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LAND SURFACE TEMPERATURE FORECASTING IN THE CONTEXT OF THE DEVELOPMENT OF SUSTAINABLE CITIES AND COMMUNITIES

The article examines the aspects of land surface temperature forecasting for effective planning and development of sustainable cities and communities. The relevance of the research lies in the need to develop effective approaches to the analysis and forecasting of climate data, for the timely determination of existing problems and ways to solve them, in accordance with civilizational challenges.

The trends of changes in the land surface temperature from the middle of the 20th to the beginning of the 21st century were analyzed, using the example of five megacities located in different regions: Tokyo (Japan), Lagos (Nigeria), Berlin (Germany), Singapore (Singapore) and Belo Horizonte (Brazil). The results of the analysis of changes in average monthly and average annual temperatures are presented. The factors affecting the formation of the temperature regime of each of the cities are determined. The role of urbanization as a key factor in the development of the city is described, the main challenges caused by it are considered.

An overview of megacities from the point of view of sustainable development was carried out. Prospects for urban development and measures aimed at reducing the urban heat island effect are considered. The role of modern technologies, in particular machine learning for predicting the land surface temperature, is described. The expediency of land surface temperature forecasting, in order to implement strategies for mitigating negative consequences and achieving the goals of sustainable development, is substantiated.

The conducted research makes it possible to be convinced of the need for a responsible approach to the design and development of sustainable cities and communities. The temperature of the earth's surface is one of the key indicators that allows you to monitor the main trends of urban life and can be an indicator of the effectiveness of strategies used to increase comfort and sustainable development.

Keywords: sustainable cities, global warming, forecasting, climate change, sustainable development goals.

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ПРОГНОЗУВАННЯ ТЕМПЕРАТУРИ ЗЕМНОЇ ПОВЕРХНІ В КОНТЕКСТІ РОЗВИТКУ СТАЛИХ МІСТ І СПІЛЬНОТ

У статті розглянуто аспекти прогнозування температури земної поверхні для ефективного планування та розвитку сталих міст і спільнот. Актуальність дослідження полягає в необхідності розробки ефективних підходів до аналізу та прогнозування кліматичних даних, задля своєчасного визначення існуючих проблем та шляхів їх вирішення, відповідно до цивілізаційних викликів.

Проаналізовано тенденції зміни температури земної поверхні з середини XX до початку XXI століття, на прикладі п'яти мегаполісів, розташованих у різних регіонах: Токіо (Японія), Лагос (Нігерія), Берлін (Німеччина), Сінгапур (Сінгапур) та Белу-Орізонті (Бразилія). Наведено результати аналізу змін середньомісячних і середньорічних температур. Визначено фактори, що впливають на формування температурного режиму кожного з міст. Охарактеризовано роль урбанізації як ключового чинника розвитку міста та розглянуто зумовлені нею основні виклики. Так, загальне підвищення температури поверхні землі в містах відображає глобальні тенденції, зумовлені урбанізацією та зміною клімату. Однак специфічні місцеві фактори, такі як ефективна кліматична політика та озеленення міст, можуть призвести до різних тенденцій зміни температури поверхн Землі, що чітко простежується на прикладі Берліна. І навпаки, швидка урбанізація та промислове зростання без адекватних заходів сталого розвитку можуть призвести до підвищення температури, яке спостерігається в Лагосі.

Здійснено огляд мегаполісів з точки зору сталого розвитку. Розглянуто перспективи розвитку міст та заходи, спрямовані на зменшення ефекту міського теплового острова. Описано роль сучасних технологій, зокрема машинного навчання, для прогнозування температури поверхні суші. Обґрунтовано доцільність прогнозування температури поверхні суші, з метою реалізації стратегій пом'якшення негативних наслідків та досягнення цілей сталого розвитку.

Проведене дослідження дозволяє переконатися в необхідності відповідального підходу до проектування та розвитку сталих міст і громад. Температура земної поверхні є одним з ключових показників, що дозволяє відстежувати основні тенденції міського життя та може бути індикатором ефективності стратегій, що застосовуються для підвищення комфорту та сталого розвитку.

Ключові слова: сталі міста, глобальне потепління, прогнозування, зміни клімату, цілі сталого розвитку.

