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A Systematic Review of Digital Strategies for Equitable Climate Adaptation in Southern African Cities

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Abstract

This research examines digital technologies adoption for equitable climate preparedness in Southern African Development Community (SADC) cities. In this review, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology was applied to 23 studies in 11 SADC cities to study smart city technologies (SCTs) as tools of equitable climate adaptation. Results found Internet of Things (IoT) and Geographic Information Systems (GIS) as key smart city tools in SADC cities, aiding equitable water systems and flood assessment respectively. However, most interventions remained limited to short-term absorptive resilience strategies, largely due to systemic barriers such as fragmented governance, financial constraints and limited community engagement, undermining long-term effectiveness and equity. The findings further revealed that participatory approaches, such as community-led GIS mapping, tended to produce more inclusive and context-sensitive outcomes, while top-down deployments often excluded low-income populations. The study identifies four strategic priorities that can strengthen SCT-led climate adaptation. These are, governance reform, innovative financing, community participation and capacity building. These priority areas can be utilised to turn SCT interventions from the current disjointed and mostly donor-dependent initiatives towards more effective and equitable climate adaptation responses. This review advances SADC urban smart technology discourse, supporting equitable climate adaptation planning.

Keywords: smart city technologies, SADC, equitable climate adaptation, inclusive urban planning

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1.0 Introduction

The resilience of cities to environmental change has become one of the more critical aspects in sustainability science (Das et al., 2024). Although climate change presents a challenge to urban sustainability globally, the need to adapt to this challenge is more urgent in African cities (Mengistu et al., 2023). Urban settlements on the continent have become susceptible to extreme weather events such as floods and prolonged droughts (Mengistu et al., 2023). The Southern Africa region, which is also represented by the Southern African Development Community (SADC) economic bloc, is a critical case in the continent. The SADC region is one of the most affected by climate change especially due to climate phenomenon such as El Niño, which has led to increased cyclones, severe drought, floods, extreme temperatures and unpredictable weather (Chang and Ross, 2024). Cities in the SADC region are faced with low institutional capacity, economic vulnerability and weak infrastructural power which has led to poor or sometimes non-existent climate adaptation policies (Gracias et al., 2023). This situation is exacerbated by the process of rapid, often unplanned, urbanisation that is taking place in cities like Harare or mega cities like Johannesburg (Ogwu, 2019; Lazaroiu and Roscia, 2018; Echendu and Okafor, 2021).

Against this background of growing difficulties, smart city technologies (SCTs) have been identified as a potential means that can help to improve climate resilience and contribute to sustainable urban planning (Mortaheb and Jankowski, 2023). SCTs are systems that combine automation, real-time data, connectivity and in many cases integrate them with advanced technology to enhance urban activities and enable instant feedback (Gracias et al., 2023). They cover an extensive field of digital technologies such as sensor networks to monitor the environment, predictive analytics using AI and spatial planning using Geographical Information Systems (GIS) platforms (Padmapriya and Sujatha, 2023; Abdulhayan, 2023). Globally, SCTs have been applied to manage domestic water systems, reduce flood risks, various weather hazards and support early warning systems (Jebaraj et al., 2023). In African contexts, successful examples include AI-enabled flood prediction in Nairobi and IoT-based water conservation initiatives in Accra (Daudu et al., 2024; Allarané et al., 2024).

However, despite gaining traction elsewhere, the adoption of SCTs in SADC cities remains limited and inconsistent (Blanco-Montero, 2021). There is a limited research body and implementation is usually reactive as opposed to strategically oriented, like implementation of post flood sensor networks in Sioma (Zambia) (Siitala and Mbale, 2023) or the attempt at externally funded smart water meters in Harare (Chirisa et al., 2024). These trends question the prospects of scaling SCTs within marginalised SADC cities' landscapes and urban spaces where informal governance and systems tend to overpower service delivery. Unlike some other cities in East or West Africa, where innovation centres and networks have facilitated applied solutions, many SADC cities remain disconnected in their strategy of digital governance systems (Daudu et al., 2024; Allarané et al., 2024; Islamic Development Bank, 2024). The digital infrastructure and policy support needed to get SADC cities like Lusaka and Lilongwe going remains elusive (Siitala and Mbale, 2023). Researchers such as Chirisa et al. (2024) and Siitala and Mbale (2023) have argued that the majority of SCT deployments in SADC cities are limited to donor-led pilots which are disjointed with rest of the urban development plans. Such mismatch between technology innovation and institutional capacity introduces a big limitation (Timothy, 2019; Mwaniki, 2017).

Nonetheless, there are avenues of entry through alternative means that can be used even in the face of such obstacles. Studies have shown the efficacy of locally developed solutions in climate adaptation or resilience (Burley Farr, 2023). Such stakeholder inclusion has been shown to be effective by Borg et al. (2021) and Cobbinah and Finn (2023) in informal settlements and can become the basis of practically applicable decentralised, low-cost smart technologies for the SADC region. The involvement of local knowledge systems and emphasis on digital inclusion could enable SADC cities to enjoy the many benefits of smart innovations without copying resource-intensive models developed in other regions. This paper fills an important gap in the literature as it undertakes a systematic review of the deployment of smart city technologies to aid climate adaptation in SADC cities. This review, unlike previous studies that concentrate on metropolitan centres that are globally connected, focuses on cities in which there is a less well-developed digital infrastructure, fragmented governance systems and exposure to climate risks. To address gaps that were identified, this study reviews the deployment of SCTs in SADC cities, with particular attention to how these technologies contribute to urban climate adaptation. The review is guided by the following objectives:

1. To map SCT deployments for climate adaptation in SADC cities.
2. To diagnose governance and financial barriers to SCT adoption for climate adaptation.
3. To evaluate how community engagement and local knowledge shape SCT-based climate adaptation outcomes.

