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KADI

Report on outcomes of pilots and lessons learned from the pilots that can be applied for supporting the development of integrated climate services for urban areas

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Executive Summary

This report presents the results of pilot projects carried out in the cities of Abidjan, Nairobi and Dar es Salaam as part of the KADI initiative, aimed at developing integrated climate services tailored to African urban contexts. The projects adopted a co-design approach involving local stakeholders (public institutions, researchers, communities), highlighting several key lessons:

1. Importance of low-cost observation networks: These tools complement satellite data and compensate for the lack of reference stations in Africa. In Abidjan, an air quality monitoring network (PM2.5) has been strengthened, while Nairobi and Dar es Salaam have tested citizen sensors for heat extremes and flooding. Connecting the in-situ observation networks to satellite remote sensing can support upscaling of the observational capacities.

2. Community participation: Involving local populations in risk mapping (Dar es Salaam) or data collection (Nairobi) has enabled solutions to be adapted to the specific needs of the area.

3. Financial and logistical challenges: persistent limitations (funding, infrastructure maintenance, warning communication) underline the need for stronger partnerships and technologies adapted to local realities.

Comparative analysis of the three pilots (Part II) reveals commonalities and specificities:

- Abidjan: Focused on air quality, with a real-time alert system and sectoral integration (health, waste management).

- Dar es Salaam: Focused on managing multiple risks (floods, heat, pollution) through participatory methods and community initiatives.

- Nairobi: Development of an early warning system for heat extremes in informal settlements, with an emphasis on co-creation.

To ensure the sustainability of climate services, three recommendations are made:

1. Consolidate institutional partnerships (e.g. collaboration between universities, meteorological agencies and municipalities).

2. Prioritize accessible technologies (low-cost sensors, dispersion models). The upscaling experiment in air quality underlined the benefits of combining the low-cost air quality sensor network with open-access satellite remote sensing.

3. Develop robust communication strategies to raise awareness among populations and decision-makers.

Finally, the co-design approach implemented in these pilot projects must be flexible enough to be adapted to other urban contexts facing similar challenges. This will help expand the impact and reach of climate services in Africa.

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ACRONYMS

AMUGA : Autorité Organisatrice de la Mobilité Urbaine dans le Grand Abidjan
ANAGED : Agence Nationale de Gestion des Déchets de Côte d'Ivoire
ARU : Ardhi University
BC : Black Carbon
CCAC : Climate and Clean Air Coalition
CCM : Communication en Conseil des Ministres
CESEC : Economic, Social, Environmental, and Cultural Council
CIAPOL : Centre Ivoirien Anti-Pollution
CNCCI : Centre National de Calcul de Côte d'Ivoire
CNRS : Centre National de Recherche Scientifique
FAIR : Findable - Accessible - Interoperable - Reusable
GEF : Global Environment Facility
GIS : Geographic Information Systems
ICOS ERIC : Integrated Carbon Observation System European Research Infrastructure Consortia
INHP : Institut National d'Hygiène Public
INS : Institut National de la Statistique
KADI : Knowledge and climate services from an African observation and Data research Infrastructure
KDI : Konkouey Design Initiative
KMD : Kenya Meteorological Department
LASMES : Laboratoire des Sciences de la Matière, de l'Environnement et de l'Energie Solaire
MESRS : Ministère de l'Enseignement Supérieur et de la Recherche
NH3 : Ammonia
NO2 : Nitrogen Dioxide
OC : Organic Carbon
PGIS : Participatory Geographic Information Systems
PM : Particulate Matter
RI : Research Infrastructure
SO2 : Sulfur dioxide
SODEXAM : Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique
SSA : Sub-Saharan Africa
SUA : Sokoine University of Agriculture
SUZA : State University of Zanzibar
TV : Television
UDSM : University of Dar es Salaam
UFHB : University Félix Houphouët-Boigny
UHI : Urban Heat Island
UTU : University of Turku
WHO : World Health Organization
WP : Work package

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INTRODUCTION

The KADI project represents a significant step forward in the development of - inter alia - climate services adapted to African cities. In a context of accelerating climate change, the continent's urban centres are facing a variety of challenges, including extreme heat waves, air pollution and abnormal rainfall (UN-Habitat, 2021). These issues underline the urgent need for robust strategies to anticipate and manage these risks, particularly in rapidly expanding cities where infrastructure is often inadequate (World Bank, 2020). One of the main obstacles lies in the lack of early warning systems and dedicated climate monitoring infrastructure, which limits cities' resilience capacity (Tall et al., 2018).

To address these challenges, the KADI project adopts an innovative approach that combines science and technology, while actively involving local stakeholders, to create climate solutions tailored to the specificities of each territory. Deliverable 2.4, entitled “Report on outcomes of pilots and lessons learned from the pilots that can be applied for supporting the development of integrated climate services for urban areas”, presents the initial results of pilot projects currently being co-designed in three major African cities: Abidjan, Nairobi and Dar es Salaam. The aim of these pilots is to test and fine-tune innovative methodologies before implementing them on a large scale. This report outlines the initial lessons learned from the co-design process and examines their transferability potential to foster the development of integrated climate services in other urban contexts. The main objective is to identify best practices and challenges to be overcome for successful implementation on a larger scale.

Pilot projects are developed using participatory methodologies, involving researchers, decision-makers and local communities. This approach is essential to ensure that the proposed solutions are not only scientifically sound, but also socially accepted and adapted to local realities (Reed et al., 2009). Although still in the co-design phase, each pilot city is working on a specific strategy to address its priority climate challenges:

- In Abidjan, efforts are focused on designing an air quality monitoring network focused on fine particulate matter (PM2.5).

- In Nairobi, the project is focusing on the development of a heat extreme warning system.

- In Dar es Salaam, the initiative explores the use of participatory science to map climate risks and build community resilience to flooding.

The comparative analysis of these experiences provides valuable insights into the challenges and opportunities of co-designing climate services in a variety of urban contexts. It also explores how co-design approaches, tested in one city, could be adapted and replicated in other environments. This thought process is essential to establish effective strategies that support the development of integrated climate services, ensuring that they are both scientifically sound and relevant to local realities.

METHODOLOGIES

The aim of the Abidjan pilot is to set up an air quality network and early warning system. In Nairobi, the pilot focuses on temperature, heat stress and experienced heat in informal settlements. The Dar es Salaam city pilot focuses on the cascading effects of heat stress, air pollution and flooding in selected informal settlement neighbourhoods. The city pilots are also investigating the use of low-cost tools and methods to ensure the long-term sustainability of the climate observations. The three pilots for different cities methodologies are described in this section. As pilots present different characteristics, each pilot applied a specific methodology. The following section details the methodologies.

Abidjan

Work carried out as part of the UFHB “Aerosols and Pollution” team's various projects has demonstrated the importance of particulate pollution in Côte d'Ivoire and Sub-Saharan Africa in general. This work has shown concentration levels of fine particles (smaller than 2.5 µm, i.e. PM2.5) are generally higher than WHO standards. These results justify the objective of this climate service, which is to design an atmospheric pollution warning system in Abidjan by developing a PM2.5 measurement network and an effective communication network to reach the end users in case of exceeding WHO thresholds. UFHB draws on its experience and network of partners to set up and monitor this climate service. Also, UFHB and CNRS closely interacted to refine the definition of the pilot cities of Abidjan and its focus on air quality, to ensure consistency between WP1 and WP2.

To achieve this objective, the climate service must first set up a particulate pollution observation network. This network must provide continuous PM2.5 concentrations, as already done by the "Aerosols and Pollution" team at its two permanent sites in Abidjan (Figure 1). The number of sites is projected to be increased through collaboration with partners in Abidjan.

Figure 1. UFHB continuous measurement sites for atmospheric pollutants in Abidjan

The meteorological parameters (air temperature, relative humidity, precipitation, wind direction and speed) needed to monitor the dispersion of this pollutant are provided through a partnership with the Société d'exploitation et de développement aéroportuaire, aéronautique et météorologique (SODEXAM). PM2.5 concentrations will be presented on maps in graphic form for the public.

To document and understand air pollution in Abidjan, the UFHB team manages continuous measurements of gaseous and particulate pollutants such as NO2, SO2, NH3, PM2.5, PM10, OC and BC. In the KADI project, the UFHB focused on particulate pollution (PM2.5) because it far exceeds WHO standards and presents more health risks but continued to measure other pollutants for scientific purposes and to further up-grade the air quality pilots beyond the duration of the KADI project. Another motivation is due to the possibility of remote detection of gaseous pollutant such as NO2, and NH3, and the perspective to include satellite observations in the air quality network and warning system. However, including many pollutants it was too ambitious to envision within the time frame and resources of the project.

Over the past months, the UFHB has acquired three measuring devices to reinforce our measurement sites but still needs several instruments to cover the whole city of Abidjan. Therefore, the UFHB team has already identified all the stakeholders who are willing and are able to contribute to upgrading the observational network and thus our climate service.

In addition to the measurements of particulate matter (PM2.5), the UFHB team has the capability to run a pollutant dispersion model.

Abidjan's pilot climate service included an effective communication system using all media (radio, TV, social networks) to provide real-time information on particulate pollution to Abidjan's population. This system is intended to ensure awareness and the protection and prevention of the population. Containment measures were taken to limit outside movement (particularly for sensitive individuals). Similarly, hospital emergency services were alerted to take care of the most vulnerable populations. In addition, recommendations including action plans to organize the services to be ready to take care of the most vulnerable populations. In addition, recommendations including action plans to mitigate air pollution were proposed to political leaders. The latter need information on pollutant sources and air pollution levels to make the right decisions to improve air quality. Evaluation of a mitigation strategy requires emission inventories (emission registers, actual consumption data) regularly updated with information produced by stakeholders.

However, realistically, financial resources are still a challenge that the UFHB team need to meet to allow maintaining a sustainable climate service. Indeed, this climate service requires the extension of the city coverage with measuring equipment, the purchase and storage of geospatial and pollution data, as well as operating costs. Measurements must be combined with pollutant dispersion models to identify the sources, which also implies numerical capabilities and the involvement of atmospheric modelling experts.

Dar es Salaam

KADI Dar es Salaam climate service pilot co-created and tested citizen science methods for collecting critically needed data and information of climate stressors in neighbourhood scale. Digital data on climate hazards, vulnerability factors and exposure is scarce in Dar es Salaam, especially on a sub-city scale. Citizen science methods provide a rapid and cost-effective alternative way for collecting data and information to back up decision-making when adapting to increasingly experienced climate change effects. Specific citizen science methods piloted in Dar es Salaam were 1) community mapping of climate stressors, 2) focus group discussions to contextualise mapping results and identify citizens' climate service needs, and 3) stakeholder workshops to bring multiple local actors around the same table and discuss possible solution pathways that answer citizens' needs.