Introduction

Planning and development of cities, taking into account the trends of future changes, is a key aspect of comfortable living. The rapid growth of megacities and expansion of production significantly increases the load on urban infrastructure, and in the absence of timely measures leads to environmental pollution and climate change.

The quality of life in cities is closely related to how cities use and manage the natural resources available to them. Today, the urbanization trend is accompanied by increasing pressure on the environment, as well as increasing demand for basic services, infrastructure, jobs, land and affordable housing [1].

According to Statista (Fig. 1), the level of urbanization in 2023 was 57%. The highest values were observed in North America (83%), as well as in Latin America and the Caribbean (82%). This indicator was the lowest in Africa and amounted to 45% [2].

The rapid pace of urbanization creates new challenges, among which the problem of climate change occupies one of the key places. According to Sustainable Development Goal (SDG) 11, the renewal and planning of cities and settlements should be done in a way that opens up opportunities for all, with access to basic services, energy, housing, transport and green public spaces, while reducing resource use and impact on environment.

Land surface temperature (LST) forecasting using machine learning (ML) can significantly contribute to achieving SDG 11 [3], which aims to make cities inclusive, safe, resilient and sustainable.

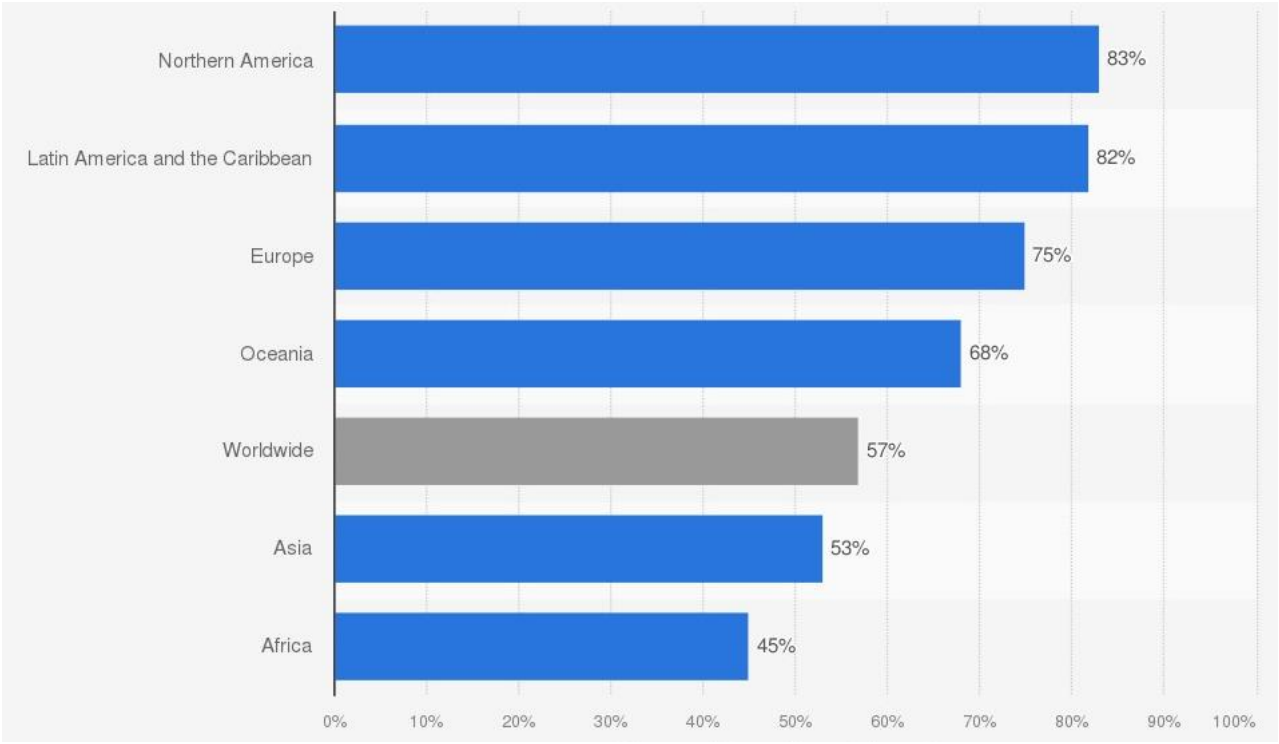

Fig. 1. The level of urbanization in each of the continents in 2023 [2]

Mitigation of the impact of the urban heat island (UHI) is especially relevant for megacities in a tropical climate zone [4]. The application of ML models to LST forecast helps identify major trends [5] and helps in planning and implementing mitigation strategies [6], including cooling, through the implementation of green roofs, urban forests, etc.