Through a synthesis of continent-wide patterns of SCT adoption with a particular emphasis on SADC cities, this systematic review critically examines the broader constraints and enablers of technology-enabled climate adaptation in one of the most climate impacted regions of the continent. The study's results are intended to benefit not only the academic discourse but also the policy making process by providing context-specific information on the possibility of adaptation scaling up in the smart city locally.

1.1 Theoretical Framework

This study adopts a hybrid framework combining Socio-Technical Systems (STS) Theory, Urban Resilience Theory, and the Capability Approach to evaluate the deployment of SCTs for climate adaptation in SADC cities. STS Theory, developed by Trist and Bamforth (1951) at the Tavistock Institute and later extended by Ropohl (1999), forms the foundational lens for this study. It stresses the mutual shaping of technology and society and highlights the linkages and interdependence between technical systems and social structures. According to the STS theory, successful SCTs require more than good technical design as they also rely on governance capacity, institutional coordination and citizen trust. However, STS has been critiqued for assuming alignment between technologies and fragmented social systems, especially in weak governance contexts (Pansera and Fressoli, 2021). In addition to the STS, the study also utilises the Urban Resilience Theory (Meerow et al., 2016; Sharifi and Yamagata, 2018). The theory defines urban resilience as comprising three major capacities which are absorptive, adaptive and transformative. Absorptive capacity involves short-term coping strategies such as ad hoc flood alerts, adaptive capacity refers to medium-term adjustments which maybe be for two to five years, while transformative entails systemic change that is meant to be a permanent part of the climate adaptation process (Meerow et al., 2016). Lastly, the study employs the Capability Approach by Sen (1999), a normative framework which has a strong emphasis on empowerment through the actual freedom that individuals have. The framework suggests that the existence of technologies like SCTs is not enough as people must be able to use, access and benefit from them. However, while the capability approach exposes equity gaps, it lacks tools for addressing infrastructural or governance deficits (Robeyns, 2021).

Thus, in the framework, the socio-technical systems theory assists in assessing the opportunities and prospects of SCT implementation at the technical and institutional level and the urban resilience theory explains the pathways and typologies of adaptation to climate change. Then the capability approach makes sure that equity, inclusion and human well-being are taken into consideration in any SCT implementation.

2.0 Material and methods

This research utilises the systematic literature review (SLR) methodology, with adherence to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA guidelines were chosen due to their transparent method of record identification and screening of studies which contributes to the replicability of research and methodological transparency (Sarkis-Onofre et al., 2021). To identify the literature on SCTs for climate adaptation in SADC cities, a structured search strategy was designed. First, the review period (2010-2024) corresponds to the emergence of SCTs into discourse on climate and wider regional strategies such as the Agenda 2063 (African Union, 2015) and SADCs Climate Adaptation Strategy (SADC, 2011). Following definition of the review period, the search was done in various databases, such as Scopus and Web of Science, JSTOR and SpringerLink, and African databases, including AJOL and Sabinet, among other relevant databases. Grey literature produced by reputable organisations such as UN-Habitat, the World Bank, AfDB, and the local governments was included. Cross-validation of such reports occurred with peer-reviewed studies when available. Backward and forward reference searches were carried out to locate other relevant sources of information through citation tracking. The role of this multi-step approach was to provide an inclusive and contextually informed evidence-base through which SCTs are to be evaluated in the SADC cities resilience.

The research compiled a list of keywords based on the research question and objectives. These keywords included “Smart City Technologies”, “Climate Adaptation,” “Smart Urban Resilience,” “Southern African Development Community Climate”, “Community-Based Climate Approaches,”, “Climate Equity,” “Climate Governance,” “Climate Funding Constraints,” and “Climate Community Engagement.” Synonyms and related terms were incorporated to broaden the search, such as “Smart Cities” OR “Urban Technologies,” “Climate Change Mitigation” OR “Climate Resilience,” “Sustainable Urban Development” OR “Resilient Cities,” “Southern Africa” OR “Sub-Saharan Africa,” “Local Participation” OR “Community Involvement,” and “Environmental Sustainability” OR “Eco-Friendly Solutions.” The keywords were combined using Boolean operators, resulting in search strings like (“Smart City Technologies” OR “Urban Technologies”) AND (“Climate Adaptation” OR “Climate Resilience”) AND (“SADC” OR “Southern Africa”). To retrieve the most relevant studies, we employed the use of Boolean searches and truncation in our search strategy. Key search terms included smart cities, climate adaptation and SADC region with the aim of balancing breadth and precision. The results were narrowed down by subject topic and language (English) to concentrate on work that is both empirical and policy related. The PRISMA flow diagram in Figure 1 demonstrates the steps that were used in the identification and selection of the studies that were review in this study.