The pilot team identified two Wards – Tandale and Kigogo - in Dar es Salaam where the activities were carried out (Figure 2). The Wards were selected by the presence of three climate stressors: Extreme heat events, flooding, and poor air quality. Several Wards in Dar es Salaam experience all these stressors, but to secure the sufficiency of project resources, selection was narrowed down to two. Kigogo and Tandale are both mostly informally constructed, but they are located in different parts of the city. ARU and UTU have existing relationships to these wards' leader offices, which enabled smooth contacting and trust between the pilot team and participated ward community members.

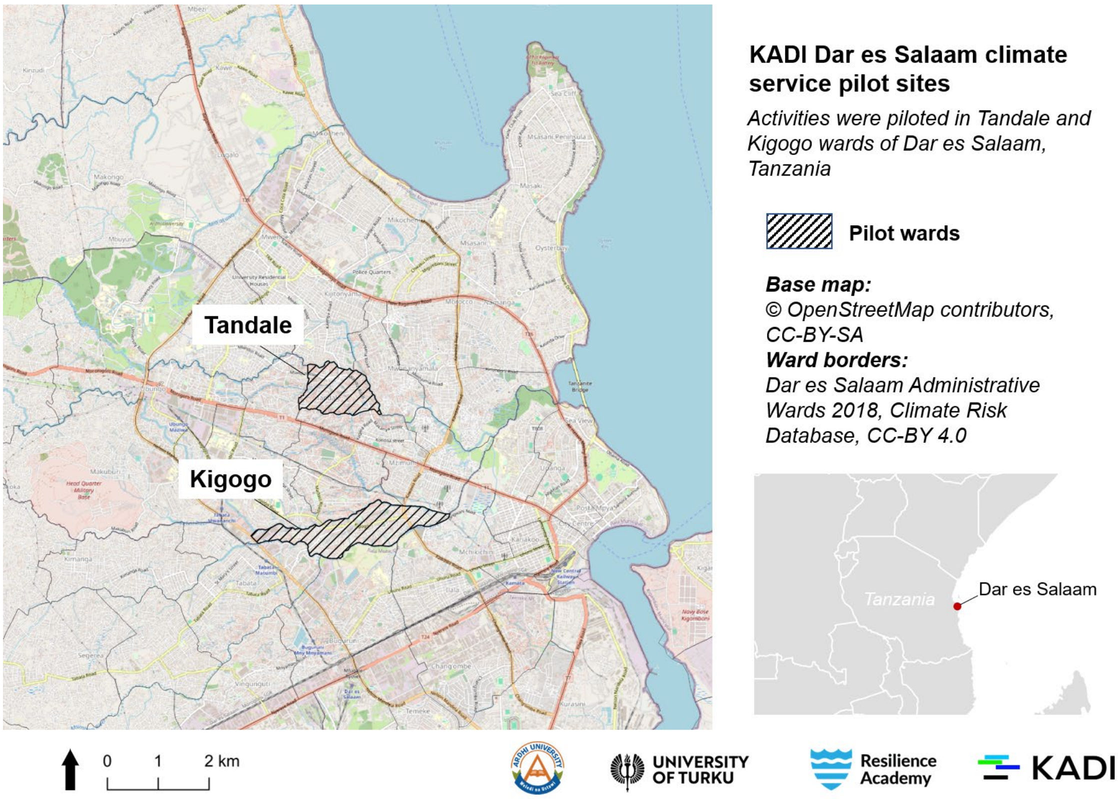

Figure 2. Tandale and Kigogo are located at the heart of the densely populated areas of Dar es Salaam, Tanzania. Image: Venla Aaltonen

Community mapping of climate risks

Community- or participatory mapping methods have increasingly been used in the context of climate change adaptation, disaster risk reduction and resilience building (Sullivan-Wiley et al. 2019; Canevari-Luzardo et al. 2015; Preston et al. 2011). Characteristic to these methods is to make local knowledge holders' voices heard in scientific processes. Using the methods often also aims to empower the participated communities and individuals to drive positive change in their living environments, and to broaden their involvement in public decision-making (Sieber 2008). Community mapping can be conducted with diverse set of tools, such as printed maps and markers, GPS devices, or online mapping survey platforms. The mapping process can be carried out as "stationary", when community members remain in one location and map out the phenomenon by adding physical or virtual markings on the map either individually or by discussing in groups. Another way is to conduct the mapping by walking around in the environment where the phenomenon is present and adding points of interest to a digital map interface with GPS devices or manually.

In the KADI Dar es Salaam climate service pilot, community mapping of climate risks took place during five days in October 2023. Ten students from Ardhi University were employed to carry out the mapping in the two selected wards, supervised by senior staff members of the universities. The students were compensated for their work and provided with mobile data access for the five field working days. An online mapping survey tool - Maptionnaire - was used to record local citizens' climate stressor experiences into digital spatial data (Kyttä et al. 2023). The Maptionnaire survey contained questions of where citizens have most often experienced floods, extreme heat and air pollution, and the locations pointed out by them were added as points and polygons into the survey tool's mobile map interface (Figure 3). Students discussed and filled out the mobile mapping survey with 400 citizens in total. As a result, geospatial data about the community members' experiences on extreme heat events', floods and air pollution locations were collected. The survey also inquired the citizens' other experiences on how the climatic phenomena have affected their lives, how they prepare and cope with the stressors, and what they would need for better adaptation in the future. Raw data was analysed separately for each mapped climate stressor with spatial density analysis to find those areas with denser concentrations of experiences. Those places and areas indicate that the climate stressor is present and strong enough for multiple citizens to notice and struggle with.

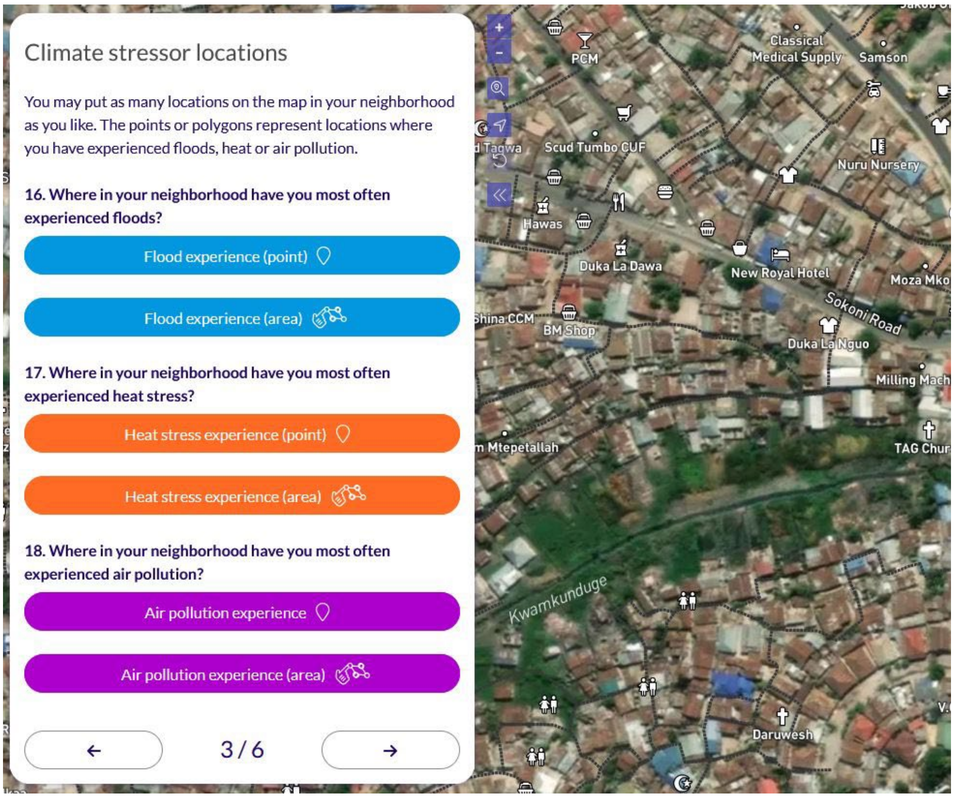

Figure 3. The Maptionnaire survey contained both spatial questions as shown in the figure, as well as non-spatial questions. The employed university students filled in the survey while discussing with respondents.

Focus group discussions

An important step in community mapping methods is to validate or contextualise the mapping results. Printed climate stressor experience maps were brought to the second piloted activity, focus group discussions, which took place in Kigogo and Tandale wards in February 2024. Two focus group discussions were held by the University of Turku and Ardhi University project staff members, one in each ward. Participants were ten community members from both wards who were both men and women, and of different ages. The participants were selected by the ward leaders, and they included such individuals who have been active in community groups and has experience on dealing with climate risks.

Focus group discussions as a qualitative research method is used to dive deeper into societal topics at hand (Nyumba et al. 2018). Participants share their viewpoints, engage in dialogue with each other, and create knowledge about the discussed phenomenon. There are several methodological alternatives to choose from when running focus group discussions. For example, the discussion can flow freely around a selected topic or be somehow structured to sections by using predetermined guiding questions.

In this pilot, aim of the focus group discussions was to validate the mapping results, and find reasons for the climate stressor occurrence. Participants discussed reasons behind climate stressor experience hotspots and were for example able to identify factors why specific areas were dense of air pollution experiences. This kind of contextualisation adds deeper value to the data drawn from community mapping activities and provides indication where intervention should most critically take place. The half-structured discussions covered also the themes of 1) information flows from authorities regarding the climate stressors, 2) local knowledge in coping with and adapting to the stressors, and 3) possible strategies and solutions that would answer the communities' adaptation needs, and who should be responsible for carrying them out - households, communities, or the local government.

Stakeholder workshop

Finally, a one-day stakeholder workshop was organised at the end of the same week in February 2024 as the focus group discussions. Twenty-five (25) participants were community members (different individuals as in the focus group discussions), Ward leaders, Ward Environmental Officers, Town planners, Tanzania Meteorological Agency representatives, and researchers and alumni students from the Ardhi University. Aim of the stakeholder workshop was to connect citizens and decision-makers to discuss existing and possible pathways to intervene with the most pressing climate-related challenges communities are facing.

The workshop started with an ice-breaker exercise introduced by the KADI team which eventually turned out to be an integral part to the discussions that followed. Participants listed challenges they face in their everyday life on post-it notes, and after a break the challenges were flagged either to be connected to climate stressors, urban planning, or to both. Second, participants were assigned to groups to discuss the most important findings from focus group discussions – climate stressor challenges, information flows, and possible solutions. Finally, shared discussion was carried out to find pathways to intervene with the most pressing challenges, such as slow information flow from authorities, little inclusion of local knowledge in early warning forecasts, and urban planning related issues that exacerbate the impacts of climate stressors.

