Ref. Ares(2025)7771016 - 17/09/2025

KADI

Long-term atmospheric and ecosystem flux observations from Kenya: metadata and data sets, atmospheric transport and trends, user needs and services in view of a sustainable research infrastructure

Deliverable 2.5. HORIZON-INFRA-2021-DEV-01-02

Funded by the European Union

kadi-project.eu

PROJECT NUMBER	OFFICIAL NAME	EXTERNAL COMMUNICATIONS NAME
HORIZON-INFRA-2021-DEV-01-02	KADI Knowledge and climate services from an African observation and Data research Infrastructure	KADI
DUE DATE OF DELIVERABLE	**REFERENCE WP AND TASK**	**BENEFICIARY IN CHARGE**
28.02.2025	WP2 AND TASK 2.5	MeteoSwiss
PROJECT URL		**EU PROJECT OFFICER**
https://www.kadi-project.eu		Pierre QUERTENMONT

VERSION LOG

NAME	DATE	AUTHORS	COMMENTS
v0.0		Danioth, Sarina	Initial work
v1.0	27/03/2025	Klausen, Jörg	final document after review by co-authors

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Executive Summary

Africa is most vulnerable to the effects of climate change. Following an earlier EU project 'Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations (SEACRIFOG)', the inter-disciplinary Horizon Europe Coordination and Support Action in African-European cooperation 'Knowledge and climate services from an African observation and Data research Infrastructure' (KADI) (grant agreement No 101037319) set out to improve the knowledge base on climate change in Africa by providing a comprehensive design for climate services. The specific objectives of KADI comprised the design for a pan-African atmospheric and climate observation system on the basis of atmospheric and climate services as guiding design principle and an extensive documentation of past and existing observing capability, contrasted with scientifically justified requirements to identify and fill existing gaps.

This report presents the outcomes of KADI Work Package WP2 Task 5, "Pilot on lessons learned from existing long-term atmospheric and ecosystem observations" with a focus on Kenya. This pilot was driven by the cooperating partners: Kenya Meteorological Department (KMD), Federal Office of Meteorology and Climatology MeteoSwiss, Agroscope and Empa, and the University of Helsinki. The specific objectives/deliverables were:

- Metadata sets available in GAWSIS-OSCAR/Surface, complemented by a summary report (this document).
- Quality-controlled datasets available at World Data Centers,
- Report/manuscript on trend assessment and seasonality of atmospheric & ecosystem observations, characterization of footprint and recommendations for future expansion of observing capability
- Identification of criteria and requirements critical for a successful and sustainable operation of atmospheric and ecosystem observations in East Africa

Following an introduction, the report identifies the main institutional actors pertinent to Kenya, and provides a catalogue of the observational assets in the country. It then assesses the available data and provides results and analysis. Importantly, the report documents user requirements and services, based on interactions with stakeholders in the country. Finally, lessons-learnt are proposed and conclusions for a future pan-African research infrastructure (RI) are drawn.

Climate change is a tremendous challenge for Kenya for many of the core economical sectors, a growing population, and urbanizing society at large. The main messages coming out of this pilot project are:

1. Many, partly divergent **requirements for climate and atmospheric observations and services** have been articulated and the Kenya Meteorological Department is involved in a plethora of programs, projects and activities to respond to these. There is anecdotal evidence that the governmental sector is struggling with the integration and operational maintenance of a multitude of observing networks, mainly due to a shortage of adequately trained staff and financial as well as technical resources.
2. Africa lacks a **comprehensive, integrated climate and atmospheric observation network and sustainable research infrastructure**. Existing systems are fragmented, limiting the availability of high-quality data required for climate services. A dedicated and sustainable research infrastructure is essential for improving climate resilience and decision-making.
3. **Collaborations** within the country, on a regional scale and with institutions outside Africa do exist (and some have existed for decades). External stimuli like KADI have the potential to strengthen existing partnerships and to trigger new ones. However, there is still a great dependence on

external, often opportunity-based funding. This compromises long-term operation and commitment, true partnership and clarity about shared strategic objectives.