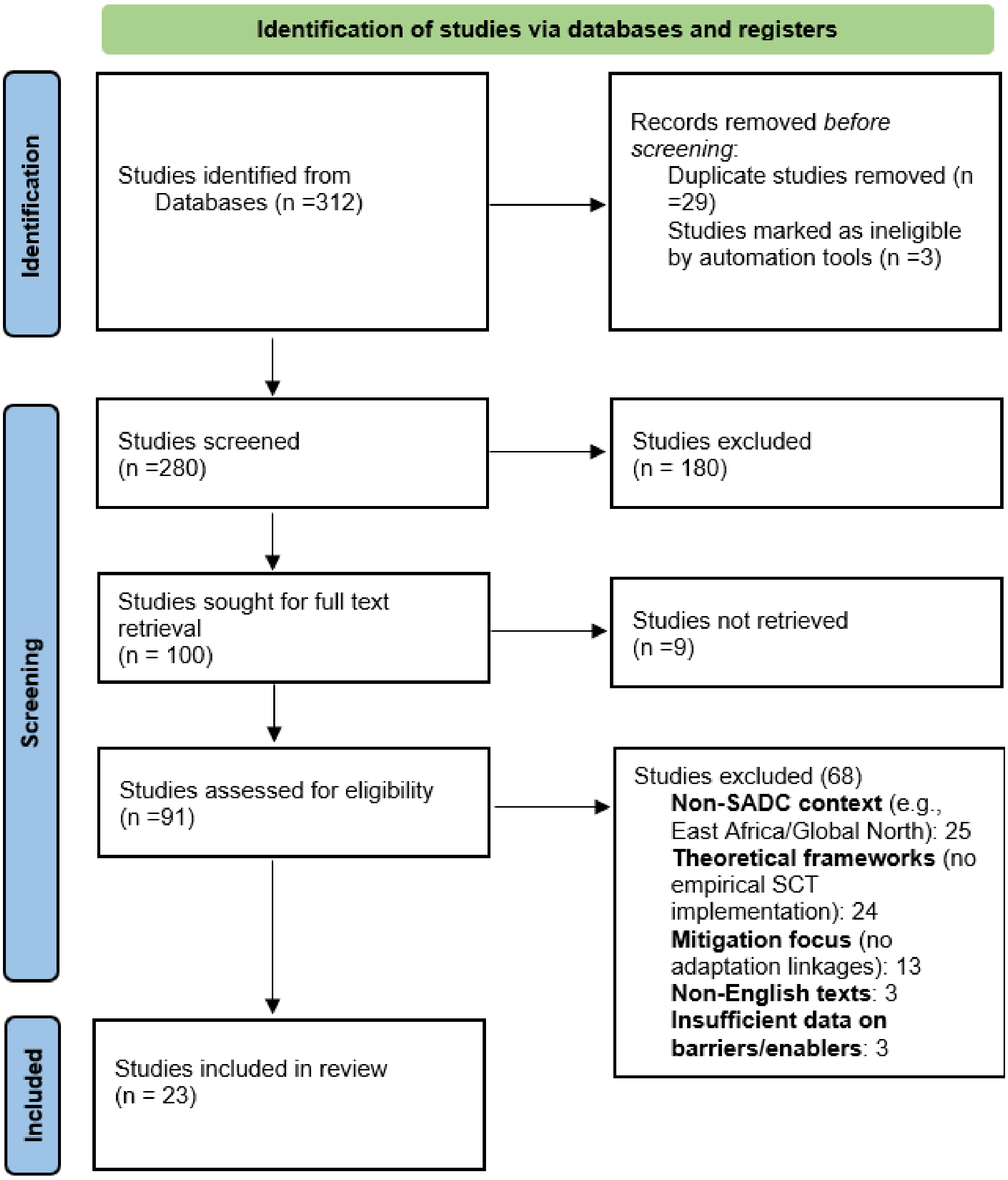

Figure 1. PRISMA flow chart

For the inclusion criteria we limited the sources to publications that studied SCTs in the context of SADC cities and addressed climate adaptation issues such as governance, policy, or socio-technical aspects in the whole implementation process. Additionally, only peer-reviewed articles, conference papers and high-quality institutional reports published between 2010 and 2024 were selected. The exclusion criteria included research carried out for cities outside SADC. However, exceptions were made for studies that provided comparative or generic experiences that could be applied to SADC. Furthermore, non-peer reviewed publications such as opinion articles, blog posts or publications were excluded in order to achieve methodological rigour.

After that we conducted full-text screening on the studies that met the inclusion criteria to make sure that they were relevant to the research objectives. The methodology made the approach to the review sound and replicable, reflecting the theme of intersection of technology, governance and climate resilience. The study design strikes a balance between depth theory and empirical inferences, forming a basis of interpretation of the role of SCTs in climate adaptation in highly urbanising and climate-climate-sensitive regions.

In the first step, 312 records were selected through academic databases. Upon initially eliminating 29 duplicate and 3 studies that did not meet the criteria marked by the automation tools, 280 records were put through the screening process. During title and abstract screening, 180 studies were excluded because they were potentially not relevant to SADC cities, did not include SCTs or did not focus on climate adaptation. A total of 100 studies were accessed at the full texts level, but only 91 of these studies were successfully retrieved. In the eligibility checks, 68 studies were excluded for different reasons. The grounds for exclusion included 25 studies whose geographic focus was outside of SADC, 24 were only theoretical works without an empirical SCT implementation, 13 studies which focused solely on climate mitigation with no elements of adaptation connection. An additional three (3) studies were excluded as they were non-English publications, followed by a further three (3) studies which lacked details on enablers or barriers tom SCT implementation. In total, 23 studies matched all inclusion criteria. Following the screening process, priority was given to literature that was directly relevant to SADC-specific SCT-based climate adaptation projects. This procedure guaranteed consistency with the regional scope and the objectives of the review. The systematic selection minimised bias and maximised transparency, which is crucial so the review adds value to discourses on smart cities and equitable climate adaptation in the Global South.