Nairobi

The Nairobi pilot was based on previous work done in Nairobi, scoping and fulfilling climate service needs related to precipitation and lack thereof as well as preliminarily high and low temperature and their effects in informal settlements. In the KADI city pilot, similar approaches were used but the focus is on temperature, heat stress, and experienced heat in informal settlements of Nairobi. The pilot included citizen science and explored possibilities of usage of low-cost sensors. After careful consideration, the pilot focused on temperature and heat stress as opposed to the initial grant agreement on air quality. The KMD team evaluated the potential for sustainability of focusing on air quality, especially without adding human resources in the form of staff after the project period lapses, as well as the possibility of acquiring and installing sensors for ambient air quality measurement in the identified sites. The team determined that upon the successful completion of the project, it would be challenging to sustain the work established. The decision to settle for temperature and heat stress was arrived at based on existing work that had successfully been done and is ongoing, working with informal settlements for rainfall warnings

The initial proposal was to work on pollution as a pilot but after consultations, the issue of heat in informal settlements appeared as a better option. This was because some preliminary work had been done on a previous project in informal settlements in the city of Nairobi and it would be easier to build on that work. Additionally, some work had also been done on identifying heat thresholds in the cities of Nairobi, Mombasa, and Kisumu. This work would form a basis to build on for the Nairobi City Pilot.

The Nairobi pilot utilized co-creation with stakeholders to determine user needs and the best way to meet them. Weather data from the nearby meteorological observation stations were the primary source of data. However more data was required particularly from the informal settlements themselves.

Over recent months, team members participated in pilot meetings organized by the lead partners and contributed to developing the work plan. While not yet implemented, citizen science will be used in determining ambient heat in informal settlements. Modalities of engaging teams that will be used to collect data have not yet been started but should start in the coming months.

Literature review

To illustrate the need for early warning for heat extremes, a literature review was carried out as part of a parallel study seeking to characterize thresholds for heat extremes in 3 major cities in Kenya including Nairobi.

Findings included the fact that Africa is plagued by a dearth of information on changing risks in extreme weather (Seneviratne *et al.,* 2022). At the same time rapid urbanization and population growth interact with climate change to increase the risk of severe impacts from extreme climate events such as droughts, floods and in more recent years' heatwaves (Dodman *et al.,* 2015). Both observations and model projections capture heatwaves and their impacts in Kenya and other Sub-Saharan Africa (SSA) countries, however not usually reported by national meteorological services and are seldom captured in extreme weather databases (Harrington & Otto, 2020). This highlights the glaring need to improve our understanding of the link between extreme heat and health to support the development of effective early warning and adaptation strategies in a rapidly warming world, to safeguard the lives and livelihoods of the people (Scrovonic *et al.,* 2018). Kimutai et al 2022 used meteorological data and hospital data to investigate the link between heat extremes and a surge in hospitalization and mortalities and found that in the cities researched, both increased during periods of prolonged heat events.

Stakeholder workshop

A user and stakeholder workshop was used to discuss needs, gaps and the most efficient ways to fill these.

Representatives from two of the main informal settlements Kibera and Mathare and intermediary organizations such as the Konkouey Design Initiative (KDI) that work in the informal settlements were the primary stakeholders. Discussions with these stakeholders involved identification of areas represented and tentative number of people to be reached, climate service gaps and needs with specific focus on heat early warning. Based on previous work done with the same representatives of the informal settlements, discussions additionally included possible ways to incorporate heat forecasts and warnings in the existing forecasts and leveraging existing programs to do so. The County government responsible for overseeing implementation of interventions were represented as key stakeholders. Conversations with the county government representatives centred on existing collaborations, needs for future collaborations as well as research needs and support required to operationalize support once heat early warnings are issued. Subsequent meetings with the county government were held to discuss the development of a guidance note for heat action plans for the city of Nairobi with particular focus on informal settlements.

Part I - Results of co-design actions in pilot projects (Stakeholders involved, tools used, results obtained)

Abidjan

Overview

The Abidjan pilot climate service was meant to set up an early warning system on particulate matter pollution using mainly observational network system on air pollution, additional data from other stakeholders including sociological, meteorological datasets. This study was undertaken in an area where we already have experiences through the participatory approach to account for the population needs. The pilot identified keys stakeholders, needed to set up the climate service. The interactions with the stakeholders enabled us to know the prior actions to be taken in case of pollution peaks and the responsible actor to carry out those actions. In addition, it also showed the contribution and role of different stakeholders in the co-production of this climate service.

Abidjan is particularly exposed to air pollution due to the rapid urbanization the lack of air quality monitoring networks and the high health-related risk associated with air pollution. The existing observational network in Abidjan has been reinforced to achieve an air quality monitoring network to enable the climate service of Abidjan pilot. The climate service in this pilot is co-designed to help control the pollution level, alert the population and inform decision making.

Activities

The establishment of the Abidjan Climate Pilot required close collaboration among numerous stakeholders. To ensure the success of this initiative, the KADI team adopted a co-creation approach, leveraging strategic meetings and in-depth discussions.

Meetings with Stakeholders

The KADI team held several meetings with key institutions, including:

- **The National Institute of Public Hygiene (INHP)**

In February 2023, discussions with the INHP team focused on selecting the pilot site: the Bingerville commune. This site represents the city of Abidjan, featuring both high-end residential areas and underprivileged neighbourhoods where several projects have already been conducted. The INHP provided a sociological and scientific database derived from projects implemented in health centres and hospitals in the commune. This collaboration enabled the design of a participatory approach questionnaire to engage the population and gather their perceptions of the health impacts of air pollution.

- **The Airport Development and Meteorological Operations Company (SODEXAM)**

The first meeting with SODEXAM took place in February 2023. Discussions revolved around accessing climate and meteorological data essential for our pollutant dispersion monitoring model. As the agency responsible for climate services in Côte d'Ivoire, SODEXAM operates in sectors such as energy, health, and agriculture. Their meteorological database and expertise in designing climate services are invaluable for the Abidjan climate Pilot.

- **The Ivorian Anti-Pollution Centre (CIAPOL)**

Discussions with CIAPOL focused on integrating existing air pollution data, particularly from the industrial sector, to create a comprehensive database covering all sectors of activity in Abidjan. In our measurements networks, we usually focus on traffic, domestic , residential and waste burning sectors. We lack measurement from the industrial sector. The collaboration with CIAPOL is needed to have a more comprehension database on air quality covering all contributing sectors. As the national agency responsible for air quality, CIAPOL will also play a critical role in disseminating results.

- **The National Waste Management Agency (ANAGED)**

In March 2023, discussions with ANAGED addressed the identification of major pollution sources, particularly residential and domestic sources. As the agency responsible for regulating and controlling residential pollution, ANAGED committed to raising public awareness about behaviours to reduce risks and supporting participatory approaches in collaboration with local communities.

- **DATA 354**

This strategic partner assists in managing and establishing the air quality database and developing the Air Quality Index.

These meetings often required multiple sessions, held either at the Félix Houphouët-Boigny University of Abidjan or at the respective institutions. The goal was to understand stakeholder expectations and secure their formal commitment to the project's various phases.

Collaborative workshop with stakeholders

Following a series of individual meetings, a collaborative workshop was organized on Friday, June 28, 2024, from 9:00 AM to 12:00 PM, in the conference room of the Faculty of Pharmaceutical and Biological Sciences at Félix Houphouët-Boigny University. This event brought together over 30 participants from various partner organizations, fostering a collaborative environment to address the critical issue of climate change (Appendice 1). The workshop aimed to strengthen partnerships and enhance collective efforts in combating climate change through the Abidjan Climate Service project. It is important to note that UFHB is directly involved in WP1, WP2, WP3 and WP5.

- **Main objectives of the meeting**
  - ➢ **Inform Stakeholders:** to brief stakeholders on the goals of the Abidjan Climate Service, ensuring their effective involvement in various project actions.
  - ➢ **Engage Stakeholders:** to secure the commitment of all stakeholders to the Abidjan Climate Service project, encouraging active participation and collaboration.
  - ➢ **Present Project Results:** to showcase the results and actions undertaken and currently being carried out within the project, highlighting progress and achievements.
  - ➢ **Plan Future Steps:** to discuss and plan future steps for the implementation of the climate service, ensuring a clear roadmap for continued progress.
  - ➢ **Identify Funding and Equipment Needs:** to identify the funding and equipment needs required to ensure the sustainability of the climate service, securing the resources necessary for long-term success.

- **Key Stakeholder concerns discussed during the KADI workshop**

Discussions identified several major concerns regarding the implementation and sustainability of the project. These concerns are structured around the six work packages (WPs) that define the KADI project. Each issue raised was discussed in direct relation to the objectives of these work packages, allowing for an in depth examination of the technical, institutional, and financial challenges of the project.

- **Ensuring the complete and coherent implementation of the KADI project**

One of the primary concerns raised by stakeholders was the need for a fully integrated and coordinated implementation of the KADI project. Participants expressed concerns about potential fragmentation among the different components of the project, particularly regarding the various work packages. They emphasized the importance of a cohesive integration of activities from WP1 (Definition of required climate services), WP2 (Climate service pilots), WP3 (Strategic infrastructure design), WP4 (Knowledge exchange platform), WP5 (Policy cooperation), and WP6 (Coordination, communication, dissemination and exploitation). A lack of coordination could limit the impact of the pilot climate service in Abidjan.

To address these concerns, discussions highlighted the need for a coordinated approach to maximize the project's effectiveness. Stakeholders insisted on several key elements for the success of the climate service, including the development of air quality indicator maps (WP1) for Abidjan, the deployment of a reliable monitoring network (WP2), the strengthening of measurement infrastructures (WP3), and the establishment of strong institutional partnerships (WP5).

In response to these expectations, the KADI team proposed a gradual and integrated strategy. This strategy is based on an initial identification of needs (WP1), followed by a progressive deployment of sensors and an alert system (WP2) while strengthening institutional collaborations (WP5). Additionally, WP6, led by ICOS ERIC, will ensure effective project management and transparent dissemination of results.

- **Securing adequate financial resources for the project**

Another major concern involved the availability of funding necessary for both the establishment and sustainability of the project. Discussions revealed significant apprehension among stakeholders about the project's ability to mobilize sufficient financial resources. Several aspects require funding, particularly the acquisition of measuring instruments and low-cost sensors (WP3), the mobilization of funding partners to ensure the project's continuity (WP5), and the financial management necessary for effective monitoring of activities (WP6).