4. A main obstacle for more institutional collaboration between **academia and governmental bodies** is free access to data and transparency about its quality, within the country but also within the region and internationally. This limits the wider use of existing observations and prevents the (co-)development of services. Opportunities for academia to help develop and/or improve much needed services are easily imagined. Yet, to realize this potential, open access to data and is required and services need to be transitioned to operational entities.
5. Initiatives like Kenya's National Framework for Climate Services (NFCS) demonstrate progress in improving **coordination among stakeholders**. Scaling up such frameworks across Africa will enhance climate service integration and effectiveness.
6. A major **challenge for long-term observations** is related to the availability of sufficient **institutional funding**, relevant competences and specific technical skill sets, combined with stable employment of and professional perspectives for the respective human resources.
7. Observational networks suffer from **inconsistent calibration, lack of spare parts, and ageing instruments**. Without sustained funding for equipment maintenance and renewal, data reliability is compromised. A strategic investment plan is needed to support long-term infrastructure maintenance. While **low-cost sensors** and innovative technologies like 3D-printed automatic weather stations (AWS) offer promising solutions, they cannot replace **high-precision reference instrumentation**. Hybrid approaches that combine cost-effective solutions with validated reference instruments are promising future avenues to ensure data quality and reliability.
8. **In the nexus of climate, air quality, and health,** poor air quality exacerbates climate-related health risks, yet air pollution monitoring remains underdeveloped in many African countries. Integrating air quality observations with climate services can improve public health responses and inform mitigation strategies.

Recommendations

- **Strengthen institutional capacity and enhance partnerships**: Academic curricula should be implemented for applied environmental and climate science/engineering to establish the necessary competences from the ground up. Specialized training, and long-term employment stability for climate scientists and technical staff are essential to ensure sustainable operations. Collaborative funding models that combine national, regional, and global support will reduce reliance on short-term external funding.
- **Invest in a pan-African research infrastructure**: Establishing a continent-wide observational system with regional coordination will fill existing data gaps and improve climate services.
- **Promote open data policies**: Governments and institutions should implement frameworks that ensure unrestricted access to climate and atmospheric data, fostering collaboration and innovation.
- **Integrate air quality and climate monitoring**: Expanding air quality monitoring within climate monitoring frameworks will provide more impactful services to mitigate environmental health risks.
- **Ensure equipment calibration and sustainability**: Dedicated budgets for the maintenance and periodic renewal of observation equipment, and reference instrumentation for the calibration of low-cost sensors will help to sustain high-quality data collection.

By implementing these strategies, Africa can build a resilient and effective climate observation system and research infrastructure that enhances national climate services, supports evidence-based decision-making, and strengthens global contributions to climate science.

CONTENTS

Introduction and background

Droughts, fires, floods and other increasingly frequent extreme events are examples for the growing impact of global climate change. Africa is known to be one of the most vulnerable continents to climate change due to its exposure to climate stress and low adaptive capacity (IPCC, 2022). To address the Paris Agreement and the UN Sustainable Development Goals, urgent action is required to combat climate change and its impacts (SDG 13). Viable solutions strongly depend on scientific evidence and its transfer towards decision makers and society in general. Improved concepts and the implementation of climate services, based on continuous observational data, in a standardised and integrated format (Dinku et al., 2017; Kulmala, 2018) are indispensable. Dedicated research infrastructures (RIs), defined here as monitoring and research capacity for climate change observation and its application, responding to societal needs and expectations, play a crucial role, and have proven useful in Europe, North America and Australia.

This report addresses the potential for a research infrastructure for atmospheric and climate services for Africa, by exploring existing capacity and challenges as well as opportunities and lessons-learnt from Kenya.

What are climate services?

Climate services can be defined as "*the transformation of climate-related data together with other relevant information into customised products such as projections, forecasts, information, trends, economic analyses, assessments (including technology assessments), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large*" (Vogel et al., 2019). The overall aim of climate services is the improvement of the management of climate variability and change by a country and different users and actors. The importance of co-developing climate services jointly by producers and users is essential (Vogel et al., 2019). Numerous activities with the aim to strengthen climate services in Africa to improve climate resilience and support sustainable development in the face of a changing climate exist. KADI and the previous SEACRIFOG project are only two projects among many past and ongoing initiatives. This report can only refer to a selection of these.
Within the range of climate services, climate monitoring stands out as it provides crucial information to numerous sectors. In the agriculture sector, information on rainfall patterns, temperature and other variables guide actors in their decisions about irrigation or crop and livestock management to improve productivity. Generally, climate monitoring plays a vital role in managing water resources effectively, especially in regions prone to droughts or heavy rainfall and floods. Moreover, climate monitoring helps identify early warning signs and is the basis for early warnings. It enables authorities to take preventive actions to minimize the impacts of extreme events. Climate monitoring also provides essential information to the health sector to assess the risk of spreading vector-borne diseases, the distribution and prevalence of disease-carrying insects or heat-related illnesses. The energy sector benefits from climate monitoring for planning and optimizing renewable resources. More examples exist.