2.1 Ethical Considerations in the Systematic Review

Ethical rigour was obtained through a transparent, objective and replicable review process as described in the preceding section. The inclusion and exclusion criteria were clearly stated and regularly used based on the PRISMA framework. To counter any possible biases in grey literature, the sources were triangulated with peer-reviewed publications and in the case where primary data are available or regional publications triangulated with these as well. Potentially conflicting studies, including industry-sponsored promotion of SCTs, were critically appraised to reduce undue influence. The ethical consideration was also applied to fair representation in the SADC region; whereby high-profile projects should not take the centre stage at the expense of low- resources contexts that are underreported. Furthermore, ethical implications of SCT implementation at the costs of SCT deployment (including the risk of digital exclusion and data privacy issues) were addressed during synthesis. Collectively, these protective measures improved the validity and equity of the overview, which future researchers can recreate or expand to support it.

3.0 Results

This systematic review integrates evidence from 23 peer-reviewed empirical studies on the implementation of smart city technologies (SCTs) for climate change adaptation in Southern African cities. The cities emerged inductively from the geographic focus of the literature. As such, the analysis covers 11 cities, namely: Cape Town, eThekwini, Harare, Windhoek, Lusaka, Maputo, Mzuzu, Johannesburg, Gaborone, Lilongwe, and Blantyre. These cases were synthesised to identify patterns across three interdependent dimensions, socio-technical dynamics, resilience capacities, and equity outcomes. Each of these dimensions was shaped by contextual factors such as governance limitations, infrastructural gaps and socio-economic vulnerabilities and mapped to the theoretical framework.

3.1 Smart City Technology Interventions

The review found that SCT interventions in SADC cities were primarily driven by IoT and GIS which accounted for 60.87% (*n=14*) of the studies (Table 1). IoT applications were reported in 8 of the 23 studies (34.8%), mainly focused on water conservation and waste management, for example, smart water metering in Harare. GIS was used in 6 studies (26.1%) for flood risk mapping and urban zoning, such as in Cape Town's informal settlements. Transformative technologies such as blockchain and AI were reported much less often, occurring in 4 (17.4%) and 3 (13.0%) papers respectively. They are still largely conceptual or pilot, held back by infrastructural gaps and low institutional capability (Blanco-Montero, 2021). Thus, the review shows that there is little adoption of transformational technologies for climate adaptation in SADC cities.

Table 1. Smart City Technology interventions

SCT Type	Primary Adaptation Focus	Representative Case Studies
IoT	Water conservation, waste management	Gambe (2015); Ripunda and Booysen (2021); Holmes (2019); Blanco-Montero (2021)
GIS	Flood risk mapping, zoning	Musungu et al. (2011)
Blockchain	Water governance, secure payments	Adeola et al. (2024)
AI	Climate adaptation, predictive analytics	Holmes (2019); Akoh et al. (2011)
Other (3D printing, automation)	Urban infrastructure readiness, skills development	Holmes (2019)

Figure 1 illustrates the frequency of each SCT type, visually reinforcing the predominance of IoT and GIS over blockchain and AI.

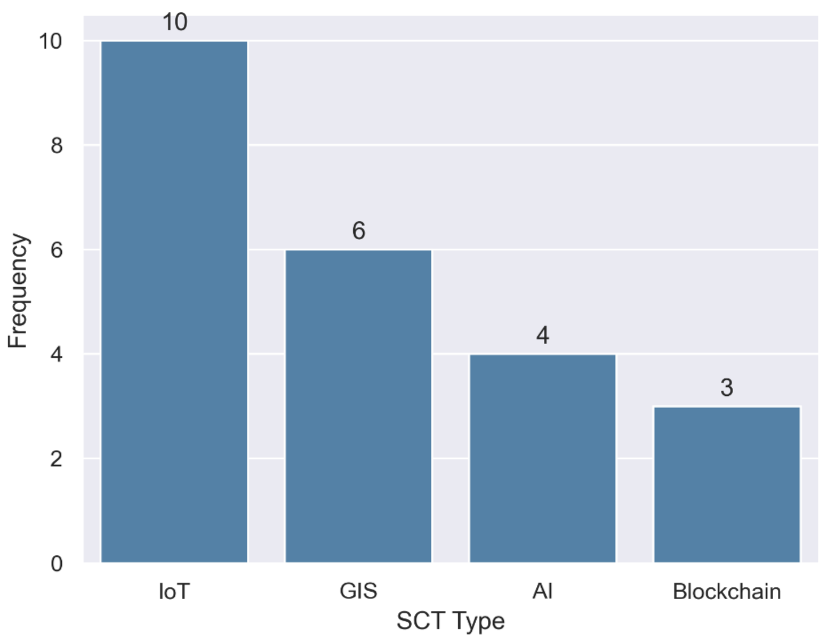

Figure 1. Count of SCT Types

3.2 Resilience Capacities

The review classified resilience strategies into absorptive, adaptive, and transformative capacities as shown in Table 2. The majority (*n=9*) focus on absorptive capacities that emphasise short-term risk mitigation. For instance, IoT-driven water rationing in Harare achieved significant water savings but excluded informal settlements due to affordability issues. Adaptive strategies (*n*=7) include participatory decision-making, as seen in Windhoek (Vhumbunu and Adetiba, 2023) and community-led planning in Maputo (van Berchum et al., 2020), though these efforts are often limited by institutional inertia. The data shows that transformative SCT strategies in SADC cities are rare with a notable example of the blockchain-enabled water governance model, which, despite its transparency, faces scalability challenges and high costs (Adeola et al., 2024). The predominance of absorptive approaches suggests a systemic short-termism that may hinder broader transformative impacts.