During discussions, participants stressed that a lack of funding could compromise the installation and maintenance of air quality monitoring equipment. They specifically highlighted the costs associated with acquiring low-cost sensors, accessing satellite data, and maintaining measurement infrastructures. Without sufficient resources, the project risks stagnation and failing to achieve its long-term objectives.

To support the successful implementation of the KADI project, various funding sources were identified, including:

- **Global Environment Facility (GEF)** finances environmental projects including urban climate initiatives in developing countries. The project should demonstrate a global environmental impact and align with national climate priorities.

- **African Development Bank (AfDB)** supports sustainable development projects across Africa. To obtain funding, a detailed proposal should be prepared in partnership with a governmental or municipal institution. The project must align with the AfDB's climate development strategies, such as the Green Growth Program.

- **National Institutions, such as the National Assembly and the Economic, Social, Environmental, and Cultural Council (CESEC)** can allocate public funds for climate initiatives through the national budget. Advocacy with policymakers is necessary to prioritize the project in budget allocations.

- **The District of Abidjan** Funds dedicated to urban development and climate adaptation for municipalities in the District of Abidjan. - **Climate and Clean Air Coalition (CCAC)** – Potential funding of up to $1 million – Funds for projects related to climate, air quality, Short lived climate pollutants (SLCP) and national policies and implementation of mitigation in developing countries.

- **Project Study Fund for Financing** supports feasibility studies and the preparation of climate projects. Accessing this funding typically requires a letter of interest, followed by a detailed proposal outlining the project's objectives, beneficiaries, and expected environmental impact.

➢ **Addressing medical waste management and socio environmental conflicts**

Beyond air pollution, some stakeholders expressed the need for the project to incorporate related issues such as medical waste management and conflicts between farmers and herders. While distinct from particulate pollution, these issues have a direct impact on environmental and climate dynamics, particularly in urban and rural settings.

Discussions highlighted the need to include these factors in climate needs analysis (WP1) and in the development of pilot services (WP2). Stakeholders particularly emphasized the importance of assessing emissions from hospital incinerators, which represent a significant source of air pollution. They also pointed out the impact of climate change on tensions between farmers and herders, due to the increasing scarcity of natural resources.

In response to these concerns, the UFHB team is committed to integrating these elements into its activities. More specifically, depending on the means available, it plans to measure PM2.5 concentrations from hospital incinerators.

➢ **Improving the availability and accessibility of climate data**

One of the key principles established for data management is adherence to FAIR principles, ensuring that all collected data is:

- Findable (Properly localized and identifiable)

- Accessible (Easily available to stakeholders)

- Interoperable (Compatible with various data systems)

- Reusable (Effectively utilized for future research and policymaking)

Data accessibility remains a major concern for stakeholders involved in the project. The collection and dissemination of environmental information must be ensured to maximize the effectiveness of the pilot climate service. Discussions revealed that several actors are worried about the availability of data obtained from in-situ measurements, satellite observations, and climate models.

To address this concern, the UFHB team reaffirmed its commitment to adhering to these principles. UFHB specified that ongoing efforts aim to centralize, secure, and effectively share data with relevant stakeholders. Partnerships with institutions such as Data 354 will enhance the management and accessibility of environmental information.

➢ **Stakeholder commitments and proposed actions**

Several stakeholders made commitments to support the project at different levels:

- **INHP** – Providing relevant sociological dataset
- **INS, SODEXAM, CIAPOL, and ANAGED** – Providing relevant data for the project.
- **LASMES Precipitation Team** – Assisting with data acquisition.
- **AMUGA** – Supporting efforts to reduce transport-related emissions.
- **Data 354** – Contributing to the data lifecycle strategy, including centralization, access control, and availability of data.
- **Autonomous District of Abidjan** – Leading the project and integrating it into funding programs.

To ensure the success and sustainability of the project, the following actions were recommended:

- Establish a Scientific Committee composed of stakeholder representatives to hold regular meetings and guide project implementation.
- Strengthen Data Collection Infrastructure to improve air quality monitoring and environmental assessment.
- Engage the Ministry of Higher Education and Scientific Research (MESRS) to draft an official communication for the Council of Ministers (CCM), ensuring high-level governmental support.

Key Achievements

The KADI project has already made significant progress, particularly in air quality monitoring and stakeholder engagement:

- Development of a participatory questionnaire to involve local populations in data collection and awareness.
- Creation of a metadata system compiling air quality measurements from multiple monitoring sites in Abidjan.
- Signing of partnerships with key organizations to support the project's implementation (SODEXAM, CIAPOL, INHP and ANAGED).
- Strengthening air quality monitoring capacity by installing advanced equipment, including:
- Weather stations for tracking climatic conditions.
- Analyzers for nitrogen oxides ($NO/NO_2/NO_x$) and sulfur dioxide (SO_2).
- Sensors for PM_1, $PM_{2.5}$, PM_{10}, NO_2, O_3, VOCs, temperature, humidity, and atmospheric pressure.

These monitoring systems have been deployed at key sites, including:

- Félix Houphouët-Boigny University
- Nangui Abrogoua University
- Banco Forest
- Industrial zones in Yopougon and Koumassi

Future monitoring campaigns will expand coverage and analyze long-term pollution trends.

Next Steps: Towards an Early Warning System

The successful implementation of the Abidjan pilot project will enable the development of an early warning system for air pollution. This system will:

- Provide real-time pollution alerts to the population through CIAPOL.
- Support public health interventions, with INHP ensuring appropriate medical responses for affected communities.
- Identify pollution sources through the air quality monitoring network and recommend necessary actions.
- Implement pollution control measures, led by CIAPOL or ANAGED, to improve air quality in affected areas.

The KADI project has laid the groundwork for improved air quality management through enhanced data collection, stakeholder collaboration, and strategic planning. The upcoming donor roundtable will be crucial for securing funding and ensuring the long-term sustainability of the project. Moving forward, continued engagement with government agencies, researchers, and communities will be essential to achieving the project's objectives.

Dar es Salaam

Overview

KADI Dar es Salaam climate service city pilot conceptualized a climate service, where community mapping was used as a methodology to co-produce missing data and information on climate risks in neighbourhood scale for climate actions in data scarce areas. The pilot also identified citizens' climate adaptation needs, and possible solution pathways answering those needs. The pilot draws on Tanzania Resilience Academy (https://resilienceacademy.ac.tz/), which is now an instiutionalised partnership program between University of Turku (UTU), and four Tanzanian universities – Ardhi University (ARU), University of Dar es Salaam (UDSM), Sokoine University of Agriculture (SUA), and State University of Zanzibar (SUZA). Resilience Academy aims to improve digital skills, competences and employment of the African youth for more effective climate risk management and resilience in cities. Several data production models, such as student and community-driven digital data collection have been developed and successfully applied by the Resilience Academy teams. All pilot activities in Dar es Salaam were carried out by UTU and ARU.

Dar es Salaam is particularly vulnerable to climate risks due to rapid and largely uncontrolled urban growth with weak land use planning, little information to assess vulnerability and risk, and a widening infrastructure gap. The most urgent climate risks impacting Dar es Salaam include recurrent flash floods, heat stress, and air and water pollution. While the causes, effects, and vulnerability patterns of flash floods are rather well understood, heat stress and air pollution have received considerably less attention in research and policymaking. There is a notable scarcity of data on these climate risks, impeding informed decision-making regarding the challenges. This climate service pilot addressed this issue by co-creating and testing an alternative way to collect the needed information in collaboration with citizens who hold a vast amount of local knowledge on climate stressors, exacerbating factors, and impacts on their living environments.

To summarize activities undertaken in the KADI Dar es Salaam city pilot, the pilot consisted of three main activities: 1) community mapping of climate risks in neighbourhood scale, 2) focus group discussions for contextualising mapping results, and 3) stakeholder workshop for co-identifying solution pathways answering citizens' climate service needs. The climate service needs were also mapped during the first two activities – a short survey asking about the needs was conducted in conjunction with the community mapping activities, and deeper discussions of what would aid citizen communities in adapting to climate change was held during focus group discussions.

Results

Citizen communities' climate service needs

Local communities' most critical climate service needs in local scale are concentrated on improvements in the urban infrastructure and services, while having access to climate and weather information alone is not sufficient. Problems in the urban infrastructure and service delivery exacerbate all three climate stressors – floods, extreme heat and air pollution. Rains and heat will always be there, but the urban fabric dictates how communities can cope with and adapt to the stressors. Coping strategies are taken by families and households (e.g. building flood-preventive walls and investing in fans), but building resilience calls for major enhancements in the basic city services, such as:

- Improving solid waste management – prevents waste burning in residential neighbourhoods that releases toxins into the air
- Increasing vegetation cover – decreases urban heat island (UHI) effect, provides shade, prevents erosion, and blocks air pollution from spreading
- Re-constructing riverbanks and improving drainage networks – prevents flash floods and stagnant water on streets

All the above-mentioned efforts require information to back up decision-making. For example, data is needed about existing and well-functioning drainage networks, blocked drainages, and drainage segments that often overflow to know critical places for rapid intervention. Actions to improve these issues require close collaboration between governments and the citizens. Focus group discussions revealed some experiences of projects that have failed due to improper planning and dismissing the knowledge of the locals. An active community member gave an example of a failed project aiming to increase tree cover in Dar es Salaam wards:

> *"[A concrete improvement would be the] development of green infrastructure by for example planting of trees. However, there is a lack of space for greenery. For instance, around April 2023, the municipality supplied over 2000 trees for plantation. However, due to lack of space the trees were planted along the river valleys [instead of the residential areas]."* - Focus group discussion participant 2024

In addition to concrete actions to improve the urban infrastructure and services, community education on climate risks was discussed to be an important avenue for better adaptation. When citizens are well aware of exacerbating factors, climate stressor effects and functioning adaptation mechanisms, they are equipped with strategies to protect themselves from harmful pollutants, to initiate action to preserve urban greenery, and to negotiate with local government for improvements in urban infrastructure and services.

Digital data on experienced climate stressors

Community mapping of climate risks in Kigogo and Tandale wards resulted in digital geospatial data layers representing places and areas where citizens' have most often experienced floods, extreme heat and air pollution. Number of mapped experiences were 1095 for floods, 406 for extreme heat, and 274 for air pollution, combined from both wards. The individual mapped experienced were analysed with spatial density analysis to find hotspots for the experiences. As a result, maps that illustrate the areas where the three stressors have been met were created, and causes for hotspots were further identified by discussing with the citizens. Below, an example of one of the resulted maps drawing from citizens' air pollution experiences in Tandale ward (Figure 4). Clear causes for example for air pollution hotspots emerged, such as official and unofficial landfills where solid waste is burned, high-traffic roads, and car demolition sites where plastic parts are burned. Flash floods are already more well-known and previously mapped phenomenon in Dar es Salaam, and the mapped experiences in this pilot align with previous work, such as Dar es Salaam flood models, participatory mapping campaigns, and flood depth measurements. As of January 2025, a scientific publication is under finalisation regarding this pilot. After publishing, the resulted geospatial datasets are shared openly in Climate Risk Database (https://geonode.resilienceacademy.ac.tz/).