Long-term observations are key to climate services

Up to date, Africa lacks a comprehensive concept and strategy for a successful operation of environmental research infrastructures and services, even though some countries have now started to develop suchlike (i.e. SAEON in South Africa). For instance, weather, climate and atmospheric composition observing capabilities in Africa are sketchy and heterogeneous and often not built for a sustainable integration into the operational infrastructures of the National Meteorological and Hydrological Services (NMHS) (Dinku, 2019). Thus, meteorological and climatological observational data, and especially data of greenhouse gases and short-lived climate pollutants are often not easily and widely available. Besides general challenges in observing and understanding climate change, particularly the carbon and water cycle in African cities and in the coastal areas are still poorly understood, while substantial alteration of these cycles is expected with a continuous urbanization of the continent.

Insights from the SEACRIFOG project

The design study 'Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations' (SEACRIFOG) prior to KADI developed a blueprint for setting up an environmental RI in Africa. The outputs of the project were an inventory of previously collected data, a spatial breakdown of sites to reduce uncertainty in global climate projections introduced by the paucity of data Africa , and an approximate cost estimate of M€ 550 over the course of 30 years at the time (and likely much larger today) Figure 1 shows an inventory of in-situ observations associated with 25 networks and initiatives on and around the African continent as of 2018 (Merbold et al., 2021), although the operating status was unknown for 84% of the sites.

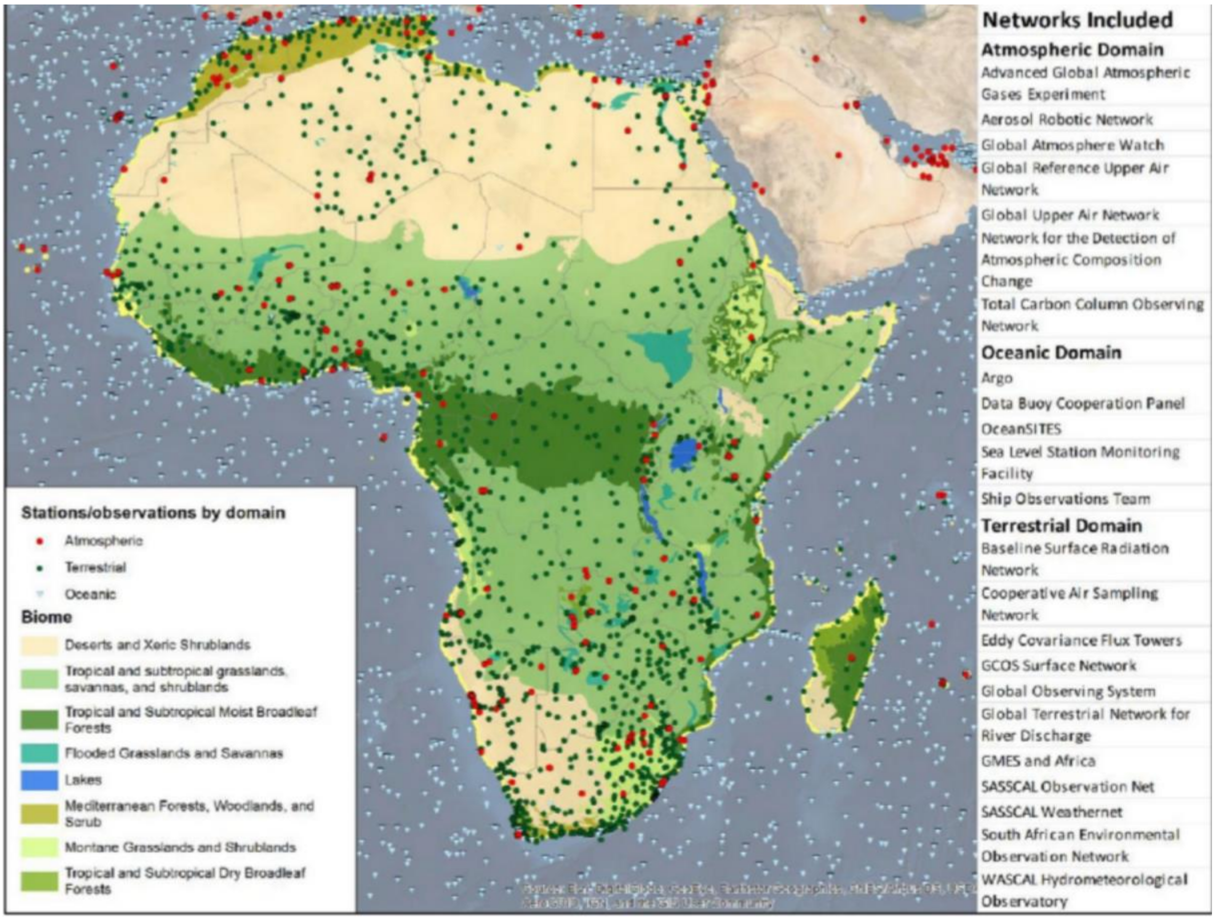

Figure 1. Observation sites associated with selected networks as of 2018. The spatial coverage as well as total numbers of oceanic sites may be misleading, as the majority of sites presented here (light blue dots) are based on the international Argo program, a global network of autonomous profiling drifters. Figure replicated from (Merbold et al., 2021).

