Theory of Climate Change Intensity Determination

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Abstract: The purpose of the study is the examination and detailed analysis of the methodology for assessing the intensity of climate change, its impact vectors at the global, regional and local levels, and the search for possible optimal solutions of a preventive and liquidation nature to minimise negative consequences. The study was conducted using general scientific methods of cognition, namely system analysis, synthesis, abstraction, generalisation, concretisation, and formalisation. The study examines the issues of adaptation to global climate change in Central Asia, in particular, in the Republic of Uzbekistan. The study determined the degree of increase in warming indicators and its impact on degradation processes in the Aral Sea and glacial melting in the region. The use of the developed formula for assessing climate change intensity at the regional level is justified, providing a basis for preventive and eliminative actions. The study's results are practically important for optimizing the National Adaptation Plan and the National Drought Management Plan. Therewith, the priority is the synergy of the goals of environmental prevention and economic feasibility, considering modern innovative opportunities for modelling, forecasting, and the direction of the development vectors of Uzbekistan towards a positive global trend of sustainable development and the prevention of climate change.

Keywords: warming; air temperature; precipitation; water supply; drought management plan

1. Prerequisites for the publication

Climate change on a planetary scale is inevitable and undeniable. Therewith, the priority source of such changes is an increase in temperature indicators, that is, warming caused by an increase in the concentration of greenhouse gases in the atmospheric air. Researchers have identified that the increase in quantitative indicators of emissions of carbon dioxide, methane, and other greenhouse gases and pollutants is caused by the active activity of mankind. Pollution, in turn, causes changes in the process of circulation and formation of the temperature regime of air masses in the lower layers of the atmosphere, causes destructive processes of stratospheric ozone, and even changes the temperature and circulation regimes of the waters of the World Ocean[1)]. Attention from the scientific community to this issue is constantly growing. The generalisation of large-scale studies in the field of climate change and the dynamic interaction of natural and social systems is conducted within the framework of the World Climate Research programme[1)].

Long-term studies under this programme allowed established that around the middle of the 20th century, there were changes in the circulation of the Southern Ocean, which is the main absorber of excess atmospheric heat on a global scale. Ultimately, carbon dioxide is actively absorbed by cool water masses, concentrating in the depths and, thus, effectively removing it from the atmospheric air. However, for several reasons, this circulation process has changes. The wind regime near Antarctica has changed, the Antarctic bottom waters have begun to warm up, respectively, the process of active absorption of excess heat has noticeably weakened. Such shifts, in turn, led to increased cloud cover over the Southern Ocean, followed by additional heat retention. This combination of factors has led to the phenomenon of progressive warming on a planetary scale.

Within the framework of the above-mentioned programme, the Intergovernmental Panel on Climate Change has been implementing a project to compare related models for many years [2)]. To date, the sixth phase of this project is successfully underway. As part of this stage, the expected changes in temperature indicators reach one and a half degrees Celsius, within the projected time frame of the next decades. Notably, the maximum process of increasing temperature indicators will affect Central Asia, which is located in the middle and high latitudes of the northern hemisphere of the planet. An exceptional feature of the circulation processes in this region is its location and the central part of the continent. Based on this, it can be argued that Central Asian countries are the most vulnerable to climate change, and Uzbekistan is no exception.

The variability of the intensity of climate change processes is due to the substantial heterogeneity of the terrain and its characteristics. Ultimately, the influence of solar energy has substantial differences in the conditions of different types of underlying surfaces, and solar radiation causes circulation processes to occur in the atmosphere. Cold air masses, which are characterised by high density, cause more pressure and move towards a warmer region with more rarefied air masses. With this movement, the properties of air change. This transformation continues in a time interval of up to seven days and depends on the characteristics of the underlying surface, air masses in the demarcation zones, and some other factors. As a result of the transformation of the properties of the air mass, the average daily temperature is set constantly. Today, using theoretical findings and samples of long-term observations, the need to assess the intensity of climate change, develop further strategies and plans for adaptation to climate change, and minimise the consequences and preventive measures is extremely urgent.