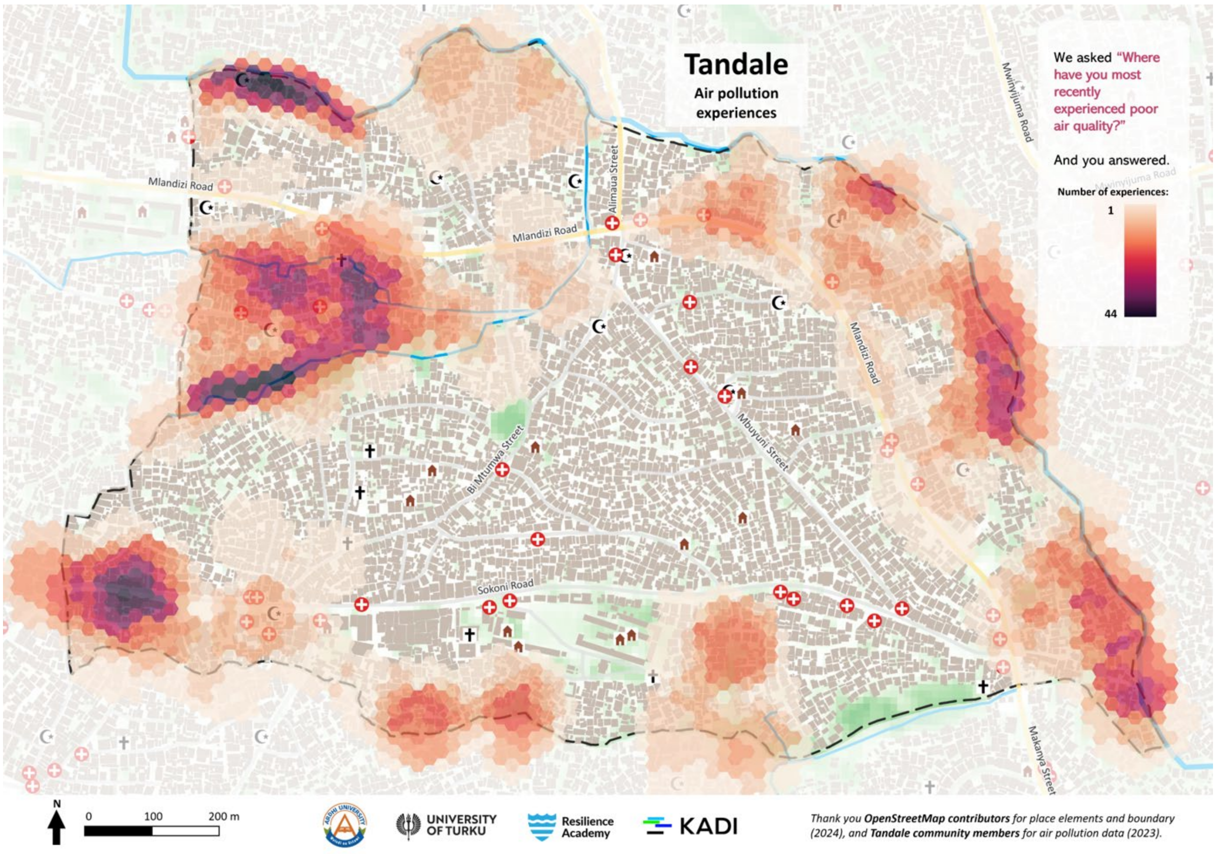

Figure 4. Much of the citizens' air pollution experiences have concentrated alongside of rivers, roads, and known official and unofficial landfills. Image: Venla Aaltonen

Community mapping (or participatory mapping) data on citizens' own subjective experiences on different phenomena has its strengths and weaknesses. The data is characterised by only containing positive observations. For example, in this pilot, the data contains points where the climate stressors have taken place. However, if a specific neighbourhood area does not have mapped experiences, it does not necessarily mean the phenomenon is not present there at all, but instead there has not happened to be anyone to experience the climate stressor as a challenge. A good example is air pollution, which is often noticed with human senses when the pollution is extremely strong – nearby heavy traffic, when smelling smoke, or when having trouble breathing. In reality, polluted air can spread rather far away from the source and be difficult to detect with senses.

Such data of human experiences inform about the most critical places where the examined phenomenon is strong or visible enough for people to notice and struggle with. In the context of adapting to climate change, places with frequent climate stressor experiences are sensitive to the materialisation of climatic stress factors and thus can be regarded as high priority where intervention should take place.

Solution pathways

Final activity of stakeholder workshop brought forward possible solution pathways that would answer the citizens' climate adaptation and climate service needs. Dar es Salaam gives early warning for heavy rainfall that may cause flash floods, as well as for extreme heat events. However, the early warnings are given to the whole city and might not be accurate for specific wards or neighbourhoods. For example, flood-prone areas, or informal settlements with little shading vegetation might experience the climate risks even though no warnings have given:

> *"Floods' extents are rather well known, but we see the need to also concentrate on extreme heat, especially inside houses, and its effects on people's health, as well as data on air quality around the city. We only use approximates and proxy data, if anything. Extreme heat warnings are given based on national-level observations, but the temperatures can be very different in Tandale and the Peninsula* (both in Dar es Salaam)*."* – Stakeholder workshop participant 2024

In addition, the information flow from authorities giving the warnings to communities is often slow. Warnings travel through many agencies, and when finally arriving to citizens, it might already be too late. A possible solution to speed up the process, and to ensure the warnings are relevant for different locations was discussed. Each ward or sub-ward could have a designated local informant who has a direct communication avenue for the Tanzanian Meteorological Agency giving early warnings to communicate about the situation in the ward and vice versa getting information from the authorities in a rapid pace.

Another lively discussion revolved around improving solid waste management. Resolving the problem of lack of an entity to collect solid waste, especially from informally constructed wards requires cooperation between citizens, governmental offices, and the private sector. Citizens must collectively make sure solid waste is collected to locations where it is easy to transport to landfills, and make sure recyclable waste is sorted properly. This calls for community education and joint effort to make sure everyone follows instructions. Role of government as the enabling actor, and private businesses as the operators were also discussed. Prominent initiatives for recycling have emerged by town planning offices, and the workshop was considered as valuable discussion forum to improve those initiatives as the citizens were brought to provide their views on the issue as well.

> *"Initiative and support from city and national government is essential. Communities can only do so much if the urban structure itself is not properly planned, and critical infrastructures does not work. City level officials pay very little attention on our Wards. Local town planners and Ward offices have more concrete ideas and strategies, such as the Kigogo recycling initiative, but resources are scarce. They* (governments) *should work with us who know the Wards and neighbourhoods. We have lived here our whole lives."* – Stakeholder workshop participant 2024

Climate service concept

Finally, the co-created entities piloted are synthesized in a scientific publication. The activities, their characteristics and objectives are wrapped into a climate service concept that highlights the role of citizens in critical climate data and information collection that aids in adaptation and resilience building efforts. This climate service concept is transferrable in other urban contexts as well, whatever the local information needs are. For example, community mapping activity can be joined with observing climate phenomena with low-cost monitoring devices to bring the local voices forth as well.

Nairobi

The Nairobi city pilot was geared towards setting the basis for delivery of early warning for extreme heat for residents of informal settlements to support anticipatory action. A participatory approach was utilized where the residents were identified as the primary stakeholders. The Kenya Meteorological Department is the agency responsible for generation of climate information while some intermediary organizations are also incorporated as secondary stakeholders or enablers in the achievement of the end goal. The local government was likewise involved as they are the ones responsible for overseeing implementation of adaptation actions.

Studies have shown that extreme heat under climate change is becoming even more critical with adverse impacts on productivity and health especially in urban areas with informal settlements. Trends of maximum and minimum temperatures in the city of Nairobi are increasing as shown in Figure 1.

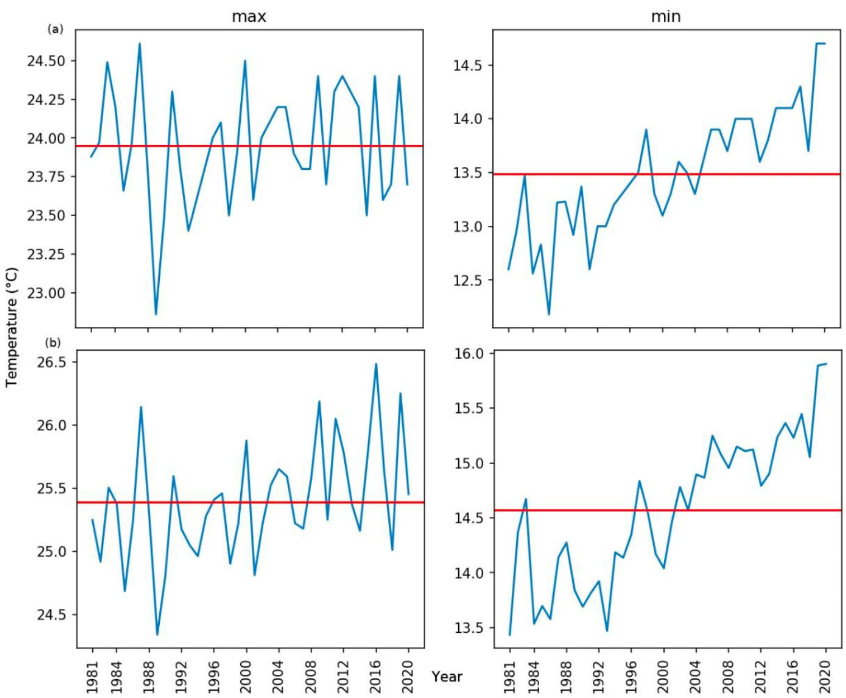

Figure 5. Trends in maximum and minimum temperature for Dagoretti (a) and Moi Airbase (b) two stations in Nairobi city for the period 1981-2020. The red line indicates the climatological mean

Results

The system map created for this pilot highlights a theory of change that involves all the identified stakeholders working collaboratively to achieve improved quality of life and longterm resilience built to urban heat stress.