In order to ensure African ownership, the SEACRIFOG project stressed the significance of developing an e-infrastructure, the need for capacity building, and the involvement of all stakeholders (Merbold et al., 2021). For the engagement of stakeholders, aimed at promoting the EU-Africa cooperation dialogue at different levels within policy, science and society, three stakeholder consultation workshops were organized (López-Ballesteros et al., 2018). Data and metadata, specifically availability, accessibility, usability, interoperability, resolution, format, and quality, were the main concerns brought up by the participants during the workshops. Furthermore, respondents frequently emphasized the value of exchanging data and knowledge (i.e., research findings and methodological guidelines), highlighting the necessity of developing not only technologies and RIs, but also robust, proactive, and cooperative networking at various levels. It was established that climate change *adaptation, not mitigation, was Africa's top priority*. A comprehensive approach that takes into account socio-economic dynamics (land tenure, urbanization, job opportunities, market access, prices, investments, etc.) was seen as an answer to most of the constraints. Furthermore the needs of mediation between scientists, traditional leaders, and agriculture because science alone is often not sufficient was highlighted (López-Ballesteros et al., 2018). The workshop results can be expressed in a list of action items as follows:

- Compile lessons learned
- Foster the African regional network(s)
- Improve QA/QC of atmospheric and ecosystem greenhouse gas observations and document existing datasets
- Submit data and metadata to data centres to improve data F.A.I.R.ness
- Assess and valorize ecosystem greenhouse gas flux data.

The KADI project

The insight from SEACRIFOG was in part the motivation for an inter-disciplinary Horizon Europe Coordination and Support Action in African-European cooperation called ‘**K**nowledge and climate services from an **A**frican observation and **D**ata research **I**nfrastructure’ (KADI) (grant agreement No 101037319). The overall aim of KADI was to improve the knowledge base on climate change in Africa by providing a comprehensive design for climate services. Moreover, a more concrete implementation plan is envisaged.

Various partners from Africa and Europe combining diverse experiences, backgrounds and viewpoints were involved in the project. The specific objectives of KADI comprised the design for a pan-African atmospheric and climate observation system on the basis of atmospheric and climate services as guiding design principle and an extensive documentation of past and existing observing capability, contrasted with scientifically justified requirements to identify the gaps. Further, networking and knowledge exchange connecting all important players from the global to the local level have strengthened the basis for a successful and sustainable cooperation. Finally, KADI has developed a solid strategy for the implementation of the provided design which will be realizable as soon as resources become available.

The Kenya pilot

This report presents the outcomes of WP2 Task 5, “Pilot on lessons learned from existing long-term atmospheric and ecosystem observations” with a focus on Kenya. Kenya was identified as an ideal showcase due to the already existing infrastructures for atmospheric observations as well as continuous ecosystem flux measurements, and a well-established long-term cooperation with the international research community. This pilot was mainly a cooperation between the Kenya Meteorological Department (KMD), Swiss project partners (Federal Office of Meteorology and Climatology MeteoSwiss, Agroscope and Empa), and the University of Helsinki (Klausen et al., 2024).
Kenya is a country that spans more than 5 km in elevation between the sea and the highest summit, Mount Kenya. As a result, numerous climate zones (from desert to tropical forests) and land use types are found. Population densities vary by orders of magnitude across the country, with highest densities in the western regions and along the coast (cf. Figure 2). The specific objectives/deliverables were:

- Metadata sets available in GAWSIS-OSCAR/Surface, complemented by a summary report (this document).
- QC’d datasets available at World Data Centers,
- Report/manuscript on trend assessment and seasonality of atmospheric & ecosystem observations, characterization of footprint and recommendations for future expansion of observing capability
- Identification of criteria and requirements critical for a successful and sustainable operation of atmospheric and ecosystem observations in East Africa