Domain analysis

The creation of climate-resistant infrastructure allows for the optimization of the use of resources, since the design of buildings occurs in such a way as to reduce the energy consumption for cooling and heating the premises as much as possible. The selection of building materials is carried out taking into account the improvement of the thermal comfort of the urban environment.

ML models are able to predict a variety of climate events [7], including heat or cold waves, allowing cities to prepare and implement emergency response plans, reducing negative impacts on residents, and preventing illnesses and deaths related to high or low temperatures. In cities and regions prone to extreme temperatures, forecasting will minimize damage [8] and ensure continuity of services during extreme weather events.

LST forecasting helps urban planners effectively allocate green spaces to cool urban areas [9], increase biodiversity, and improve air quality, which contributes to balanced urban development [10]. From the point of view of energy efficiency, forecasting temperature trends will allow optimizing energy distribution and reducing the load on energy networks. Also, LST forecasting will contribute to the integration of renewable energy sources by determining the required amounts of heat in regions for the placement of solar power plants.

Environmental monitoring allows continuous monitoring of temperature changes, helping cities monitor progress toward environmental goals [11] and adjust development strategies based on the data. Thus, prompt response to potential or existing changes will contribute to the preservation of urban biodiversity by ensuring the maintenance of suitable habitats for different species, thereby contributing to ecological balance. By using ML to predict LST, cities can make informed decisions that will increase sustainability, resilience and livability, directly contributing to SDG 11.

The concept of sustainable cities involves the implementation of measures aimed at balancing environmental, social and economic needs. The main goal is to ensure a high quality of life, while at the same time minimizing the impact on the environment.

Trends in the land surface temperature in megacities

The study of changes in the temperature of the Earth's surface was conducted for 5 megacities located in different parts of the world and in different climate zones for the period from 1950 to 2010:

– Tokyo, Japan (Cfa);
– Lagos, Nigeria (Aw);
– Berlin, Germany (Cfb);
– Singapore, Singapore (Af);
– Belo Horizonte, Brazil (Aw).

Data from the dataset was used for the research [12] from Kaggle. Calculations and graphing were carried out with the help of the python programming language, in particular were used libraries matplotlib [13] and pandas [14].

Tables 1 – 5 show the change in the average LST in Tokyo for the decade from the middle of the 20th to the beginning of the 21st century. Figures 2 – 6 reflect the trends of changes in average monthly and average annual temperatures.

Tokyo has implemented a variety of green initiatives, including promoting energy efficiency, reducing carbon emissions, and encouraging the use of public transportation. In addition, the number of green areas and parks has increased in the city in order to stimulate the development of urban biodiversity and mitigate the UHI effect.

Table 1

Trends in the LST in Tokyo

Decade	Average LST	Difference
1950 – 1960	12.888367	–0.024708
1960 – 1970	12.796517	–0.091850
1970 – 1980	12.625583	–0.170933
1980 – 1990	13.320158	0.694575
1990 – 2000	13.378808	0.058650
2000 – 2010	13.820500	0.441692