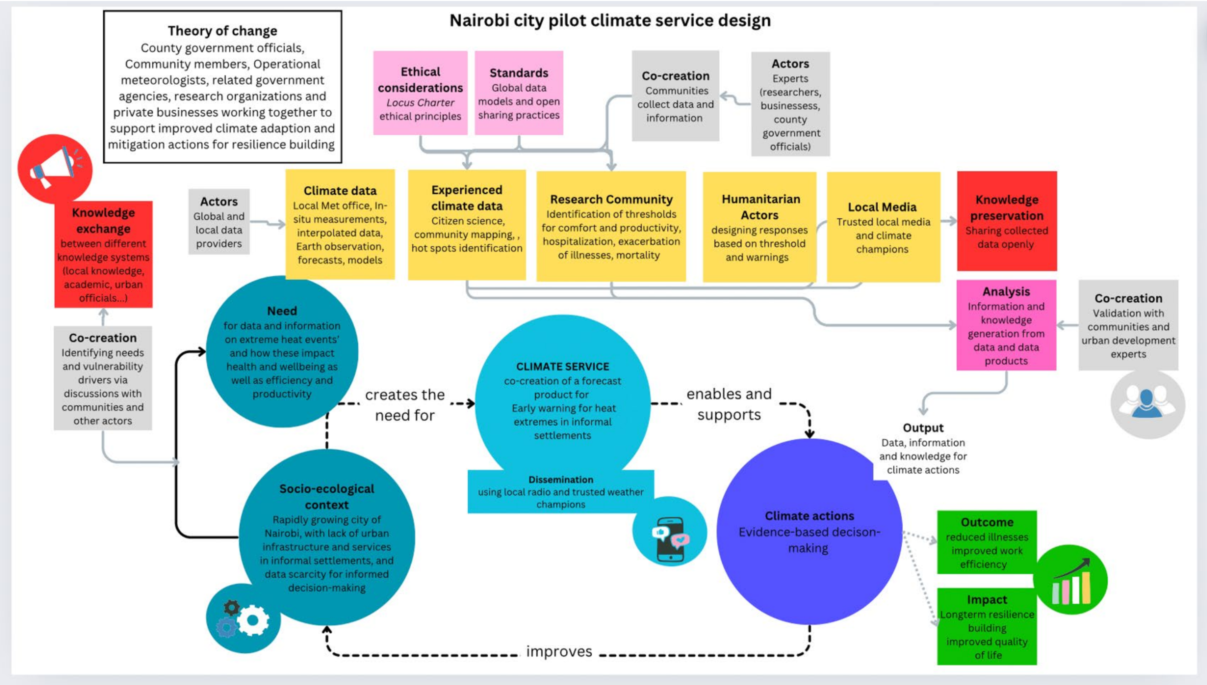

Figure 6. Mapping system of the pilot city of Nairobi

Exploring upscaling of the air quality services for African cities

In parallel to KADI city pilots, the University of Helsinki and related project participants conducted a pilot where local air quality monitoring was combined with Earth Observation data. The objective was to explore the scalability of the combination of local air quality monitoring sensing with satellite remote sensing for spatially resolved air quality applications. Although this work was not part of the specific KADI city pilots in Abidjan, Dar es Salaam and Nairobi, it provides valuable insights on low-cost tools and innovative ways to combine different data sources for climate service production in the context of rapidly growing African cities. This work was conducted in Dar es Salaam and Nairobi, and thus the experiences from the corresponding city pilots are complementary.

The Abidjan pilot underlined the opportunities and benefits of low-cost air quality sensing for local air quality solutions and early warning systems. We wanted to explore the scalability of the combination of local air quality monitoring sensing with satellite remote sensing for spatially resolved air quality applications.

While global air quality datasets derived from model outputs provide valuable insights into $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 µm) distribution, their reliability remains uncertain in data-scarce regions such as Africa. Unlike Europe and North America, where extensive networks of ground-based monitoring stations enable robust validation of satellite-derived air quality estimates, African cities lack sufficient ground reference stations, limiting the accuracy of such models over the continent.

To address this data gap, advancements in low-cost air quality sensors—priced at under $2,500 per unit—along with satellite-based remote sensing products, present a viable approach for improving air quality datasets. By combining the broad spatial coverage of satellite sensors with the high temporal resolution of ground-based sensor networks, a locally validated air quality representation was developed for Nairobi and Dar es Salaam. This method provides these cities with a cost-effective means of obtaining high-resolution air quality data, facilitating evidence-based decision-making.

To explore the scalability of the low-cost sensor networks and satellite remote sensing for African cities, used data from low-cost air quality sensing network (calibrated against reference-grade instruments if possible) as a ground truth to constraint remote sensing data. We used spaceborne measurements of aerosol optical depth (AOD) at 0.47μm and 0.55μm that were obtained off the Moderate Resolution Imaging Spectroradiometer (MODIS) platforms (Lyapustin et al., 2018). Data of tropospheric gases – SO_2, NO_2, HCHO, CO and O_3 – from the Tropospheric Monitoring Instrument (TROPOMI) on board the Sentinel-5p satellite were also obtained (Veefkind et al., 2012).

Low-cost sensors data was obtained from local collaborators at Airqo (AirQo, 2024). A machine-learning based approach was used to constrain satellite data to these local air quality networks, allowing us to develop estimates of air pollution in Nairobi and Dar es Salaam. Existing reference monitors at Eastern Africa GeoHealth Hub were used to further ensure that the estimates were comparable to ground sensors. Data from low-cost air quality sensor networks operated by the Dar es Salaam Institute of Technology were also included in the analysis.

The major advantage of this method is that we were able to estimate air quality at high spatiotemporal resolution (daily, in 1km x 1km grids) that are constrained to ground instruments, allowing us to obtain reasonably accurate air quality information even in data-scarce regions. In principle, the same approach can be applied to other urban areas in the region, since satellite data from the Sentinel-5p system have almost global coverage. Furthermore, the code required to produce the data is designed to work remotely on Google's cloud server, meaning that users only require an Internet connection to obtain these air quality maps.

Results

Dar es Salaam

On the air quality maps developed over Dar es Salaam, 1825 sets of daily rasters of PM2.5 from 2019-2023 in 1km x 1km resolution are available at https://doi.org/10.5281/zenodo.13959948. The link above also contains codes necessary to create those air quality maps presented in Figure 7.

We identify that PM2.5 concentrations were about 33.1 ± 7.4 μg/m3 around Dar es Salaam (Figure 7). According to the EPA's 2024 air quality standards, these values fall into the 'Moderate' category. Following regional weather patterns, with two dry seasons (the warmer December-February period and the cooler June-August period) and two rainy seasons (March-May and September-November), seasonal variations were observed in PM2.5 concentrations. Higher concentrations occurred during the dry seasons, peaking in July-August and with a smaller peak in January-February. In July-August, average PM2.5 concentrations around Dar es Salaam were 47.3 μg/m3, categorizing it as 'Unhealthy for sensitive groups'.

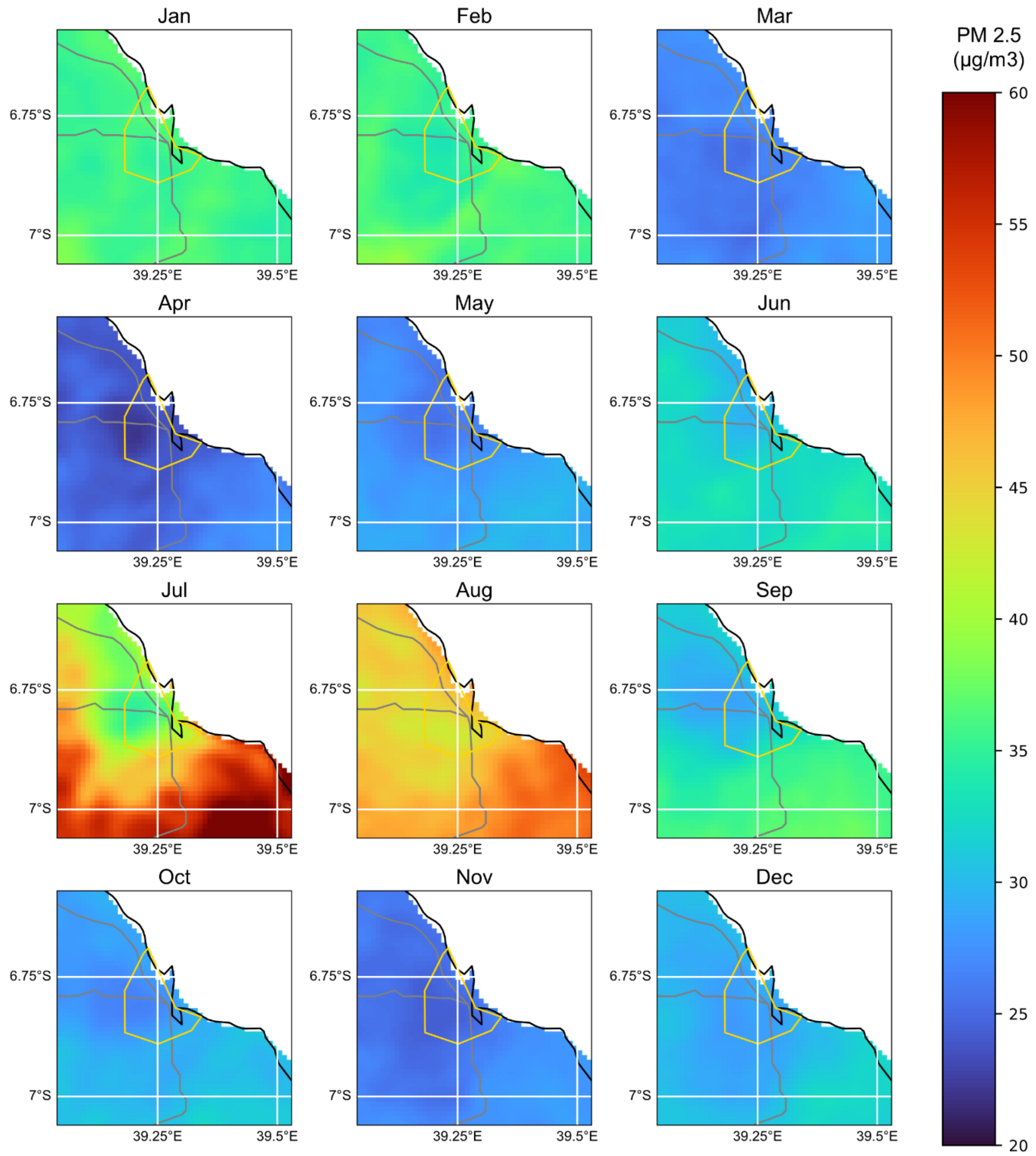

Figure 7. Estimated PM2.5 levels during 2019-2023 aggregated by months at Dar es Salaam. White areas on the map indicate water areas, grey lines indicate major roads, and the yellow outline indicate the urban centre boundary.

