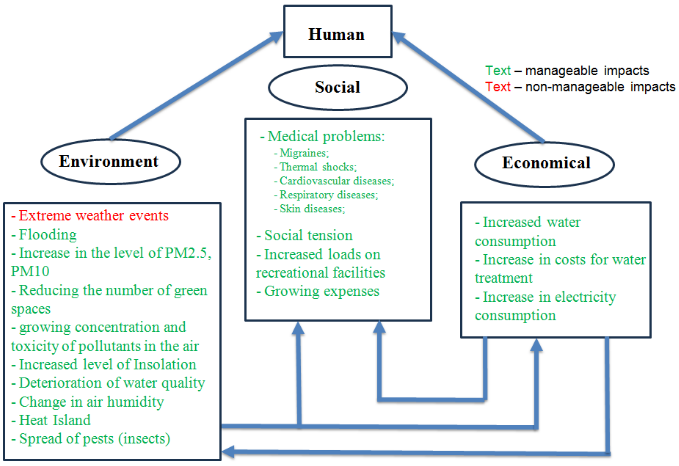

Fig.1. System sketch: effects of climate changes on humans in city

System Structural Analysis

Using the system sketch, the most important components of problems in the system "residents-climate-living conditions" were defined for Obolon district and listed as follows:

1. Flooding – the one caused by heavy rains over untypically short periods; this problems connected to the storm water collection system, which is not designed to receive such high volumes of runoff;

2. Air pollution – it is typical problem of cities, but extreme heat leads to the formation of secondary pollutants, raise human health hazards.

3. Urban heat island is a part of settlements microclimate, but climate changes are able increase its intensity.

4. Green spaces decline is also common issue for urban green infrastructure, due to combined pressure of environment pollution of all components; but climate changes accelerate this process and also force the change of species composition.

5. Water quality issues appear in various forms in cities, but due to climate changes and intensified urban heat island, additional polluted runoff enters local water bodies without treatment, thus compromising water supply to local residents and enterprises.

6. Medical problems are the direct consequence of heat waves and urban heat island intensification, leading to reduced quality of air and water.

7. Pressure on recreation facilities – it is growing, since overall area of green spaces is declining, but people in search for cool and shaded areas are more interested in visiting recreational areas of a city.

8. Growing expenses of urban residents appear due to longer working hours of climate control systems and medical expenses to treat heat induced health disorders.

9. Demand for power – it is general trend for urban areas, but air conditioning systems, additional water treatment and pollution control lead to increasing power consumption.

The defined components of the problem were studied in terms of their mutual interactions. The impacts within the system were rated from 0 to 4 (Fig.2). These interactions were also presented as a figure, demonstrating interactions and mutual impacts of different strengths and potential for positive feedback loops (Fig.3). The system is dynamic and has high variability of states over time.

	Flooding	Air pollution	Urban heat island	Green spaces decline	Water quality issues	Medical problems	Pressure on recreation facilities	Growing expences	Demand for power	Impact
Flooding		1	0	2	4	3	2	4	2	18
Air pollution	0		2	3	1	3	2	2	2	15
Urban heat island	0	4		4	3	4	4	4	4	27
Green spaces decline	3	4	4		3	2	3.5	2	1	22.5
Water quality issues	0	1	0	2		4	3	4	1	15
Medical problems	0	0	1	0	0		3	4	4	12
Pressure on recreation facilities	0	2	2	3	2	2		1	1	13
Growing expences	0	3	0	1	1	4	2		0	11
Demand for power	0	4	3	1	1	1	0	4		14
Effect	3	19	12	16	15	23	19.5	21	15	

Fig. 2. Impact matrix

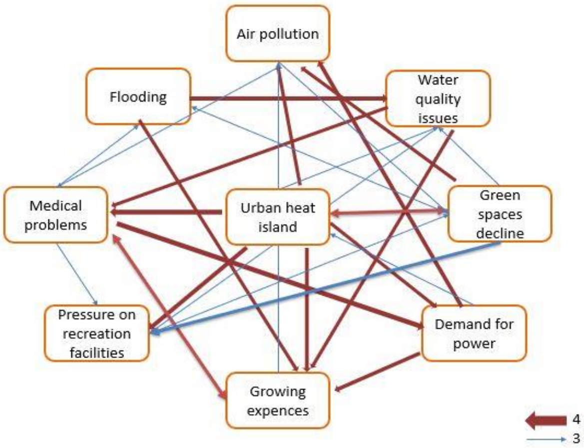

Fig.3. Most important impacts in the system

Based on the sums obtained from Impact Matrix, impacts were plotted to separate causes from effects (Fig.4). Urban heat island and flooding are the obvious causes of most problems in the city, while health issues and living standards are the most affected.