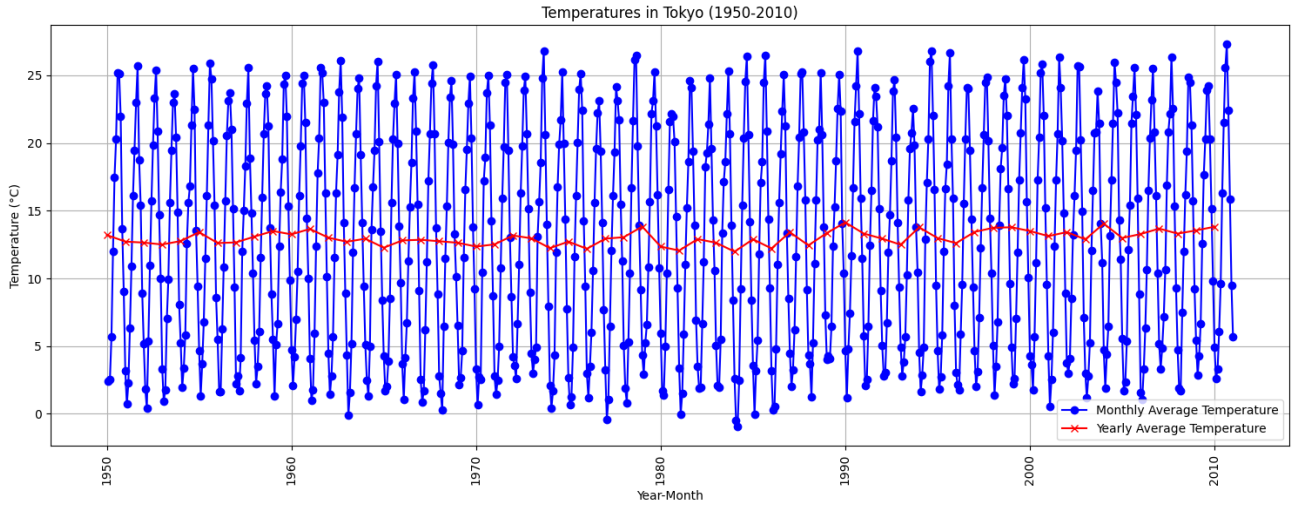

Fig. 2. Analysis of changes in average monthly and average annual temperatures in Tokyo

Nowadays, Lagos has significant environmental problems such as inefficient waste management, air pollution and flooding. Although the city is working to attract renewable energy sources and increase resilience to climate change, as well as innovations in health and education, but most of the problems still remain unsolved. The reason for this is the rapid pace of urbanization. As the main economic center of Africa, Lagos has a fairly developed economy, with sectors such as finance, manufacturing and technology. Efforts are being made to diversify the economy and support sustainable business practices.

Table 2

Trends in the LST in Lagos

Decade	Average LST	Difference
1950 – 1960	26.653900	0.068517
1960 – 1970	26.740900	0.087000
1970 – 1980	26.892192	0.151292
1980 – 1990	26.987500	0.095308
1990 – 2000	27.296042	0.308542
2000 – 2010	27.793333	0.497292

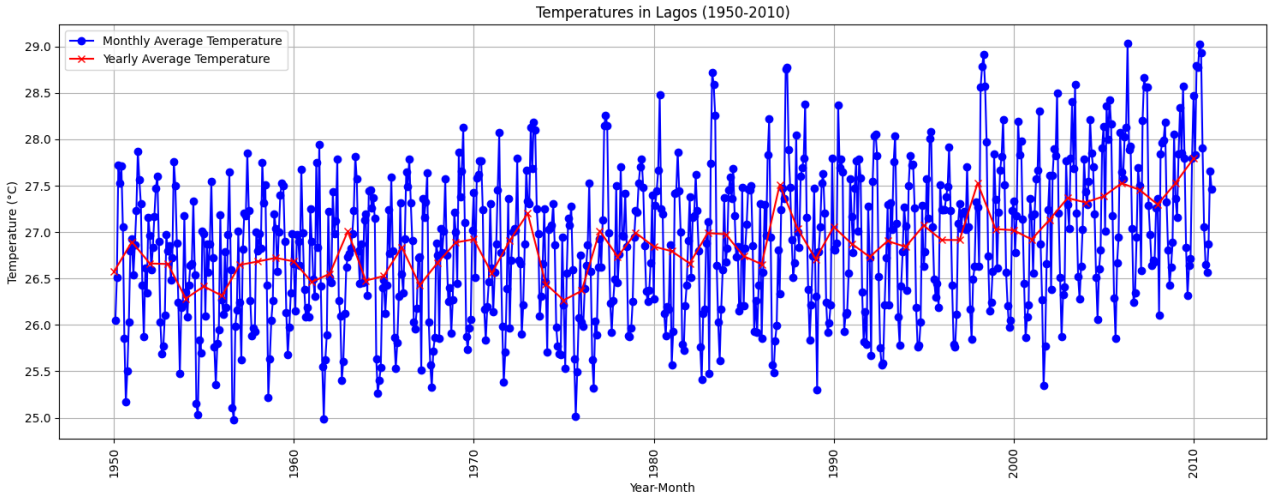

Fig. 3. Analysis of changes in average monthly and average annual temperatures in Lagos

