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Research Article

DIGITAL TOOLS FOR LOCAL GOVERNMENTS' CLIMATE CHANGE ADAPTATION

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ABSTRACT. The impacts of climate change directly affect the decision-making processes of local governments, given their critical responsibilities in infrastructure, disaster management, urban planning, and service provision. In this regard, digital tools have become indispensable components of policy and planning, enabling local administrations to identify, monitor, and design adaptation strategies for climate-related risks. This study analyzes the current use of digital tools by local governments in Türkiye's climate adaptation processes and proposes recommendations for future improvement.The research evaluates the role of Geographic Information Systems [GIS], remote sensing platforms such as the Copernicus Climate Data Store and Google Earth Engine, big data analytics, cloud-based storage, and AI-supported decision-support mechanisms like Climate-ADAPT and the Urban Adaptation Support Tool. Local governments apply these instruments across a broad spectrum, ranging from disaster early warning systems and open data portals to climate scenario modeling and participatory decision-making platforms.Findings reveal that digital solutions provide significant contributions to forecasting risks such as floods, droughts, and heatwaves, supporting green infrastructure planning, developing carbon emission inventories, and enhancing public awareness. Beyond offering technical data, digitalization creates strategic opportunities for participatory governance, institutional capacity building, and transparent decision-making, thereby strengthening local climate adaptation policies.The study concludes that advancing the effective and sustainable use of digital tools by local governments in Türkiye requires coherent policy frameworks, capacity-building initiatives, and data standardization. By integrating these measures, local administrations can enhance resilience, foster inclusive governance, and play a more effective role in combating the escalating challenges of climate change.

Keywords: *Climate change, Digital tool, Local government, Participation.*

INTRODUCTION

Today, climate change is considered a multidimensional phenomenon that directly affects the responsibilities of local governments, including infrastructure, disaster management, planning, and service delivery [1]. The Intergovernmental Panel on Climate Change [IPCC] Sixth Assessment Report [AR6] emphasizes that digital technologies play a critical role in enhancing urban adaptation capacities through data collection, analysis, decision support, early warning, and participatory governance processes [2].

With the localization of global climate policies, digital transformation has become a key mechanism that strengthens the adaptive capacity of local governments and reduces the risks associated with insufficient adaptation [3]. In this context, three digital technologies stand out: Internet of Things [IoT]–based real-time monitoring and early warning systems, big data analytics and artificial intelligence applications, and Geographic Information Systems [GIS] [4,5]. IoT sensors continuously monitor environmental variables and provide early warnings against floods and extreme heat events [4]. Big data and artificial intelligence significantly contribute to optimizing climate projections and integrating adaptation–mitigation strategies [4]. GIS, meanwhile, is indispensable for identifying risk zones and integrating spatial adaptation actions into planning processes [5].

These technologies collectively form a holistic adaptation ecosystem. GIS and remote sensing platforms [such as the Copernicus Climate Data Store and Google Earth Engine] are essential tools for monitoring climate trends and spatially identifying risk areas [5,6,7]. Big data analytics, cloud-based storage systems, and AI-supported decision-support tools [e.g., Climate-ADAPT, Urban Adaptation Support Tool] provide decision-makers with a robust knowledge base by integratively analyzing historical and future-oriented climate data [8].

Google Earth Engine, by processing large-scale satellite imagery, offers local governments high-resolution analytical capacity on issues such as urban heat islands, green space distribution, and the monitoring of water resources [9]. Through these digital infrastructures, climate adaptation is transformed from a purely technical process into a multilayered structure shaped by citizens' experiences and participation, while digital platforms evolve into new-generation "participation interfaces" that pluralize decision-making processes [8,10].

DIGITAL TOOLS

Geographic Information Systems [GIS]

Local governments play a critical role in the climate change adaptation process, particularly in identifying risks, modeling impact scenarios, and determining priority intervention areas [11]. In this context, GIS emerges prominently in three key stages: risk and vulnerability analyses, scenario modeling–decision support, and communication–visualization [5,6].