Many papers and studies are devoted to the search for optimal solutions to this problem, in particular, modern researchers B. Clark et al.[3)-4)] and E. Hawkins et al.[5)] pay maximum attention to finding effective approaches to investigating the issue in recent publications. J. Abatzoglou et al.[6)] in their study focus on positioning the anthropogenic impact factor as the basis of negative consequences and actively develop models for minimising it, considering global climate changes. E. Fischer et al.[7)] conceptualise their paper around the trend of increasing the impact of extreme impacts of global climate change in the form of regional and local negative phenomena that directly or indirectly have a substantial socio-economic and environmental impact. A group of researchers led by L. Gudmundsson et al.[8)] in their study argue that effective management of risks that arise for local aquatic ecosystems as a result of global climate change can minimise the negative impact and stabilise degradation processes at the regional level.

Despite the rather high level of scientific interest in the issue considered in this study, the search for optimal innovative solutions for the effective management of risks arising from the negative impact of global climate change continues. In particular, for Uzbekistan, this problem is particularly relevant against the background of the growing trend of desertification and drought. The purpose of this study is to contribute to the scientific base for optimising the climate risk management system, analysing and assessing the impact of climate change intensity, and developing a system of preventive measures.

2. Materials and methods

The research conducted a critical review of existing methods used to assess the intensity of climate change across various research platforms and frameworks. The aim was to identify appropriate approaches and tools that are currently available for assessing climate change intensity. The review examined the strengths and weaknesses of different methods and evaluated their suitability for accurately measuring and quantifying the intensity of climate change. By analyzing and comparing these methods, the research aimed to provide insights into the most effective and reliable approaches for assessing climate change intensity in order to guide future research and decision-making in this field. There were observed such platforms as Climate change adaptation planning, research and practice platform[9)] and Climate Change Knowledge Portal of the World Bank Group[10)]. The analysis also was focused on best practices of climate change impact assessments and climatic data and tools at international and regional sites (e.g., official country data portal on greenhouse gas emissions of the UNFCCC (United Nations Framework Convention on Climate Change)[11)], Catalogue for Climate Data of the WMO (World Meteorological Organization)[12)], the Central Asia Climate Information Platform[13)] and Portal of Knowledge for Water and Environmental Issues in Central Asia (CAWater-info)[14)]). Unfortunately, the authors could not find appropriate approaches for the evaluation of climate change intensity.

The expediency of using the formula proposed earlier by the authors[1)], in particular, for determining the intensity of climate change at the regional level, is justified:

$$J_i=\sum_{t=10} (T^x V)^x R^x G^x K_K{}^x K_c{}^x K_{nr} \qquad (1)$$

In this formula, the intensity of climate change is calculated based on the values of atmospheric humidity (V), average annual surface air temperature (T), considering the prevailing wind direction (R), geographical location of the region (G), and correlation coefficients according to the specific features of the area (K_k), cyclicity (K_c), losses of natural resources (K_{nr}). Notably, it is usually suggested to use the values Rnw=0.7 (cold season) and southwest Index Rsw=0.3. As for the geographical location of the region, according to the WCRP (World Climate Research Programme) forecast[1)], the proposed values are G=2 for the Temperate Zone, G=1 for the Polar Belt, and G=1.5 for the Tropical and Equatorial Belts. The K_k value is determined according to the specific features of the territory (forests, rural, or urbanised areas, etc.). Ks characterises the number of repetitions of anomalies and natural hazards. K_{nr} depends on the amount of natural resources lost.

The scientific novelty of this formula is predetermined by the fact that a review of normative, conceptual and empirical sources at the global and regional levels showed that such a method has not yet been proposed by anyone before.