Berlin is well-known for its commitment to sustainable development. Major improvements are seen through innovations in public transport, renewable energy initiatives and green urban planning. The city has many parks, green roofs and urban gardens. Berlin has a strong economy with a predominant focus on science-intensive manufacturing and technology, as well as creative industries. The city supports startups and sustainable economic growth, focusing on innovation and green technologies.

Table 3

Trends in the LST in Berlin

Decade	Average LST	Difference
1950 – 1960	8.958958	–0.098117
1960 – 1970	9.214600	0.255642
1970 – 1980	9.274858	0.060258
1980 – 1990	9.821700	0.546842
1990 – 2000	10.287450	0.465750
2000 – 2010	8.606833	–1.680617

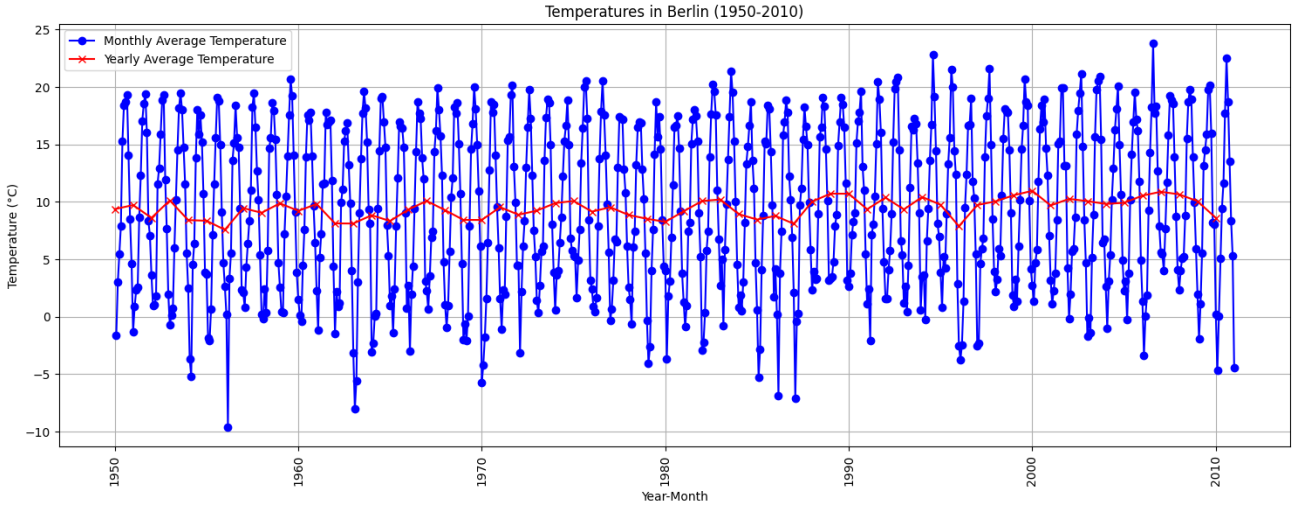

Fig. 4. Analysis of changes in average monthly and average annual temperatures in Berlin

Singapore is considered a world leader in sustainable urban development, with a strong focus on green buildings, water conservation and waste recycling. The city-state has extensive green spaces and initiatives to reduce its carbon footprint. Singapore's economy is highly developed and diverse. It includes the financial sector, technology and trade. The city supports sustainable business and innovation, striving for long-term economic sustainability.