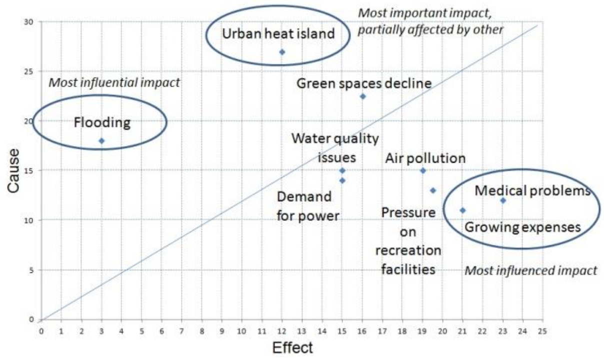

Fig.4. Impacts Interactions in the system

There is a range of impacts involving both of these aspects and therefore able to provoke additional effects if forcing trends are not checked.

Multi-Criteria Evaluation

At the next step the modeling process puts its focus on the choice of efficient solutions to the problem. Since the main research question was about the reduction of the intensity of climate changes effect on the residents of Obolonsky district, the Factors of City climate formation were considered from the point of their potential contribution or prevention of the urban adaptation to climate change. The analysis showed that the massive of factors can be divided into input factors, which create and limit the potential for adaptation and output factors, which represent the desired effects from adaptation (Fig. 5).

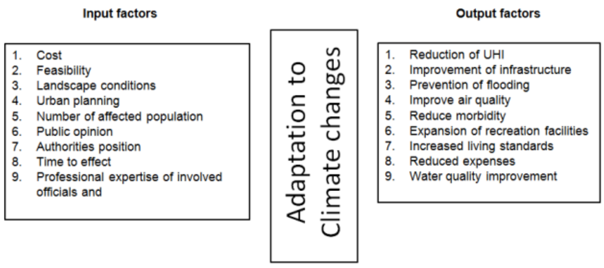

Fig. 5 Factors important for decision making in adaptation of urban environments to climate changes

For the purpose of modeling the shortlist of factors, reflecting efficient adaptation, was formed and includes:

- Reduction of UHI
- Prevention of flooding
- Improve air quality
- Reduce morbidity
- Water quality improvement
- Cost
- Feasibility

For each of the factors considered, the weights (w) were assigned according to their relative importance for the adaptation efficiency via pair-wise matrix comparisons (Fig. 6).

Relative weights of factors were assigned by the members of the team individually and then revised and final weights were assigned by compromise between assigned individual weights. The general idea of the pair-wise comparison is reverse symmetry: in each pair of factors one was rated as 3-6-9 and then the second factor would be granted a reverse weight – 1/3-1/6-1/9 correspondingly. If both factors are equally important, they are both given rating of 1.

	Reduction of UHI	Prevention of flooding	Air quality improvement	Reduce morbidity	Water quality improvement	Cost	Feasibility	Weight
Reduction of UHI		1.00	1.00	1.00	3.00	3.00	3	12.00
Prevention of flooding	1.00		0.33	0.17	1.00	3.00	3	8.50
Improve air quality	1.00	3.00		1.00	1.00	6.00	3	15.00
Reduce morbidity	1.00	6.00	1.00		3.00	3.00	3	17.00
Water quality improvement	0.33	1.00	1.00	0.33		3.00	3.00	8.67
Cost	0.33	0.33	0.17	0.33	0.33		1.00	2.50
Feasibility	0.33	0.33	0.33	0.33	0.33	1.00		2.65

Fig. 6. Weighting matrix for adaptation factors

As it is seen from the Fig. 6 the most important targets are reduced morbidity and improved air quality, followed by reduction of the urban heat island. The lowest weights of costs and feasibility are explained by the general assumption of the working team that building adaptation potential of a city under current condition cannot be limited by costs (it is managed via dividing projects into stages), nor by technical feasibility, which will be important, when considering and comparing exact actions.