3. Results

3.1 Central Asia and Uzbekistan

Global warming trends, presented in the studies by hydrometeorological stations in Uzbekistan, are characterised by a stable character[15)]. Indicators of average annual temperatures recorded by a series of observations since 1950 by the stations of the country indicate a trend of stable temperature increase, which is almost twice as high as the indicators of natural variability and indicates the relevance of the consequences of global warming for the territory of Uzbekistan in particular. Therewith, the rate of warming varies in different regions of the country and reaches the highest rates in the northern regions of the Republic and megacities (up to 0.43ºC for a period of 10 years), and the lowest – on the territory of mountainous areas (up to 0.14ºC for the same time period).

In general, the average value of the temperature increase indicator on the territory of Uzbekistan can be considered the limit of 0.27^{0}C for 10 years since the 1950s. Notably, the process occurs against the background of the influence of natural variability, which gives a synergistic effect and causes substantial fluctuations in the indicators of average annual fluctuations. The increase in the rate and strength of climate change in the region under study is largely due to the degradation of the Aral Sea ecosystem. The climate of Uzbekistan is becoming drier and hotter every year, and the number of dust storms and snow drifts of considerable intensity is growing.

According to the UN World Meteorological Organisation[12)], the maximum temperature in 2022 was recorded on the territory of Uzbekistan (47ºC, observation points in Navoi province). The Center for Hydrometeorological Service (Uzhydromet), at the request of Gazeta.uz[16)], provided meteorological data of 13 cities of Uzbekistan for the summer months of 49 years – from 1972 to 2021 (Figure 1).

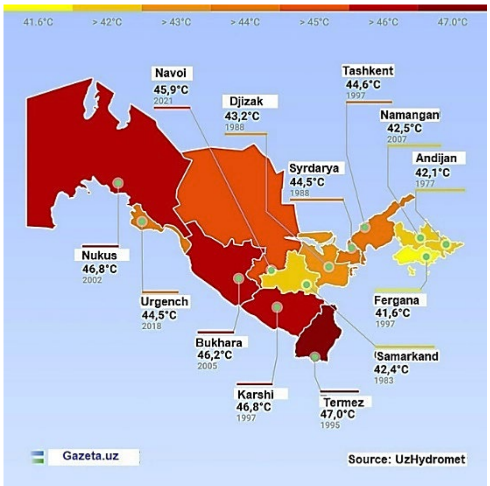

Fig. 1: Infographic: How the summer temperature has changed in Uzbekistan over half a century

Until the 1960s, the Aral Sea served as a natural climate regulator, levelling sharp fluctuations in temperature indicators in Central Asia, due to the large area of the water surface and the volume of water. Air masses coming mainly from the western direction over the territory of the Aral Sea were heated in winter and cooled in summer. Due to such intensive processes, moisture circulating with air masses fell in the form of precipitation over mountain ranges in the autumn-winter period, replenishing the snow and ice cover. The ecological catastrophe of the Aral Sea caused substantial negative changes in this circulation system, disrupting the distribution of moisture in Central Asia.

The arrival of air masses from the North and West in winter (wet ocean masses from the Atlantic and Arctic belts), which lose maximum moisture on the way through the continent is typical today. A high-pressure zone is formed due to the cooling of the territory, and the high-altitude systems of the Tian Shan and Pamir along the perimeter of the region (Figure 2). The situation became more complicated after the environmental disaster of the Aral Sea. Notably, climate changes in the Aral Sea basin are characterised by substantial intensity and reach twice the temperature increase (0.29ºC) compared to world averages (0.14ºC). This is primarily due to active drying processes in the marine system itself.