Drawing on the urban resilience framework, the study categorised resilience strategies into the absorbent, adaptive and transformational capacities (Table 2). The most common strategy was absorptive, mentioned in 9 of the 23 studies (39.13%), which targeted short-term coping strategies like decentralised alert systems or temporary rationing of water resources. An example is that drainage network monitoring prevented localised flooding in Lusaka (Nyimbili et al., 2024). Adaptive strategies (7 studies, 30.43%) entailed institutional learning and adaptive governance instruments like climate dashboards and zone-responsive governance. For example, real-time weather information was used in the decision-making of municipal level in Windhoek (Vhumbunu and Adetiba, 2023). This allocation signifies a disproportionate emphasis on the short-term containment occupation, and a limited thrust to progress structural resilience or long-term capacity.

Table 2. Resilience Capacities and Outcomes

Resilience Capacity	Definition	Key Outcomes and Examples	Equity Implications
Absorptive	Short-term risk mitigation	IoT water metering reduces losses (Gambe, 2015); rapid waste management (Blanco-Montero, 2021)	Often excludes low-income households

Adaptive	Medium-term systemic adjustments	Participatory decision-making (Scott and Taylor, 2023); community-led planning (Kareem et al., 2020)	Partial inclusion; institutional barriers persist
Transformative	Long-term systemic change	Governance realignment (Holmes, 2019); blockchain-enabled water governance	High costs and skills gaps limit scalability
Mixed	Combination of strategies	Integrated stormwater harvesting (Mukome, 2024); urban agriculture (Jagganath, 2021)	Outcomes depend on local conditions and investment

3.3 Socio-Technical Dynamics and Governance Barriers

Based on the review, two important patterns come into light concerning socio-technical dynamics. First, there is a constant mismatch between SCT interventions and local socio-political conditions. Although various studies report technically successful SCT implementations, many fail to account for local economic realities, informal settlement dynamics or community attitudes. For instance, in Mzuzu, Malawi, predictive flood modelling overlooked informal housing patterns and struggled with adoption in low-income areas due to affordability constraints and mistrust in data collection (Gumindoga et al., 2024). Such a mismatch compromises sustainability and inclusivity aspects of SCT projects over the long-term. Data-driven projects which focus purely on efficiency and do not consider either affordability or trust often lead to low-income populations being left out. In the same sense, government flood modelling remains a technological tool that often fails to capture community knowledge or informal ways of the city, which reduces its usefulness in climate adaptation.

Second, the barriers based on issues of governance are a common trend. The fragmented policy frameworks, weak institutional coordination and siloed departmental mandates have not supported the integration and scaled-up deployment of SCTs in various SADC cities (African Development Fund, 2022). There is evidence of how fragmented governance structures constrain cross-sectoral collaboration and tends to marginalise community-led efforts. Although comparative lessons have been brought forth by areas that are not under SADC, the review establishes the possibility of a moderately centralised system of governance that extends both coordinated decision-making and stakeholder inclusion (African Development Fund, 2022).

This relationship is visualised in Figure 2, which maps SCT efficacy against levels of governance centralisation using data extracted from the 23 reviewed studies. The figure synthesises empirical patterns across the sample, showing how varying degrees of centralisation correlated with reported implementation outcomes. Studies were categorised by governance structure (fragmented, moderately centralised, or highly centralised) and SCT outcomes were assessed in terms of scale, inclusivity, and sustainability.