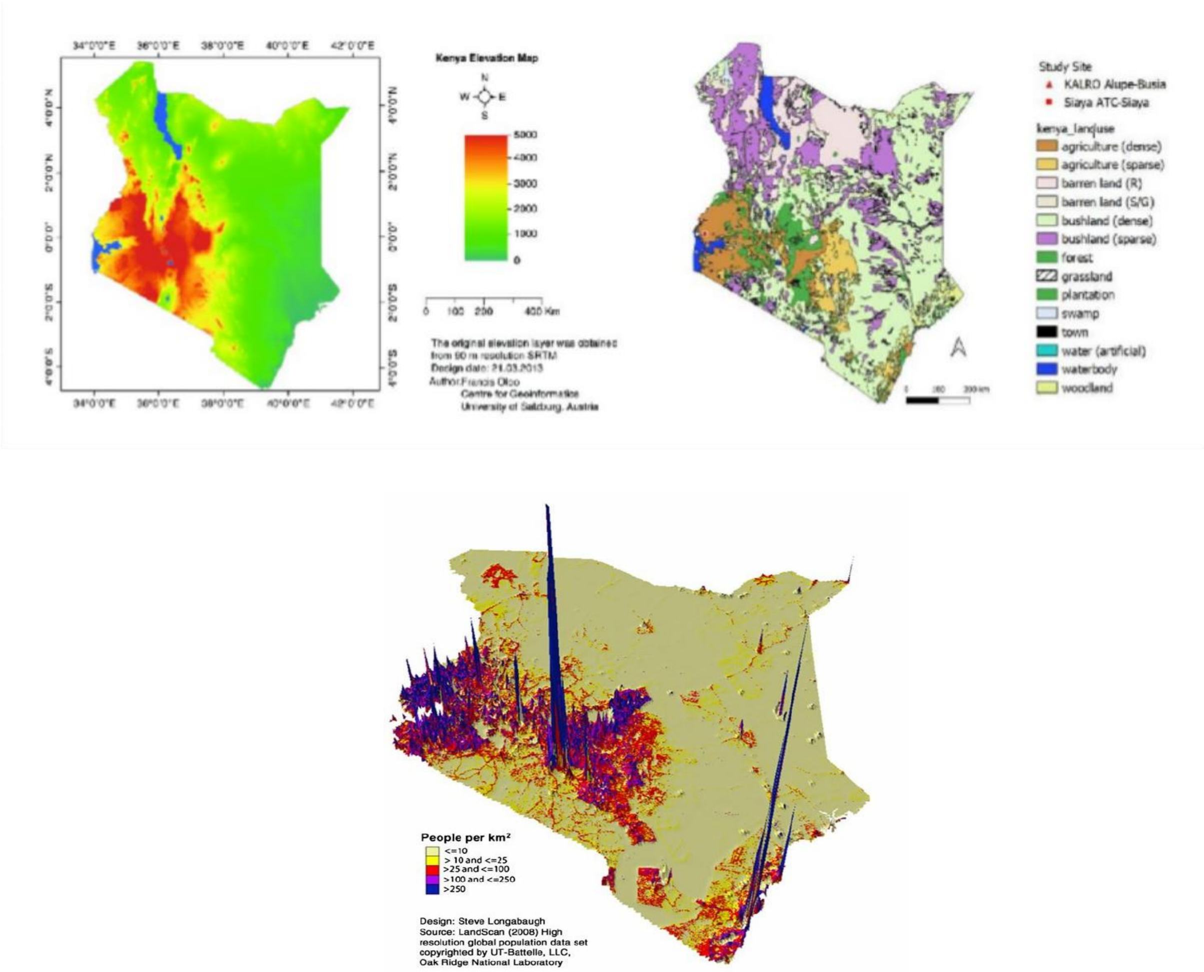

Figure 2. Elevation map of Kenya (top left) (Oloo et al., 2015), land use (top right) (Cheserek et al., 2021) and polulation densities (bottom) (Jayne and Muyanga, 2012)

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Actors for weather and climate services in Kenya

Global scale

The intergovernmental World Meteorological Organization (WMO, https://wmo.int/), to which 193 states and territories belong, has been the United Nations specialised agency for weather and climate since 1950. Relevant programs include

- Global Framework for Climate Services (GFCS), https://gfcs.wmo.int/site/global-framework-climate-services-gfcs
- World Climate Research Programme (WCRP), https://www.wcrp-climate.org/

The WMO supports the NMHS in their work and in fulfilling its international commitments in the areas of disaster risk reduction, climate change mitigation and adaptation, and sustainable development. Kenya is a WMO member in Regional Association I: Africa.