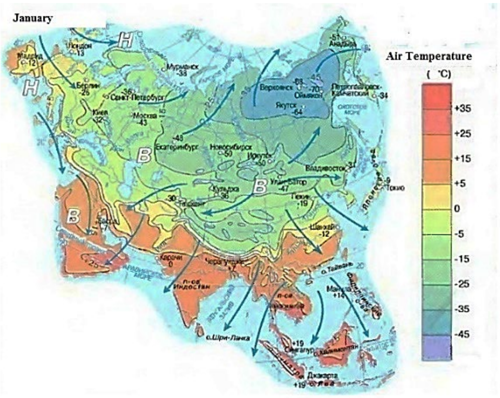

Fig. 2: The process of air and moisture circulation in winter in Central Asia

Thus, it can be argued that in winter in this region there is an area with maximum pressure indicators on a planetary scale – a quasi-stationary Asian maximum. Therewith, the predominance of anticyclones and substantial hypothermia in the depths of the continent caused a decrease in precipitation in the region over the past 20 years, and a substantial decrease in temperature indicators (up to -30ºC). Precipitation is distributed unevenly, most of it falls over a flat area, which leads to a decrease in the long-term snow and glacial reserves of the region.

The summer period is characterised by substantial changes in meteorological conditions in the Aral Sea basin. This is due to the priority of the low-pressure area over the Asian high. Oceanic air masses arriving in summer cause dry and hot climatic conditions, and sea humidity does not substantially affect the situation. Such conditions cause average July temperatures in the range of 30ºC with peaks up to 45ºC in the time interval of the last 10 years (Figure 3).

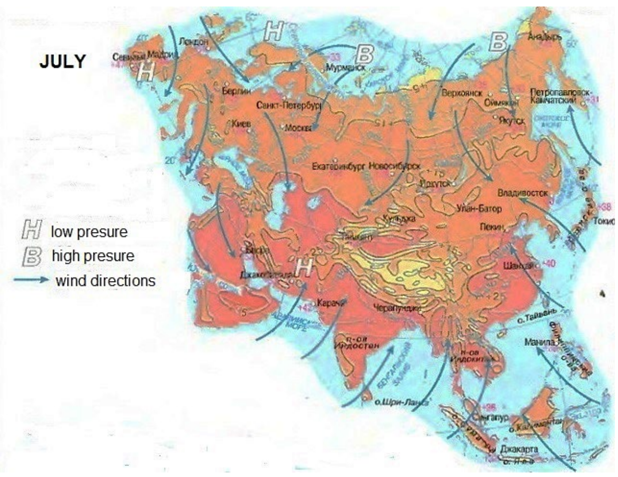

Fig. 3. The process of air and moisture circulation in summer in Central Asia

As a result of the described processes, in the last 20–25 years there has been a substantial decrease in precipitation in the summer period and an increase in aridification (Figure 4). One of the most global and dangerous consequences of such processes is the intensive melting of perennial glaciers (30% of glacial masses over the past 40 years).

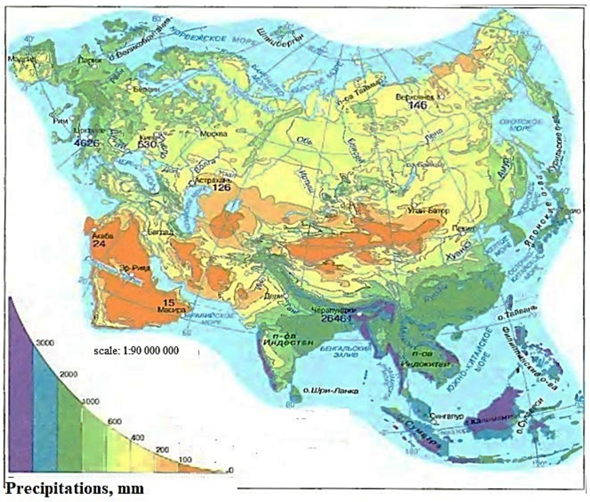

Fig. 4: Aridification processes in the Central Asia region

Considering the water ecosystem of the region today, its persistent and inevitable disruption can be stated, which has catastrophic global climate consequences. The degradation of the Aral Sea ecosystem and the emergence of new desertification regions are catalysing global warming processes on the territory of Uzbekistan. A separate problem is also the degradation of the glacial system, which inevitably affects the stability of the water system of the country. The processes of desertification that occur as a result of these changes have recently become uncontrolled, with catastrophic large-scale consequences of a social, environmental, and economic nature.