GIS integrates multilayered datasets such as climate projections, satellite imagery, land use, topography, population, and infrastructure to reveal the spatial distribution of climate-induced hazards—including floods, droughts, and extreme heat—and to identify high-risk areas [12]. This function supports the targeted planning of adaptation measures such as green infrastructure and natural drainage systems; moreover, the dissemination of risk maps on open data platforms strengthens public awareness and participatory planning processes [12].

Additionally, GIS enables the testing of alternative adaptation scenarios based on variables such as land-use change, temperature increases, and population projections, thereby helping to determine which measures provide the highest risk-reduction impact [5,6,9]. GIS-based monitoring mechanisms also evaluate the spatial and temporal effects of implemented measures, providing an integrated framework for processes such as carbon inventory development and adaptation performance assessment [5,6,9,12].

The strong visualization capacity of GIS enhances transparency and public engagement by enabling citizens to more easily understand climate risks. The integration of citizen-science data and NGO-generated datasets into GIS systems brings together local knowledge and technical data, thereby supporting "bottom-up" adaptation approaches [1,2,8].

Copernicus Climate Data Store [CDS]

The Climate Data Store [CDS], a core component of the Copernicus Climate Change Service [C3S], is an integrated digital infrastructure that provides climate data spanning from the past to the future within a single platform [13]. Through its extensive dataset—comprising observations, reanalyses, seasonal forecasts, and global climate projections—CDS enables researchers and policymakers to make evidence-based decisions in climate adaptation [7,13]. The free availability of multidimensional atmospheric, terrestrial, and oceanic data provides a reliable and continuous information source for local governments [7,13].

The fifth-generation ECMWF reanalysis dataset [ERA5], provided by the European Centre for Medium-Range Weather Forecasts [ECMWF], allows high-resolution monitoring of temperature, precipitation, and wind patterns, and is widely used in GIS-based models for water management, agricultural resilience analyses, and urban heat island assessments [14].

CDS offers three fundamental functions for adaptation planning: risk monitoring, scenario analysis, and decision support. The "Climate Indicators for Europe" dataset provides indicators related to temperature, precipitation, drought, and flooding, thereby supporting localized risk assessments [7,13]. The CDS Toolbox facilitates the online analysis and visualization of these datasets, making technical information more interpretable and actionable for decision-makers [7,13].

With its open-access structure, CDS serves not only scientists but also local governments, the private sector, and civil society. This feature enhances transparency in local climate planning and strengthens data-driven participatory decision-making processes. It also contributes to integrating adaptation policies with disaster management, spatial planning, and green infrastructure investments, thereby supporting long-term resilience capacity [1,8,10].

Google Earth Engine [GEE]

Google Earth Engine [GEE] is a cloud-based remote sensing and spatial analysis platform with large-scale data processing capacity that stores and analyzes satellite imagery and environmental datasets [9]. Integrating extensive data sources such as Landsat, MODIS, and Sentinel, GEE enables the analysis of large-volume spatial data directly through a web browser via its JavaScript and Python APIs, and through this accessible structure enhances the climate monitoring capacity of local governments [9].

GEE's contribution to climate adaptation lies in its ability to monitor processes such as land-use change, loss of green infrastructure, urban heat island formation, and flood risk at high spatial and temporal resolutions [5,6,9]. Similarly, the platform has become a widely used tool for microclimate assessments, suitability analyses for urban green infrastructure, and the identification of climate-induced risks such as extreme heat [5,6].

Big Data Analytics and Cloud-Based Storage Systems

Big data analytics [BDA] and cloud-based storage systems constitute essential technological components for managing the increasing volume, velocity, and variety of data in climate change adaptation processes [9]. BDA processes large and heterogeneous data streams and generates meaningful indicators, early warning signals, and predictions through machine learning and statistical methods [4]. Cloud infrastructures, meanwhile, enable scalable and cost-effective storage and analysis of these datasets, thereby enhancing the data processing capacities of local and regional actors.