Alternative approaches to adaptation of the district to the climate changes were built around a major conceptual principle, used to develop the possible action plans:

- Sc.1 – **Nature-based solutions** - Development of green and blue infrastructure.

- Sc.2 – **Complex of organizational solutions,** which does not need major interventions into infrastructure and build the result on combination of small, but efficient unit changes, including change of coloration on buildings; shading systems; outdoor systems for cooling (irrigation, fountains, etc.); improvement of drainage system.

- Sc.3 – **Engineering solutions** – this scenario represent the most intensive reconstruction of a city, which includes urban transport modernization, development of renewable energy facilities, renovation of industrial areas to remove major sources of environment pollution and put the enterprises their on track to sustainability

These scenarios or strategies of adaptation were rated using MCE and the equation (1).

To make the factors comparable in terms of units, they were transformed into relative indices, based on utility diagrams, demonstrating the dependencies between the values of factors and adaptation efficiency. These diagrams (Fig.7) were set based on available research data and competence of the participants.

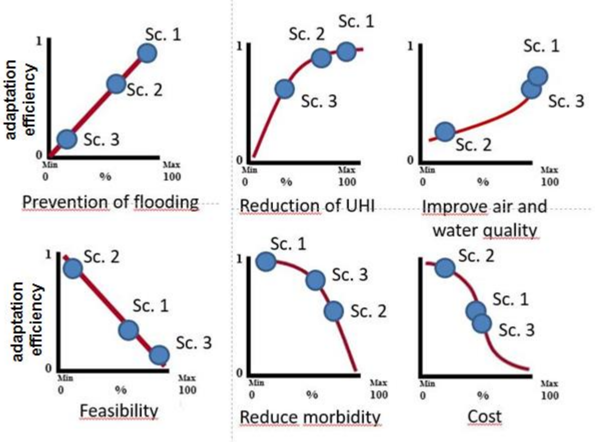

Fig. 7 Utility diagrams, showing dependence between the value of factors and efficiency of urban area adaptation

By combining the factor values in terms of adaptation efficiency (they are shown for each scenario at Fig. 7) and relative weight in the system the total sums of utilities for each strategy were derived and plotted on the diagram (Fig.8).

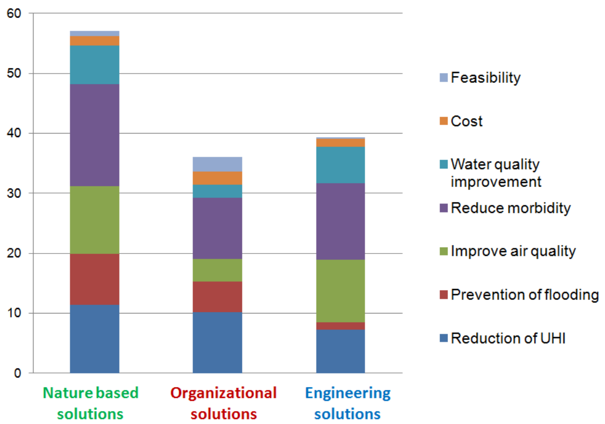

Fig. 8 Comparison of adaptation scenarios

Scenario 1 – Nature-based solutions, received the highest score, since it is able to reduce urban heat island intensity, improve air and water quality as well as reduce morbidity better than others.

It is also able to provide additional opportunities apart from climate adaptation:

- Create new jobs;
- Motivate the improvement of urban planning legal framework;
- Increased efficiency of resource use;
- Expand recreational opportunities and provide tourist attraction.

However, it will probably cause displacement of some population and problems with transport routes redevelopment.

Support and maintenance of created green and blue infrastructure is costly in terms of finance and labor.

5. Conclusions:

Based on the MCE, we observe that the first scenario (nature based solutions) has the greatest cumulative score compared to the others.

Another important result of modeling is that organizational solutions, which are relatively easy to implement and finance, are almost comparable in the achieved effect with the Engineering solutions, which include massive reconstruction and modernizations of industrial areas, urban transport and infrastructure.

As a result stakeholders may choose the option with Organizational solutions due to its cost-benefit ratio.

If the improvement of human health is in the focus, that the Nature-based solution option will be the optimal one, but if the reduction of Urban heat island is a priority, than the Organizational solutions may be seen more attractive. Some parties could be also interested in the third scenario because it is advantageous for economic reasons will give positive effects beside climate adaptation itself.

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