Climate change has a substantial impact on the parameters of the environment and the life of society. There is a shift in the boundaries of the seasons, the cyclicity and distribution of precipitation are disrupted, changes in the land landscape (desertification, waterlogging) occur, and the volume of water use and evaporation increases. As secondary consequences – climate migration and negative impact on the economy.

Based on this, it can be argued that the search for and implementation of effective solutions to stabilise the water system of the region should become a priority area of action that requires joint efforts. Stabilisation of the glacial system and ecosystems of the upper water intakes is possible through the introduction of innovative measures. Therewith, it is necessary to focus efforts on preserving and increasing water resources, optimising the efficiency of their use, stabilising the state of the Aral Sea, minimising the impact of drought, and stopping desertification processes. An integrated approach that considers the maximum number of influential factors will become the basis for optimising the socio-economic wellbeing of the region.

3.2 Drought risks and the international obligations of Uzbekistan in this regard

Uzbekistan was the first country in Asia to ratify the United Nations Convention to Combat Desertification (UNCCD)[17]. Notably, the Republic took part in all the processes and stages of preparing the agreement. In 1995, Uzbekistan officially joined the Convention[18]. In the same year, the Main Directorate of Hydrometeorology of the country was appointed. Obligations under the convention contributed to the development of the National programme of action to combat desertification (1999). This programme has retrained active actions in the following areas:

– minimising the process of land degradation;
– regeneration of land that has undergone partial drainage;
– reclamation of areas affected by desertification.

Notably, initially, the programme was rather weak in programmatic and political aspects, despite the support of the international community[19]. The effectiveness was not marked by substantial practical achievements, which is partly due to the lack of adequate funding from budgetary sources. The Hydrometeorological Service is not able to fully fulfil its obligations under international agreements, because it does not have the necessary experience, resources, and powers. There was a need to create an authorised body for the implementation of the convention, which would take on the functions of volumetric monitoring, forecasting, analytics, training, and coordination of interaction at the local, regional, and national levels. In addition, the forecasting and early warning system should be included in the risk analysis system as an integral component.

In 2017, there was a targeted social observation of public opinion on issues related to drought. The study covered various strata, and as a result, initiated the identification of the main policy vectors in the field of reducing drought risks in Uzbekistan:

–optimisation of efficiency and rational use of water resources;
–selection and introduction of drought-resistant varieties of crops;
–introduction of irrigation systems and irrigation technologies;
–support of agricultural market participants in the introduction of a drought risk insurance system[20].

A logical continuation was the adoption in 2019 of Special Resolution No. PP 4204 "On measures to improve the effectiveness of work to combat desert and drought in the Republic of Uzbekistan". This resolution stated "In order to increase the efficiency of work to combat desertification, restore degraded lands and ensure the effective implementation of the international obligations of the Republic of Uzbekistan related to the UN Convention to Combat Desertification, allocate the following additional functions to the State Committee of the Republic of Uzbekistan on Forestry:

–implementation of preventive measures for desertification and drought, including reforestation and protective afforestation;
–implementation by the Republic of Uzbekistan of international decisions and commitments to effectively combat drought and desertification processes;
–establishment of a process of effective interaction with regional and international organisations to minimise the effects of desertification and drought;
–development of an effective system for coordinating the actions of government bodies at the regional and national levels"[21].

4. Discussion

Since the middle of the last century, active changes in the global climate system have been recorded: an increase in the temperature of atmospheric air and world ocean waters, a decrease in ice and snow cover, and an increase in the level of the World Ocean. The vast majority of such changes are atypical. There is an increase in the frequency and duration of droughts, the spread of the phenomenon of desertification. Finding ways to optimally assess the intensity of climate change for further development of adequate practical programmes and solutions is a problem that many researchers of the present time are working on[22)-25)].