Regional scale (East Africa including Kenya)

Regional Climate Centres (RCC), defined as centres of excellence that strengthen the capacity of WMO Members in each region to deliver the best climate services to national users are important entities. The African Center of meteorological applications for development (ACMAD, https://acmad.org/) is the African continental weather and climate watch institution and the African Centre of excellence for meteorological application for sustainable development (ACMAD, 2023). This pan-African RCC is mandated to build capacity of NMHSs and other regional centres to provide weather and climate services in order to reduce disaster impacts. ACMAD provides continental scale forecasts, advice and warnings to the African Union, Regional Economic Communities and humanitarian organizations.

The East African Climate Center ICPAC (Intergovernmental Authority on Development (IGAD) Climate Prediction and Application Center, https://www.icpac.net/) provides climate services specifically to eleven East African countries (ICPAC, 2023). The ICPAC emerged in 2003 from the Intergovernmental Authority on Drought and Development (IGADD), which itself was formed in 1986 with the goal to reduce impacts on droughts and other natural disasters. Since 2014 the ICPAC is accredited by the WMO as a RCC of excellence in the provision of climate services to national and regional users of Eastern Africa. The ICPAC provides various services in the areas of climate forecasting, agriculture and food security, capacity development, climate change, disaster risk management, environmental monitoring, water resources and climate information dissemination. Other relevant organizations and initiatives include

- Climate and Development Knowledge Network (CDKN) Africa, https://cdkn.org/regions/africa
- Consultative Group on International Agricultural Research (CGIAR, https://www.cgiar.org/research/cgiar-regions/east-and-southern-africa/), specifically, Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA, https://aiccra.cgiar.org/)
- United Nations Economic Commission for Africa (ECA, https://www.uneca.org/)
- African Climate Policy Centre (ACPC, https://www.uneca.org/acpc)
- African Group on Earth Observations (AfriGEO, https://www.africageoportal.com/pages/afrigeo)
- Building Resilience and Adaptation to Climate Extremes and Disaster (BRACED, http://www.braced.org/)

- Climate for Development in Africa (ClimDev-Africa, https://www.climdev-africa.org/)
- International Network for Climate and Health for Africa (Clim-HEALTH Africa, https://climhealthafrica.org/)
- Intra-ACP Climate Services and related Applications Programme (ClimSA, https://www.climsa.org/)
- Enhancing National Climate Services (ENACTS, https://climhealthafrica.org/projects-enacts/)
- Future Climate for Africa (FCFA, https://futureclimateafrica.org/)
- Global Framework for Climate Services (GFCS) Climate Services Adaptation Programme in Africa, https://climhealthafrica.org/projects-gfcs/
- Global Monitoring for Environment and Security and Africa (GMES & Africa, https://gmes.africa-union.org/)
- Integrated Drought Management Programme (IDMP, https://www.droughtmanagement.info/)
- Monitoring of Environment and Security in Africa (MESA, http://csc.sadc.int/en/mesa)
- Science for Weather Information and Forecasting Techniques (SWIFT, https://africanswift.org/)
- Trans-African Hydro-Meteorological Observatory (TAHMO, https://tahmo.org/)
- Transformative Environmental Monitoring to Boost Observations in Africa (TEMBO, https://temboafrica.eu/)
- Transforming Water, Weather, and Climate Information through in Situ Observations for Geo-Services in Africa (TWIGA, https://website.twiga-h2020.eu/)
- Weather and Climate Information Services for Africa (WISER, https://www.uneca.org/WISER)

The observational capacity provided by some of these programs/initiatives are described in more detail in section 'Catalogue of observational assets' below.

National scale (Kenya)

Historical evolution

Meteorological observations in Kenya started in 1890 at the Mombasa Old Observatory. However, organized meteorological services were established in 1929 as part of the British East African Meteorological Service (BEAMS), which was an inter-territorial service covering Kenya, Uganda, Tanganyika and Zanzibar (presently Tanzania), and Northern Rhodesia (presently Zambia).

The BEAMS became a branch of the Meteorological Office of the Air Ministry of the United Kingdom in 1943, and was known as the Royal Air Force Organization (RFO). The main mandate of the Service was issuance of forecasts for military aviation. The facilities were made available during the war, particularly with respect to communication and special observations by aircrafts. They resulted in increased interest in the knowledge of weather conditions in East Africa, eventually leading to enhancement of forecast accuracy. BEAMS became a department under the British East African High Commission (BEAHC) between 1947 and 1948 and was renamed the East African Meteorological Department (EAMD).