Table 4

Trends in the LST in Singapore

Decade	Average LST	Difference
1950 – 1960	26.766367	–0.005950
1960 – 1970	26.791750	0.025383
1970 – 1980	26.927142	0.135392
1980 – 1990	27.143550	0.216408
1990 – 2000	27.282542	0.138992
2000 – 2010	27.603500	0.320958

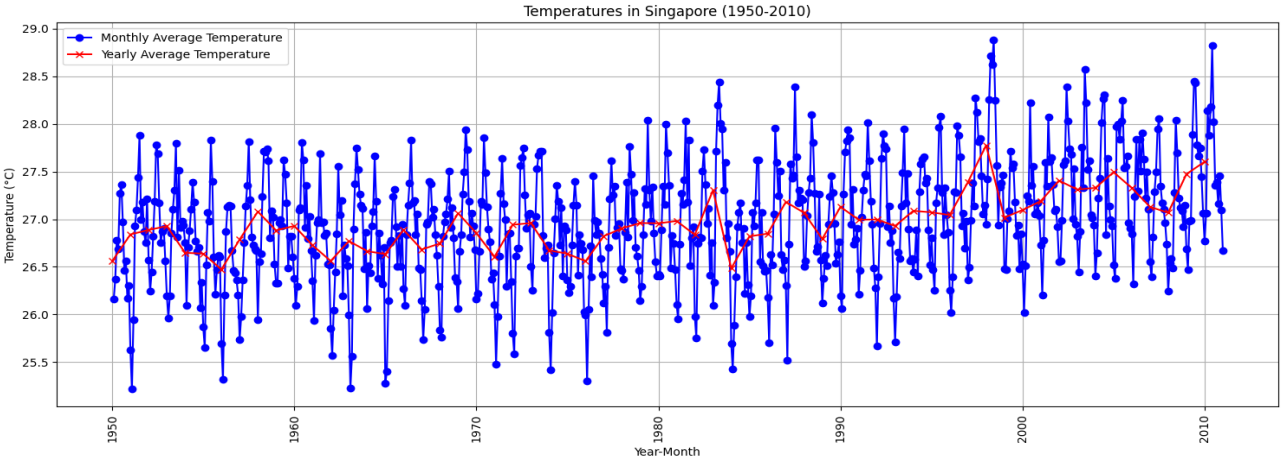

Fig. 5. Analysis of changes in average monthly and average annual temperatures in Singapore

A wide range of environmental initiatives have been implemented in Belo Horizonte, including urban forest restoration programs, water management and waste reduction programs. The city promotes the development of sustainable transport and energy efficiency. Belo Horizonte has a developed economy with mining, manufacturing, and service industries dominating. The city supports sustainable economic development and innovation, with a focus on green job creation and entrepreneurship development.

Table 5

Trends in the LST in Belo Horizonte

Decade	Average LST	Difference
1950 – 1960	21.256667	0.039508
1960 – 1970	21.254833	–0.001833
1970 – 1980	21.598125	0.343292
1980 – 1990	21.799525	0.201400
1990 – 2000	22.016983	0.217458
2000 – 2010	22.116333	0.099350

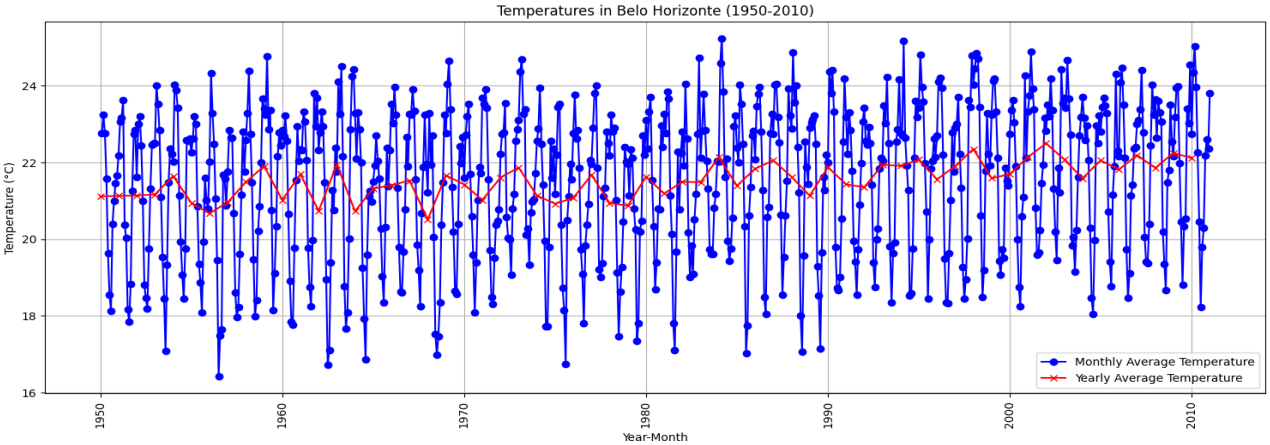

Fig. 6. Analysis of changes in average monthly and average annual temperatures in Belo Horizonte