Despite the ambiguity of the conclusions about the nature of global warming and the existing discrepancy in estimates of the impact of anthropogenic factors on climate change, and the lack of effective unanimity in the international community regarding decisions in global climate policy, Uzbekistan needs to develop a long-term regional policy for effective assessment of climate change, followed by the development of a set of preventive and optimisation practical measures. This is emphasised in papers by N. Mygkova[15], and it is hard to disagree with her.

Modern researchers B. Clarke et al.[3)-4)] insist on the need for a comprehensive assessment of the intensity of the impact of global climate change on regional ecosystems, considering the full range of types of anthropogenic stress as the primary source of negative climate trends. This view is continued in their study by E. Fischer et al. [7], focusing on the need to develop an effective climate change monitoring system to prevent the occurrence of extreme adverse events. Such phenomena include desertification and drought, which have huge negative consequences not only of an ecological but also of a socio-economic nature[26)-28)].

Most researchers who investigate the problem under study come to a common opinion in their papers – climate change has a substantial impact on the environment and human life. In addition, global warming causes a distorted activation of the hydrological cycle – moisture, which is sorely lacking in regions suffering from droughts, falls in the form of unpredictable extreme precipitation[29)-30)]. It is urgent to conduct an effective assessment of the intensity of climate change, followed by the development of comprehensive preventive measures and taking harsher measures of responsibility for insufficient implementation of international standards on sustainable climate[31)-33)].

This thesis is consistent with the conclusions of researchers E. Hawkins et al.[5)], paying maximum attention to finding optimal innovative solutions for effective management of risks arising from the negative impact of global climate change. Researchers are convinced that only the development and effective implementation of industry recommendations on preventive and localisation measures for climate change, provided that an integrated approach is applied, can stop the processes of degradation of aquatic ecosystems at the local level, and on a planetary scale, such a preventive policy will allow soon to optimise destructive processes in the World Ocean and even reduce the rate of ice sheet degradation. It is difficult to disagree with researchers because only the synergy of monitoring and practical activities can have a substantial impact on global climate processes.

Timely and effective assessment of the intensity of climate change and the investigation of possible consequences allows for examining the interaction between climate change and its impact on society and the ecosystem in general at the regional and global levels, in all the complexities of relationships[34)-35)]. Global risks actualised by climate change have substantial political, economic, and social consequences. This study agrees with the opinion of J. Abatzoglou et al.[6)], who examine the factors of actualisation of global climate change through possible risks and their global consequences. Researchers note the need to systematise climate data and expand the range of parameters under study.

The current state of scientific knowledge does not yet allow for building conceptual large-scale climate models that would open up opportunities for effective monitoring and reliable forecasting. B. Clark et al.[3)] are convinced of this, emphasising that the main source of uncertainty in assessing the intensity and forecasting of climate change remains the destructive state of ice sheets. Based on this, researchers recommend that when assessing the vulnerability of ecosystems to climate change and predicting consequences, at the current stage, an empirical forecast should be taken as the basis of research, considering current trends in climate change.

Since an effective process of adaptation to climate change involves regional development with mandatory consideration of the level of vulnerability and risk assessment, its goal today should be to move from spontaneous and fragmented measures to systems of pre-developed preventive and levelling actions[36)]. The use of modern tools for optimal risk assessment, system modelling and impact forecasting will allow the creation of a comprehensive system for assessing the intensity of climate change and its impact on various aspects of life at the regional and global levels. Therewith, the quantitative indicators that can be obtained using the formula proposed in this study can become practical support for further research and the development of effective climate monitoring models.

5. Conclusions

The study analyzed the impact of global climate change and explored solutions for mitigating its negative consequences at regional and local levels. The study proposed an optimal formula for assessing regional climate change intensity, considering local influential factors. It emphasized the importance of an integrated approach to climate risk management and the development of prevention policies at national and regional levels. The study identified research priorities, highlighted the need for systematic assessment of climate change intensity, and called for further investigation into preventive climate policies and innovative monitoring and forecasting methods. The proposed evaluation method can guide experts in developing a national plan to combat drought in Uzbekistan.

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