Nairobi

Maps that estimate air quality over Nairobi are available at https://doi.org/10.5281/zenodo.13959948. From these maps, we estimate that average PM2.5 concentrations were 21.7 ± 2.8 μg/m3 around Nairobi (Figure 8), corresponding to 'Moderate' category according to the EPA's 2024 air quality standards. Similar to Dar es Salaam, higher concentrations occurred during the dry seasons, peaking in July-August and with a smaller peak in January-February. The air quality around Nairobi in July-August has average concentrations at about 27.0 μg/m3, within the 'Moderate' category.

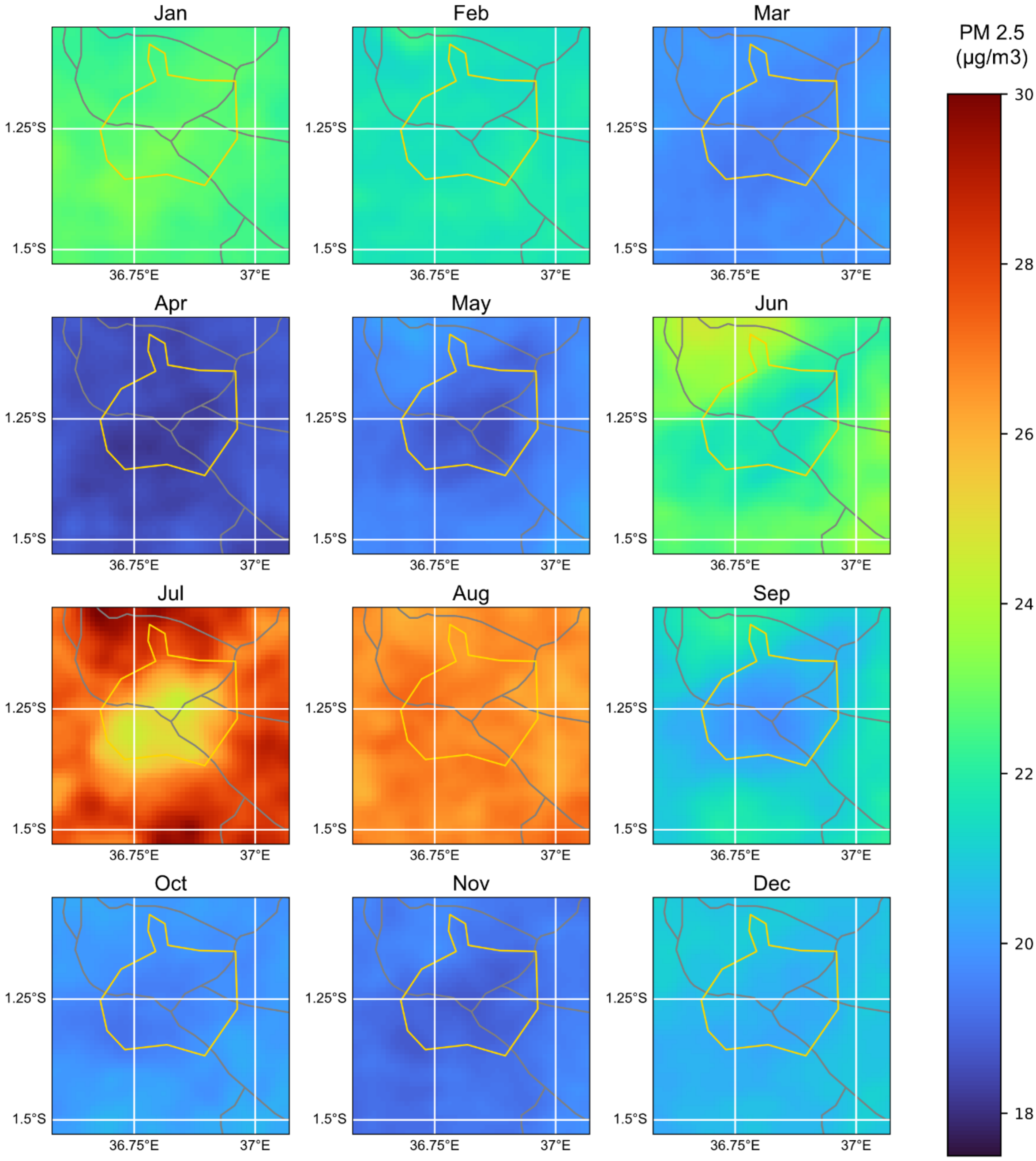

Figure 8. Estimated PM2.5 levels during 2019-2023 aggregated by months at Nairobi. Grey lines indicate major roads, and the yellow outline indicate the urban centre boundary.

These maps showed that air quality over Nairobi and Dar es Salaam are not uniform over the cities with local hotspots as well as seasonal variations. More detailed analysis is needed to identify specific drivers causing good/poor air at the various neighbourhood. For example, more vegetation cover or less combustion activities may lead to better air quality.

We stress that these maps are only estimates and cannot be considered superior to reference air quality instruments on the ground. Given their approximation, they cannot be considered as truths for legislation or policing. Policies developed in these cities should also be developed with other considerations in mind, not just solely on these air quality maps. Nonetheless, these maps have raised a potential cost-effective avenue for data-scarce cities to have some idea of local air quality. Also, the usage of satellite data could supplement existing air quality monitoring infrastructures in these cities by enlarging the spatial and temporal coverage.

As a summary, leveraging low-cost sensor networks in combination with satellite remote sensing, our upscaling exercise demonstrated the feasibility of developing accurate, high-resolution air quality datasets for African cities. This hybrid approach holds significant promise for air pollution monitoring, public health assessments, and environmental policymaking, particularly in low-resource settings. Further research and investment in ground calibration infrastructure and algorithm refinement could further enhance the precision and applicability of these methods, ultimately contributing to sustainable urban air quality management in Africa.

The scientific case is of the upscaling is presented in a KADI publication submitted for publication (Chua et al. 2025).

PART II - Summary of results and cross-cutting lessons

Comparative analysis of the three pilots

A. **Commonalities**

1. ***Role of Stakeholders***

- In all three cities, the success of the pilot projects relies on strong stakeholder engagement, including governmental agencies, research institutions, and local communities.
- Governmental bodies (CIAPOL in Abidjan, Meteorological Department in Nairobi, local town planners in Dar es Salaam) play a central role in decision-making and policy implementation.
- Collaboration between public and private actors, including universities and NGOs, enhances data collection, analysis, and the design of climate adaptation strategies.

2. ***Importance of Participatory Tools***

- Citizen engagement is a core component of each pilot, ensuring that local knowledge and experiences inform decision-making.
- Participatory mapping has been used in both Dar es Salaam and Nairobi to identify hotspots for air pollution, heat stress, and flood risks.
- In Abidjan, a participatory questionnaire was developed to involve the population in air quality monitoring and awareness.

3. ***Challenges Faced***

- **Data Gaps and Infrastructure Limitations**: All three cities face issues related to limited monitoring infrastructure, inconsistent data, and insufficient funding.
- **Weak Policy Implementation**: Despite existing environmental regulations, enforcement remains a challenge due to lack of resources and coordination.
- **Urbanization and Informal Settlements**: In Dar es Salaam and Nairobi, informal settlements lack adequate infrastructure, exacerbating the impacts of heat stress, flooding, and air pollution.
- **Communication Barriers**: Slow information dissemination hinders effective early warning systems in all three cities.

B. **Local Specificities**

1. ***Abidjan***

- **Focus on Air Quality Monitoring**: The pilot emphasizes real-time air quality monitoring and early warning systems to inform the population.
- **Integration with Health Sector**: The INHP is directly involved in addressing public health concerns related to pollution exposure.

- **Industrial Pollution Hotspots**: Major monitoring sites include industrial zones (Yopougon, Koumassi), highlighting the need for emission control measures.

2. ***Dar es Salaam***

- **Climate Risks Beyond Air Pollution**: The project covers a broader range of climate stressors, including extreme heat and urban flooding.
- **Solid Waste Management as a Key Concern**: Waste burning in informal settlements is a major source of air pollution.
- **Community-Led Initiatives**: The project emphasizes local initiatives like tree planting and recycling, driven by community engagement.

3. ***Nairobi***

- **Emphasis on Extreme Heat Early Warning**: Unlike Abidjan and Dar es Salaam, Nairobi's pilot is focused on setting up early warning systems for extreme heat in informal settlements.
- **Co-creation:** the pilot focused on a bottom up approach and co-creation to design the climate service
- **Seasonal Air Quality Variations**: Unlike Abidjan, which focuses on industrial emissions, Nairobi's air pollution varies significantly by season, with peaks during dry months.

Table 1. Summary of local specificities

Criterion	Abidjan	Dar es Salaam	Nairobi
Primary Focus	Air quality monitoring and early warning systems	Climate risk management (flooding, heat, pollution) and urban adaptation	Heat extremes early warnings in informal settlements
Monitoring Methods	Meteorological stations, NO_2/SO_2 analyzers, PM sensors	Participatory mapping, GIS analysis	Meteorological stations. Air quality mapping using sensors, monitors, and satellite data
Key Stakeholders	CIAPOL (pollution alert), INHP (health), ANAGED (waste management), SODEXAM (meteorology)	Municipalities, citizens, local authorities, researchers	Meteorological department, local government, NGOs, informal settlement residents
Waste Management Role	Industrial waste control and improved monitoring	Waste removal to reduce air pollution	Recycling and reducing emissions from waste combustion
Early Warning System	CIAPOL issues pollution alerts	Flood and heatwave warnings, though with limited local precision	Heat extreme alerts targeting slums, but with transmission delays

Lessons Learned

1. ***The Need for Multi-Stakeholder Collaboration***

- Effective climate services require strong partnerships between governments, research institutions, private sector, and communities.
- Decentralized approaches, such as ward-level informants in Dar es Salaam, could be applied in Abidjan and Nairobi for faster information dissemination.

2. ***Combining Participatory Data with Scientific Monitoring***

- All three pilots show that engaging communities in data collection can complement scientific monitoring.
- Nairobi's approach of integrating satellite and ground-based data could be replicated in Abidjan and Dar es Salaam.

3. ***Urban Planning and Infrastructure Matter***

- While climate stressors exist in all cities, poor urban planning worsens their impacts.
- Solid waste management in Dar es Salaam, industrial emissions in Abidjan, and heat stress in Nairobi all require tailored urban planning interventions.