In 1965, the EAMD was placed under the East African Common Services following the establishment of the East African Community (EAC). With the break-up of the EAC in 1977, all the common services collapsed and their functions were transferred to the jurisdiction of the respective partner states. In the case of Kenya, the Kenya Meteorological Department (KMD) was established as a National Meteorological Service (NMS), but without an Act of Parliament, as a department in the Ministry of Power and Communications. Since 1977, the KMD has been domiciled in various ministries including Ministry of Power and Communications, Ministry of Transport and Communications, Ministry of Information, Transport and Communications, Ministry of Transport, Ministry of Environment and Mineral Resources, Ministry of Environment, Water and Natural Resources, Ministry of Environment, Natural Resources and Regional Development Authorities, Ministry of Environment and Natural Resources, and currently under the Ministry of Environment, Climate Change and Forestry.

Current situation

The application of weather, climate and water information and related services helps to improve the safety and well-being of people, reducing poverty, increasing prosperity and protecting the environment for future generations. Meteorological Services offer critical contributions to meeting the targets of the country's goals such as Kenya's Vision 2030, the National Climate Change Action Plan, the United Nation (UN) Sustainable Development Goals (SDGs), the Sendai Framework for Disaster Risk Reduction and other relevant environment and climate-related conventions.

Under the mandate of the Government of Kenya and the WMO Convention, the Kenya Meteorological Department (KMD, https://meteo.go.ke/) as Kenya's NMHS provides early warnings, weather and climate information for safety of life, protection of property and conservation of the natural environment (KMD, 2023).

KMD has close ties to the Ministry of Agriculture, Livestock and Fisheries, the National Drought Management Authority and the Kenya National Disaster Operation Centre. KMD is recognized as the single and authoritative voice and source on matters of severe weather and extreme climate events in Kenya. KMD's mission is to provide and facilitate weather and climate information services for sustainable development with the vision to be a world class weather and climate service (KMD, 2023).

The core functions of the Department include data collection and monitoring, data processing, analysing and forecasting, data telecommunication and exchange, dissemination of warnings, advisories and alerts for severe weather and extreme climate events, data management and archival of quality meteorological and climatological records as wells as education and training in meteorology and related sciences to enhance capacities on meteorological services (KMD, 2023). Overall, the KMD offers services in the fields of weather forecasting, aeronautics, ocean, hydro-meteorology, agro-meteorology, bio-meteorology, climate, consulting and data management.

Since 2012, there have been County Meteorological Services (CMS, https://meteo.go.ke/services/county-meteorological-services), which are the sub-national meteorological services of the KMD to provide the respective county with relevant weather and climate information (KMD, 2023). Each of the fourty seven (47) CMOs is headed by a County Director of Meteorological Services who is in charge of the respective decentralized service at the county level.

KMD has participated in a number of projects/initiatives to enhance its national observational and services capacity. Some of these are national activities of regional programs, such as

- Enhancing National Climate Services (ENACTS, https://climhealthafrica.org/projects-enacts/)
- Kenya Climate Smart Agriculture Project (KCSAP, https://kcsap.go.ke)
- 3D-Printed Automatic Weather Station (3DPAWS, https://www.comet.ucar.edu/node/543)

The observational capacity provided by some of these programs/initiatives are described in the next section.

Catalogue of observational assets

Meteorological data consists of directly observed and derived data. Meteorological observed data contribute to saving both lives and property, and provide the basis for better understanding of the climatology of severe weather and extreme events such as tropical cyclones, El Niño/La Niña, floods, heat waves, cold waves, droughts and other natural hazards.

These data originate from land, upper air, marine/ocean and remote observing stations which provide temperature, rainfall, wind speed and direction, pressure, relative humidity, radiation, sunshine hours, and air quality.

- Land observing stations in Kenya include:
- Synoptic Meteorological stations
- Automatic weather stations
- Aerodrome Meteorological stations
- Hydro-meteorological stations
- Agro-meteorological stations
- Air pollution monitoring stations
- Dedicated manual rainfall stations
- Upper air (radiosonde, ozone sonde) stations

These are complemented by aircraft observations (AMDAR, AIREPs, PIREPs), satellite observations, and ocean observations. This report only considers the land stations.

Cataloguing Tools

SEACRIFOG inventory tool

The SEACRIFOG Inventory Tool (https://seacrifog.saeon.ac.za/, cf. Figure 3) was developed to analyse Africa's carbon observation networks. Metadata on relevant variables, observation infrastructures, existing data products and methodological protocols are systematically captured. The tool is a public information resource on the state of environmental observations across the African continent and the surrounding oceans.