Cloud architectures [IaaS, PaaS, SaaS] provide a flexible workflow for integrating heterogeneous data sources such as satellite imagery, sensor networks, administrative records, and citizen-generated data [15]. By allowing users to rent virtual machines and storage resources without the need for physical hardware, these systems make it possible to conduct

computationally intensive flood modeling or climate data analyses on platforms such as Amazon Web Services [AWS] and Microsoft Azure [16,17]. Furthermore, they facilitate application development processes by offering databases, Application Programming Interfaces [APIs], and analytical tools [18].

The European Climate Adaptation Platform [Climate-ADAPT]

Climate-ADAPT is a platform developed by the European Environment Agency [EEA] and the European Commission, serving since 2012 as Europe's central knowledge hub on climate change adaptation [8]. Updated in alignment with the post-2020 European Green Deal and the European Climate Law, the platform supports the development of national and local adaptation strategies by providing policy documents, risk analyses, case studies, indicators, and analytical tools [19].

The platform's core function is to offer a shared data infrastructure that can be utilized by various actors, including local governments, public institutions, and research organizations [19]. Although Climate-ADAPT is not a direct artificial intelligence–based system, it is notable for its capacity to integrate with external tools that use data analytics and machine learning [4,19]. By incorporating national population datasets and resources such as the Copernicus Climate Data Store, Climate-ADAPT enables the spatial analysis of socio-economic indicators and assists in identifying areas most vulnerable to climate hazards [1,7].

Urban Adaptation Support Tool [UAST]

The Urban Adaptation Support Tool [UAST], developed within the Climate-ADAPT platform, is a digital decision-support tool specifically designed to assist urban administrations in systematically planning their climate change adaptation processes [20]. Aligned with the European Commission's Mission on Climate-Neutral and Smart Cities initiative, UAST provides a six-stage framework that guides cities through the adaptation cycle: assessment of the current situation, risk and vulnerability analysis, definition of adaptation visions and targets, selection of priority actions, identification of financing and implementation processes, and monitoring and evaluation [1,20]. This structure enables the identification of climate hazards and socio-infrastructural vulnerabilities, the formulation of strategic direction, and the strengthening of implementation capacity.

UAST integrates with data sources such as the Copernicus Climate Data Store and the European Climate Data Explorer, allowing for the spatial analysis of temperature, precipitation, and sea-level projections; thus, it supports the development of adaptation plans that are up-to-date, evidence-based, and data-driven [1,7,20]. The platform also provides access to knowledge networks and best-practice examples across Europe, thereby enhancing institutional learning and collaboration.

In Türkiye, metropolitan municipalities and cities in the Marmara Region employ similar digital tools in their adaptation action plans, and the localization of such instruments can serve as an important bridge between the national adaptation strategy and Europe's digital knowledge infrastructures [11,13,20]. Overall, UAST is regarded as a comprehensive digital tool that guides cities step-by-step through adaptation planning processes, supports data-driven analyses, and strengthens stakeholder participation.

A summary table is provided below, presenting the advantages, disadvantages, and application areas of the digital tools discussed above.

Table 1. Comparison table of digital tools, including their advantages, disadvantages, and areas of application