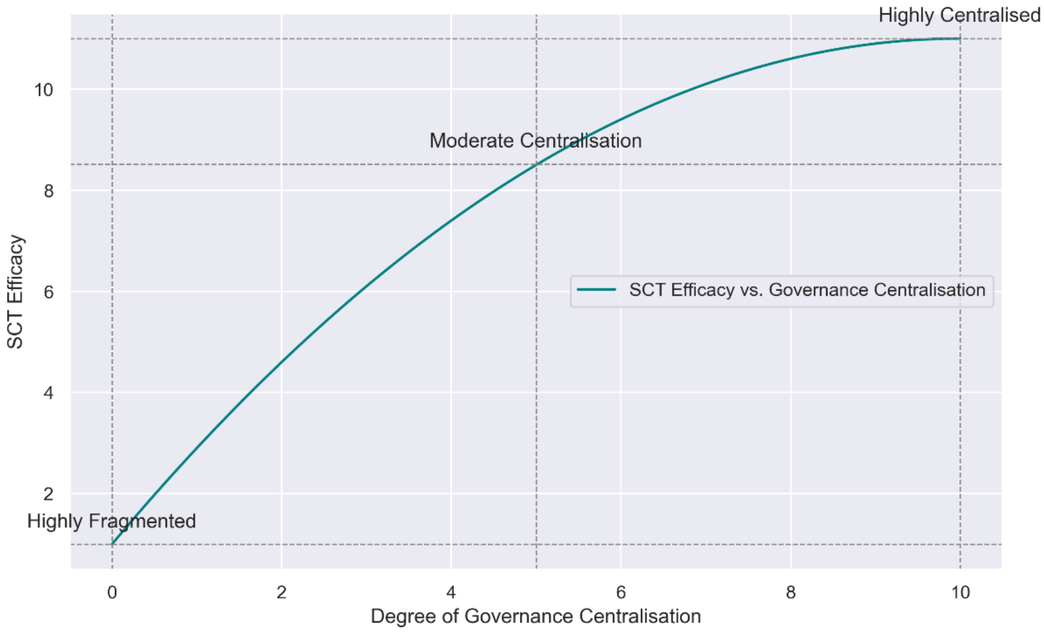

Figure 2. SCT Efficacy vs. Governance Centralisation

3.4 Equity Outcomes and the Capability Approach

The findings showed that SCT deployment showed mixed results in terms of equitable distribution of the solutions. For instance, participatory GIS projects in Cape Town have in certain instances facilitated the ability of informal settlement communities to make direct contributions to flood-risk maps, which targets location-related vulnerabilities (Musungu et al., 2011). Notwithstanding this successful example of an equitable implementation, the study identified that most SCT implementations are partially inclusive. This was more evident when the implementations were analysed by SCT type. Based on the analysis, IoT applications were the most exclusive in their implementation. Only about 20% of the studies were inclusive of all stakeholders including locals and low-income populations, 50% were partially inclusive and 30%

were outright exclusionary. This trend indicates that even when the technology such as smart water metering systems using IoT might increase efficiency and ultimately benefit people through lower bills, they tend to benefit formal areas of the cities and pose the threat of exacerbating the current socio-spatial disparities.

The trend is reflected in AI-based interventions in which most (75%) are not inclusive at all. Moreover, none of the instances of AI-based interventions were classified as including vulnerable populations. In contrast, the blockchain-based solutions represent slightly balanced equity outcomes, with approximately one-third fully inclusive and the other two-thirds partially inclusive and no instances of exclusion. These differences are briefed in Figure 3, which shows a heatmap reflecting the equity performance of various SCT types in case examples.

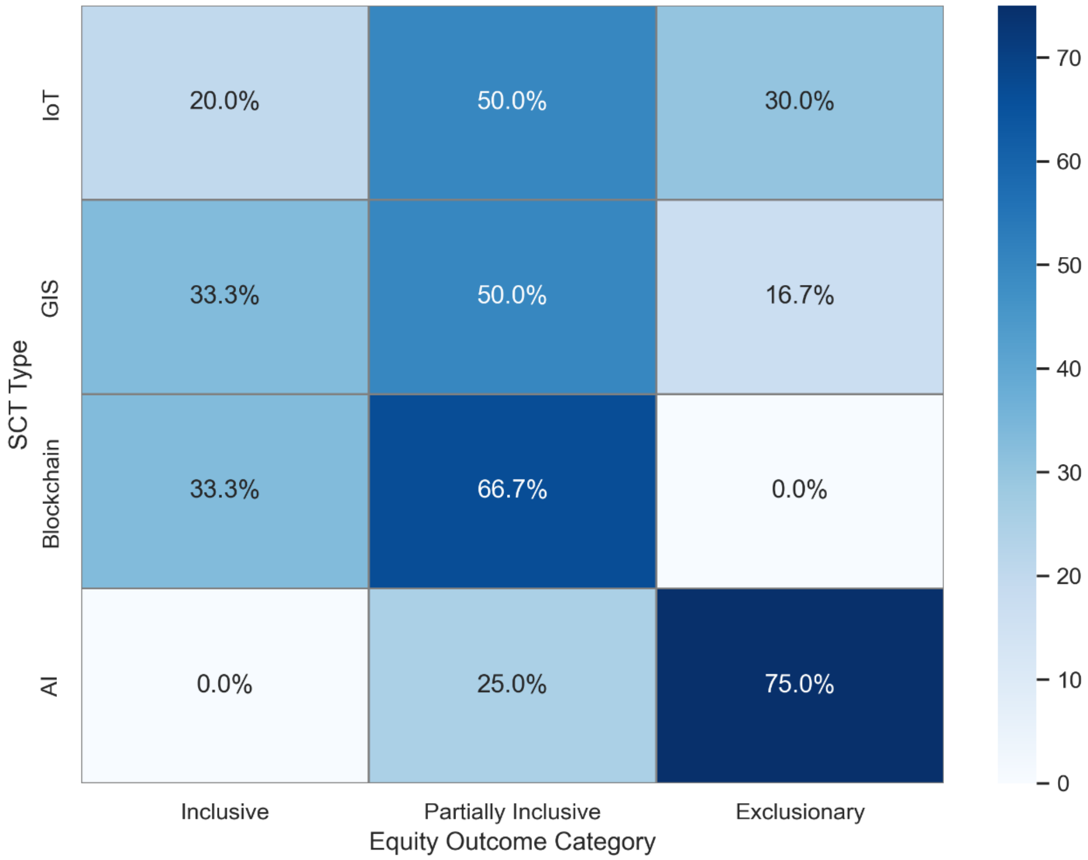

Figure 3. Heatmap of equity outcomes by SCT type.