The impact f the development of sustainable cities on land surface temperature

Each city has its own unique approach to sustainable development that reflects its specific challenges and opportunities. Variations in LST trends observed for different cities can be explained by factors such as: level of urbanization, climate policy, local geography and socio-economic conditions.

Most cities experience rising temperatures due to the UHI effect, where built-up areas are warmer than rural areas due to human activities, reduced vegetation and increased surface area that absorbs and retains heat [15], e.g. asphalt and concrete. The overall increase in LST observed in most cities is 0.2–0.4°C per decade. Therefore, it can be concluded that global climate change is contributing to overall warming trends, affecting cities around the world.

The highest LST increase of 0.49°C for the period from 2000 to 2010 was observed in Lagos. As the city experiences rapid population growth and expansion, this leads to more construction and less green space, which amplifies the UHI effect.

A decrease in LST of more than 1°C was recorded in the first decade of the 21st century in Berlin. This is mainly due to an effective climate policy. Berlin has implemented strict climate action plans, focusing on reducing emissions, increasing energy efficiency and promoting green building standards. The city has invested heavily in urban greening projects such as green roofs, urban forests, and parks that can cool the urban environment. Berlin's extensive public transport network reduces residents' dependence on cars, thereby reducing emissions. The use of renewable energy sources and strict energy efficiency measures in buildings contribute to the reduction of heat output.

Urban planning and policies cities such as Berlin, with advanced urban planning and strong environmental policies, can counter rising temperatures through green practices. More developed cities usually have better resources to implement and maintain cooling measures, while fast-growing cities such as Lagos may prioritize growth over sustainability.

One of the most important factors is geographical and climatic conditions. Natural geographical features and climate influence the temperature of the Earth's surface. Thus, coastal cities can have different temperature dynamics compared to inland cities.

Conclusions

The overall increase in LST in cities reflects global trends driven by urbanization and climate change. However, specific local factors, such as effective climate policies and urban greening, can lead to different LST trends, which is clearly seen in the example of Berlin. In contrast, rapid urbanization and industrial growth without adequate sustainable development measures could lead to the higher temperature increases seen in Lagos.

The lack of visible results in reducing LST in Singapore and Tokyo by 2010, despite their strong emphasis on sustainability, can be explained by several factors.

Singapore is one of the most densely populated cities in the world. Intensive urbanization may negate some of the benefits of sustainable development efforts. The large number of buildings, roads and other infrastructure creates a significant UHI effect. In addition, Singapore's tropical climate means naturally high temperatures and humidity. This baseline can make it difficult to observe LST declines, even in the presence of substantial resilience measures.

However, many of Singapore's large-scale environmental initiatives and sustainable development projects have been implemented more aggressively since 2010. Therefore, the consequences of these initiatives may not be immediately visible.

Tokyo is a sprawling metropolis with high built-up density, which contributes to a strong UHI effect. Tokyo's industrialization and economic growth in the second half of the 20th century led to significant environmental problems. Overcoming these historical consequences may take time, and the benefits of new initiatives will be visible in the near future.

Although Singapore and Tokyo have made significant efforts toward sustainable development, the complexity of urban heat islands, historical development patterns, and the enormous influence of global climate trends may delay visible results in LST data. It is possible that continued efforts will show significant improvements in mitigating the growth of LST in these cities.

The conducted research makes it possible to be convinced of the need for a responsible approach to the design and development of sustainable cities and communities. The temperature of the earth's surface is one of the key indicators that allows you to monitor the main trends of urban life and can be an indicator of the effectiveness of strategies used to increase comfort and sustainable development.

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