Digital Tools	Advantages	Disadvantages	Areas of Application
Geographic Information Systems [GIS]	It enables spatial data integration, risk mapping, scenario modeling, participation and visualization, while enhancing transparency and accountability.	It requires a high level of technical expertise. The accuracy and up-to-dateness of the data depend on the user.	Forecasting flood, drought, and heatwave risks; green infrastructure planning; carbon emission inventory development; and enhancing public awareness.
Copernicus Climate Data Store [CDS]	It provides long-term climate data and projections, offering opportunities for data integration and modeling. The CDS API facilitates streamlined data access.	It requires substantial big data processing capacity, and some datasets can be complex.	Risk and change monitoring, scenario and modeling support, participation, and decision-support functions.
Google Earth Engine [GEE]	It provides large-scale data analysis capabilities through JavaScript/Python APIs, high processing power, satellite data integration, and opportunities for spatial and temporal analysis.	It has a steep learning curve and requires stable internet connectivity and adequate technical infrastructure.	Land-use and land-cover change assessment, urban heat island analysis, flood and drought monitoring, and evapotranspiration mapping.
Big Data Analytics & Cloud-Based Storage	It manages challenges related to data volume, velocity, and variety, and provides scalability and flexibility through IaaS, PaaS, and SaaS models.	It poses security and data privacy risks and requires financial resources and technical expertise.	Flood, drought, and heatwave risk analyses; carbon emission inventory development; and large-scale data processing.
The European Climate Adaptation Platform Climate-ADAPT	It provides a shared data infrastructure, access to best-practice examples and knowledge exchange, and integration with various databases.	Artificial intelligence is not directly integrated, and some datasets are not up to date.	Climate scenario modeling, risk classification, vulnerability analysis, and stakeholder communication.
Urban Adaptation Support Tool [UAST]	It supports data-driven decision-making, provides access to knowledge networks at the European level, and enhances stakeholder participation.	Some integrations require technical infrastructure, and its adaptation in Türkiye is limited.	Urban-level adaptation planning, risk and vulnerability assessment, prioritization of actions and financing strategies, and monitoring and evaluation.

DISCUSSION AND CONCLUSION

When global and Turkish examples are examined, the role of digital tools in local governments' climate change adaptation processes reveals a distinct gap between their high potential and their practical use [1,10]. Although digital platforms such as the CDS, Climate-ADAPT, UAST, GIS, and remote sensing provide scientific and data-driven decision support, the lack of technical infrastructure and institutional capacity—particularly in small and medium-sized municipalities—significantly limits their effectiveness [1,7,11,12,19,20]. In Türkiye, the metropolitan-centered nature of national strategies further constrains the

widespread adoption of localized adaptation practices [11]. Therefore, a comprehensive policy framework is required to fully harness the potential of digital tools in enhancing adaptation capacity. Such a framework can be structured around five strategic pillars:

Localized pilot applications that test GIS-, CDS-, and AI-based platforms in small and medium-sized municipalities;

National data-sharing and standardization policies that strengthen data integration and quality standards;

Institutional capacity-building and training programs that enhance technical expertise and data literacy;

Participatory governance mechanisms supported by citizen-generated data and open data portals;

Research–practice integration aimed at optimizing data-processing models [1,4,7,12].

Pilot projects can test the applicability of digital tools across different socio-economic and geographic contexts, and successful examples may be scaled up. Data-sharing policies should be supported by hybrid cloud models that ensure compatibility and data security across platforms such as GIS, GEE, and CDS [1,7,9,11,12]. Within institutional capacity-building, modular training programs for CDS, BDA, and GEE should strengthen the data literacy not only of technical staff but also of decision-makers [4,7,9,11,14,15]. However, the literature indicates that examples where GEE is directly integrated into local governments' adaptation planning remain limited, highlighting a gap in practical implementation. Moreover, user capacity, data resolution issues, and accessibility constraints for local actors are among the factors influencing the platform's effective use [1,7,9,11]. Nonetheless, GEE offers substantial potential for applications such as early detection of urban heat islands and flood-prone areas.

Participatory governance tools should also support the long-term sustainability of adaptation strategies by increasing their societal acceptance [1,19,20]. Platforms such as Climate-ADAPT and UAST not only provide data but also offer structured tools that guide cities through the adaptation cycle. Although the adoption of these tools is relatively strong in metropolitan areas, their implementation remains weak in small-scale municipalities due to technical and institutional limitations [1,11]. The advantages of digital tools extend beyond risk mapping and scenario analysis to include social vulnerability assessment, stakeholder engagement, and governance processes [1,10,19,20].

In conclusion, the multidimensional contributions of digital tools to climate change adaptation—ranging from risk analysis and vulnerability assessment to spatial planning and participatory governance—indicate a broad and strategic transformation. The effective adoption of these tools has thus become a fundamental requirement for strengthening adaptation capacity.

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