3.5 Participatory Approaches as Catalysts for Success

A key pattern that emerged from the review is how participatory methods led to more balanced and effective smart city interventions. Projects that engaged communities in planning and decision-making and also integrated local knowledge experienced tangible climate adaptation gains across all populations in the cities (Musungu et al., 2021; Mwaniki, 2017; Kareem et al., 2020). In Windhoek, stakeholder engagement in climate adaptation was facilitated by programmes such as climate-smart agriculture and community learning platforms, though institutional constraints still inhibit their effectiveness (Vhumbunu and Adetiba, 2023). Another example as highlighted by Gambe (2015) is the use of digital systems plus the readiness of available instruments like the SMS alert in the city of Harare has the potential of managing the realities of under-resourced locations better.

These facts indicate that it will be necessary to implement structural changes in governance to make SADC cities more resilient. Collective, more comprehensive forms of organising should supplant fragmented mechanisms, and fair access can be achieved by financing solutions, including subsidies and shared-cost models. To facilitate sustainable effects, there will also be a need to enhance skills locally on the use and maintenance of technology. Combined, these measures can guide the development of an environment in which smart technologies can play a significant role in adapting to climate variability in cities across the subcontinent.

4.0 Discussion

The study revealed a multifaceted relationship between the technological intervention, institutional arrangement and the socio-economic realities in the SADC region. To bring the findings into context, the results of the study are interpreted in using the established theoretical perspectives (STS, urban resilience and capability approach), used in the work to define trends in SCT adoption for climate adaptation in the region.

4.1 Socio-Technical Realities of Smart City Technologies in SADC

The findings demonstrate that technological capacity can only partially affect the success of SCTs in SADC cities. Rather, to succeed, they should be aligned with institutional capacity and community involvement. This is in line with the STS which emphasises that technologies do not exist in vacuum as they need some enabling structures and social authority to operate. This is exemplified by smart meter projects in Cape Town (Ripunda and Booysen, 2021) and stormwater harvesting in Durban (Mukome, 2024), where their technical creativity eventually ran into the limits of a poor institutional coordination process and lack of citizen participation. Since the most of SCT interventions fail on the STS test (lack of social authority), they end up being short-term (absorptive resilience) initiatives rather than long-term urban climate adaptation processes.

On the other hand, in cities where participatory modalities have enhanced results like in Lusaka, Maputo and Windhoek, these approaches are hardly institutionalised to become a permanent trait of governance. This is an underlying structural limitation of the receptiveness or transformative capability of participatory forms of governance.

Furthermore, fragmented decision-making and siloed planning continue to be major barriers in SCT adoption. The examples of Windhoek and Cape Town prove that in most cases, smart city initiatives work independently of larger urban constructs or national SCT plans (Scott and Taylor, 2023; Musungu et al., 2011). Consequently, emerging ideas cannot be replicated or reconstructed as each city initiates, implements and runs its projects separately.

The patterns identified in the findings demonstrate one of the central insights within the STS theory. The study revealed that SCTs that are not integrated into the institutional structures or align with the priorities of the population cannot be sustained. To illustrate this in cities such as Mzuzu, Harare and Lusaka, smart water and flood resilience initiatives may have achieved technical success but lacked social compatibility which has made the efforts either a continuous tug-of-war (Harare) or led to the abandonment of the initiatives (Lusaka) (Gandidzanwa and Togo, 2022; Vhumbunu and Adetiba, 2023). For SADC cities, without these underpinnings, SCTs face the prospects of enshrining exclusion or even failure in the long run.

4.2 From Absorptive to Transformative Resilience - Pathways and Constraints

To assess SCT interventions, the Urban Resilience Theory provides a valuable typology, including absorptive, adaptive and transformative capacities. The empirical findings indicate that majority of SCT interventions in SADC are in the absorptive stage. Most of these were set up to deal with short term shocks (such as ad hoc water rationing, early warning systems) rather than being vehicle of long-term systemic adaptation.

However, critical analysis of the findings indicate that absorptive strategies dominance is more than just a technical concern since it represents wider structural limitations. Major SCT implementations are pilot-only, donor-led, and unsustainable in the financial scheme of things. They are largely characterised by designs that focus more on the short-term returns rather than long-term integration due to the necessity to adapt the plan to external sources of funding. A prime example is the eThekwini IoT waste management systems and smart metering in Cape Town, which were demonstrably successful initially but could not be scaled and do not comprise an inclusive infrastructure (Blanco-Montero, 2021; Ripunda and Booysen, 2021).

This partial transformation to adaptive or transformative resilience can further be attributed to the post-colonial legacies of cities, where informal settlements were marginalised both spatially and institutionally (Birkmann et al., 2022). Nevertheless, there has been instances where participatory GIS (PGIS) approaches have enhanced mapping precision, including in Cape Town and Windhoek. However, the inclusion of informal communities in fundamental planning processes remains weak, undermining their long-term effectiveness (Musungu et al., 2011; Scott and Taylor, 2023).

4.3 Inclusion, Equity, and the Limits of Access

Lastly, in the view of the Capability Approach (Sen, 1999), SCTs should increase the real freedoms of people which is the capacity to enjoy, utilise, and access the said technology. The findings, however, depict disturbing trend that emerged of consistent SCT exclusion within SADC cities, especially the low-income community and informal settlements.