4. ***Improving Early Warning Systems and Communication***

- Nairobi and Dar es Salaam highlight the need for localized, real-time early warning systems for heat stress and flooding.
- Abidjan's air quality early warning system could be expanded to include alerts for extreme heat and flooding.

Cross-cutting lessons

The Abidjan pilot project - lessons learned :

1. Interdisciplinarity and knowledge exchange

The diversity of the resource persons involved in the co-creation of the climate service is essential to the success of the project. These people come from different backgrounds and have different experiences, particularly regarding the participatory approach (e.g. INHP), the implementation of climate services (e.g. SODEXAM) or the technical aspect of producing the early warning system (e.g. Data354), which is essential for guaranteeing the effectiveness of the climate service. Discussions with them have given us ideas about the role that each of them can play and increased our knowledge of all the resources needed to achieve the objective.

2. Stakeholders, actors and the community

The pilot project began by mapping out all the necessary stakeholders. One of the main stakeholders is the population, and the idea is to involve them to better understand their needs and take them into account. Access to the population should be through local and administrative communities. In this way, we can leverage on local knowledge in carrying out the pilot project. The effectiveness of the proposed service is also significant if the population is involved in the co-creation process. All the individual meetings with the various stakeholders and the group meetings organised as part of the workshops have enabled us to gain a better understanding of the role and commitment of each actor.

3. Strengthening the observation network

To implement this climate service in the city of Abidjan, we need to strengthen our observation network with more observed sites to take into account all sources of pollution. This will also improve the accuracy and quality of the early warning system, which is of the utmost importance for the end users. In our pilot city, this objective has been achieved through the collaboration of some key stakeholders (for example, CIAPOL), but also through the involvement of the UFHB team in other projects aimed at improving air quality for the population. It is also necessary to ensure sustainable, long-term monitoring of our observation network to produce up-to-date scientific results on the state of atmospheric composition.

4. Data analysis and modelling

The creation of metadata provides an overview of the observation data available, so that it can be analysed and communicated to end users in a variety of ways. This makes it possible to provide areas affected by pollution with information and to find out about people's experiences (e.g. what they are doing? how they want to be helped) via questionnaires. The modelling resources we have, thanks to the Côte d'Ivoire National Computing Center (CNCCI), are one of the key elements of RI for monitoring the dispersion of atmospheric composition.

5. Effective communication

This aspect is essential if the results are to have an impact on end users. It will be implemented through the media and the development of telephone applications to inform people.

Dar es Salaam city pilot - lessons learned

1. **Skills development and capacity building:** Proper training for community mappers is essential for the success of the mapping - understanding the mapped phenomena, skills to use mapping tools, and knowing data quality requirements. In KADI Dar es Salaam climate service pilot, students from Ardhi University had previously attended Resilience Academy community mapping campaigns. However, training days were organised prior deploying to Kigogo and Tandale wards to make sure the students know what the mapping objectives are, how the mapping survey is constructed, how the Maptionnaire-tool works, how proper sampling in the wards is ensured, and in what formats community members' climate stressor experiences are recorded to data. Based on resulted data and student feedback, training was sufficient and provided the students with necessary skills to conduct the mapping on the field. Discussions with community members increased the students' knowledge of climate stressors and their effects on the communities.
2. **Stakeholders, actors and community:**
    2.1. **Higher education institutes:** Large (community) mapping campaigns are either time- or human resource intensive. This pilot applied the Tanzania Resilience Academy concept where higher education students are employed to conduct mapping activities on the ground. Large number of students can complete a mapping campaign in a fraction of the time it would take from for example one or two project staff members. The approach has its underlying values in providing real-world skills development and employment opportunities for the students, while streamlining digital data collection. In the context of KADI RI design, continuous partnering with higher education institutes would allow a pipeline to employ students from relevant disciplines

to get employment opportunities and collect large amounts of needed data on various phenomena in any local setting.

2.2. **Citizens:** Understanding citizens climate service needs, and leveraging their vast local knowledge in RI operation

2.2.1. When co-creating climate services for city- or sub-city scale, the most important stakeholder are the citizens. Actively listening the citizens' needs for climate services that would improve the quality of life and resilience against climate change effects must be embedded in the climate service development process. In this pilot, citizens climate service needs were scoped by discussing with 400 community members in two Dar es Salaam wards, in conjunction with the community mapping activities.

2.2.2. Citizens have vast knowledge on their living surroundings. This knowledge can be strategically integrated to research infrastructure activities in several ways. The citizens' knowledge can substitute other data and information sources (e.g. ground observations or Earth Observation data) with additional otherwise invisible information, or with a validation aspect. Engaging with citizen communities builds trust and ownership, which leads to wider utilisation of RI services on the ground.

2.3. **Other local city-actors:** Engaging with wide range of local stakeholders, such as local government on different decision-making levels and sectors, research institutes, private businesses, and NGOs, is utmost important in designing, creating and managing climate services. However, as noticed in this pilot as well, many actors have their plates full with day-to-day responsibilities. Thus, a proper incentive and clear objectives must be introduced for the actors to engage with the activities. Respecting their time and other resources is critical. In this pilot, a satisfactory number of local players were able to participate in the stakeholder workshop activity. Many of the stakeholders were contacted through research team's personal connections. A setback was encountered when no NGOs were representatives were able to participate the workshop, even though they have an important role in community development initiatives.

3. **Observations, monitoring and measurements:** Citizen science is a relevant and inclusive approach to observe climate stressors and risks, particularly in regions where data scarcity presents challenges for research and decision-making.

3.1. Citizen contributions to climate observation - whether through participatory/community mapping, mobile applications, or low-cost sensors - help supplement existing datasets and provide information especially on the local and hyperlocal contexts. For example, while EO data can provide broad-scale insights, citizens' ground-level observations often reveal nuances that are invisible from space, such as specific locations where flooding impacts households, or micro-level sources of air pollution. In this pilot, examples of these micro-level air pollution sources are solid waste burning in wards due to insufficient waste management and burning of plastic car parts by small businesses conducting car demolition.

3.2. Integrating citizen science approaches to research infrastructure operations has the possibility to simultaneously enable knowledge co-creation processes with the citizens, maintain communication channels for feedback, and promote long-term engagement. Ideally, citizens see how their science contributions lead to tangible actions or policy changes through the RI operations.

3.3. Conducting citizen science activities require multi-disciplinary expertise, from both natural and social science fields. In this pilot, it also became evident that contribution form an expert with community development background was essential in conducting the pilot activities, especially the focus group discussions. When integrated to research infrastructure operations, good existing participatory or citizen science practices and expertise from various organisations should be leveraged. To give examples within KADI project community, the Resilience Academy approach can be applied to different local contexts, and participatory approaches are widely used by the Kenya Meteorological Department in their activities.

4. **Data analysis:** Participatory GIS (PGIS) data has its own requirements for analysis and usage. These data often contain only positive observations, especially when mapping people's experiences. For example, even though there are no recorded experiences of a climate stressor in a specific area, it does not necessarily mean that the phenomenon is not present there in reality. Instead, there might not be any perceived experiences due to e.g. inaccessibility of the area. This kind of PGIS data does however indicate those areas and places where the phenomenon has strong positive presence, and where the phenomenon overlaps with human activities.
5. **Data sharing / ethics:** When working with communities and managing participatory digital data, secure and ethical practices are at the essence. Careful consideration is needed when deciding if and how the data is shared openly available for others to utilise. In this pilot, sensitive information of e.g. community members home locations is not openly shared. Instead, only the citizens' climate stressors experiences are shared in a processed format as aggregated spatial density data layers. Thus, when participatory data is utilised in RI operations, sharing it openly requires steps in between raw data collection and sharing, as well as receiving acceptance from participants.

Nairobi city pilot - lessons learned

1. **Enhancing observational network:** since there are only 4 meteorological stations in Nairobi and only two are in the immediate vicinity of the target informal settlements, the need for improved observations was very evident. The informal settlements themselves by virtue of the building materials create a micro-climate (heat) whose characteristics are not captured by the nearby meteorological stations. Low cost sensors would be an option as these have been successfully used in other regions.

2. **Leveraging Citizen science:** to further supplement meteorological observations working with the residents spread across strategic areas and providing the low cost sensors and required training will support validation of the early warning forecasts. This is utilized successfully in Dar Es Salaam pilot and in other regions and sectors

3. **Co-creation:** this process though employed could further be refined by incorporating more stakeholders and more iterative sessions as well as involving various branches of the meteorological department beyond the forecasters. This would likewise contribute to capacity enhancement.

4. **Information dissemination:** previous projects have utilized local champions as part of the dissemination process for early warning. These would send short messages in the manner quickly and easily recognized by residents and this increased trust as opposed to messages form the meteorological department directly.

5. **Involving local city governance:** with long term resilience being the end goal, involving local government at inception stages is crucial in ensuring the success of the endeavour. Local government is responsible for among others, facilitating development of green infrastructure, developing and implementing adaptation plans. For ownership of the outcomes and possible responsibilities it is crucial to onboard these as early as feasible.

PART III - RECOMMENDATIONS FOR FUTURE OPERATIONALIZATION

Consolidation of climate services

- Establish financing mechanisms for acquiring necessary equipment.

- Create and/or reinforcing/ strengthening inter-institutional collaboration frameworks for sustainable data management.

- Develop strategies for effective data sharing and public communication to maximize the impact of climate services. This involves making data on greenhouse gases and other climate variables publicly available through international data centres and local platforms.

- Maintain regular communication with African stakeholders through surveys and meetings to ensure the services meet their needs. This includes engaging with local meteorological departments, research institutions, and community organizations.

Implementation of climate services

- Form partnerships with national, regional and international actors for service deployment.

- Prioritize accessible technologies adaptable to local realities.

- Utilize advanced modelling and data analysis tools to enhance the accuracy and reliability of climate services. This includes using Earth System Model simulations, observation-based verifications and satellite remote sensing to improve parametrization of African land-surface attributes.

Replicable design principles

- Develop a practical guide based on co-design methodologies and pilot results.

- Identify regional networks for sharing best practices.

CONCLUSION

KADI's pilot projects demonstrate that a collaborative approach adapted to local contexts is essential to strengthen the climate resilience of African cities. The involvement of stakeholders, the use of participatory data and the integration of scientific tools have made it possible to design relevant climate services.

However, major challenges remain, including the sustainable financing of infrastructures, the maintenance of observation networks and the effectiveness of warning systems. The integration of these services into public policy and the creation of long-term cooperation frameworks will be crucial to their success.

The lessons learned from these experiences, in particular the comparative analysis of the three cities (Part II), offer a replicable model for other urban contexts facing similar challenges. A flexible approach, combining technical innovation and community anchoring, will be crucial to extending the impact of climate services in Africa and protecting populations from growing climate risks.

KADI

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