The findings show that the major determinant of SCT exclusion was the type of technology underpinning the intervention. For example, IoT interventions are 20% inclusive against AI is very much exclusionary with 75% implementations excluding stakeholders such as the community. This trend can be attributed to the high costs of these novel technologies, inadequate access to digital infrastructure and insufficient digital literacy levels in the community (Birkmann et al., 2022). This has the effect of increasing inequalities instead of decreasing them. For example, smart meters have mostly favoured affluent suburbs, excluding informal settlements because of cost prohibition and infrastructural deficiency (Gandidzanwa and Togo, 2022).

Though blockchain-based apps seem more promising with regard to inclusivity, they are constrained by illiteracy and credibility. Therefore, this study affirms Sen's (1999) assertion that availability (of a technology) cannot be equated with capability unless individuals are free and able to use it in a meaningful and beneficial way. The failure to address this gap in systematic policies to increase digital access and encourage co-design with communities means that SCTs may further entrench socio-economic disparities instead of constructing an equitable resilience.

4.4 Key Strategic Implications for Climate Resilience

To advance equitable and effective SCT deployment in SADC cities, several strategic shifts are needed. Table 3 summarises four critical priorities, governance reform, innovative financing, community participation and capacity building, that emerged from the study's findings.

Table 3. Strategic Implications for Equitable Smart City Technology Deployment in SADC Cities

Strategic Priority	Key Insight	Operational Focus
1. Governance Reform	Fragmented, siloed governance structures limit SCT scalability.	Institutionalise cross-sectoral coordination (for example, between ICT, urban planning, and disaster risk management); embed SCTs in adaptive policy frameworks.
2. Innovative Financing	Donor-driven models are short-term and unsustainable.	Promote decentralised finance models, cost-sharing, and targeted subsidies to ensure equitable access. Encourage private sector involvement.
3. Community Participation	Top-down SCTs risk exclusion; participatory approaches improve resilience.	Embed participatory design processes (for example, PGIS, community-generated data) especially in informal settlements and flood-prone zones.
4. Capacity Building	Even well-designed SCTs fail without skilled personnel and institutional support.	Invest in digital literacy, technical training, and maintenance capacity within municipalities and communities.

These priorities underscore that climate resilience in SADC cities hinges on more than technological innovation. In addition to that it also depends on reconfiguring the institutional and social ecosystems in which technologies are embedded. Governance reform enables strategic alignment and cross-sectoral integration financial innovation broadens access and sustainability; participatory approaches ensure context-sensitivity and inclusion and capacity building secures long-term implementation.

Taken together, these interconnected strategies form the foundation for transitioning from short-term absorptive responses to long-term adaptive and transformative resilience.

5.0 Limitations of the study

The study has a number of limitations which need to be identified to place the results in context. First, the evidence base has been biased towards bigger economies in SADC like South Africa and Zimbabwe where there is more documentation regarding SCT interventions. This hinders the possibility of generalising the results to smaller or poorer-documented member states such as Eswatini, Lesotho, Madagascar or Botswana, in which case implementation dynamics may not be the same at all. Second, this SLR specifically considers only climate adaptation to the exclusion of other interventions that may be mitigation-oriented. This can lead to exclusion of integrated resilience strategies that can overlap with or explain what drives SCTs for urban climate adaptation. Finally, the study used only English-language studies which may have excluded applicable research studies that were written in French or Portuguese, which are official languages in certain SADC countries like Mozambique, Angola and Madagascar. Consequently, the regional diversity of SCT practice and experience might not be comprehensively represented in the analysis.

6.0 Conclusion and Future Directions

The research investigated how SCTs are employed in climate adaptation in SADC cities, including the prevalent technologies, barriers to systemic adoption and whether participatory techniques mediate or produce variations in adoption. The study revealed that IoT and GIS are most implemented, specifically to help with water control and flood risk mapping. the study also showed that more advanced technologies such as AI and blockchain are still in their early stages of implementation and that the majority of SCT interventions are limited to short-term absorptive approaches.

Among the most significant obstacles are the fragmented and siloed governance approach as well as the financial and poor integration among the local institutions. Siloed decision-making prevents embedding the long-term SCTs into long-term resilience planning. Furthermore, SCTs adoption in the SADC region is often top-down implementation which makes low-income populations unrepresented and destroys social confidence. On the other hand, participatory models prove that equity and effectiveness can be created by integrating the local knowledge. Such strategies are however not well institutionalised but rely on donor funding. Most of the SCT initiatives may end up being stagnant due to the lack of long-term financing mechanisms.

SADC cities should incorporate integrated governance structures to transform to adaptive and transformative resilience by aligning SCTs to participatory urban planning. Financial innovation by means of selective subsidies, cost-sharing, and decentralised financing is necessary to increase access. Greater emphasis and further investment should be placed upon community-led implementation as a means of closing socio-technical divides, in addition to ongoing investment in digital literacy and institutional capacity. The study contributes to the existing literature with the help of a resilience-equity-participation lens of SCTs in the Global South the critical synthesis of the socio-technical and governance system influence on the technological adaptation of needs in the urban context of Africa.

Future research should focus on developing equity-based smart city technology implementation frameworks that are grounded in local contexts and capable of addressing socio-economic disparities in climate adaptation.

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