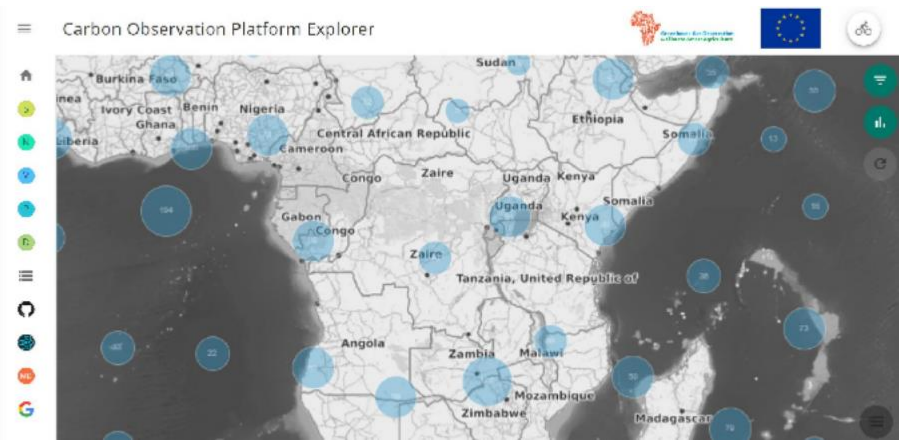


Figure 3. Screenshot from SEACRIFOG Inventory Tool

OSCAR/Surface

While some inventoring had already been done during SEACRIFOG and information continues to live on the project's portal, OSCAR (Observing Systems Capability Analysis and Review tool) is WMO's official and operational repository of metadata on surface-based (OSCAR/Surface, https://oscar.wmo.int/surface) and space-based (OSCAR/Space) observations. In OSCAR, metadata can be registered, managed and archived and therefore the platforms allow critical reviews of how well capabilities address requirements (WMO, 2023). The metadata are represented in compliance with the WMO Integrated Global Observing System (WIGOS) metadata standard (WMDS) using curated vocabulary from the WMO Codes Registry (https://codes.wmo.int/wmdr). At the beginning of KADI, a mere 39 stations were registered for Kenya. During the project, this number was considerably increased to 179 (cf. Figure 4; as of February 2025). The process of registering more assets in OSCAR/Surface is ongoing.

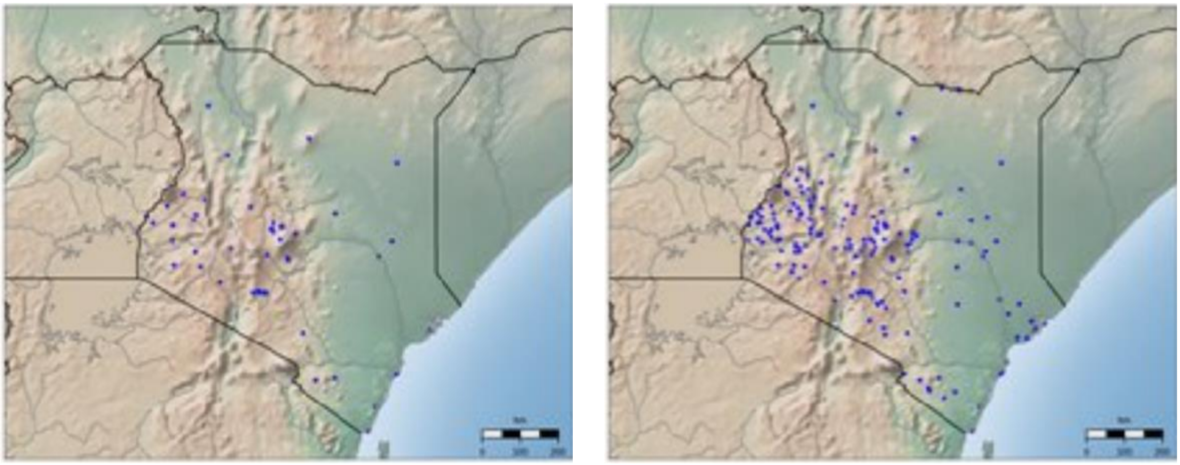


Figure 4. Status of registration of observational assets within the territory of Kenya at the outset of KADI in September 2022 (left) and in December 2024 (right). Source: https://oscar.wmo.int/surface/.

Atmospheric composition observations

In a long-standing collaboration between the Kenya Meteorological Department KMD and the Federal Office of Meteorology and Climatology MeteoSwiss, with further Swiss support by the Swiss Federal Laboratories for Materials Science and Technology Empa and the Paul Scherrer Institute PSI, two stations have been operated and evolved for several decades in support of the World Meteorological Organization's Global Atmosphere Watch (GAW) program (Henne, Klausen, et al., 2008; Henne, Junkermann, et al., 2008; Jalkanen et al., 2009; Kirago et al., 2023). GAW aims at monitoring and understanding long-term trends, variability, and changes in the composition of the atmosphere. GAW stations are located worldwide and gather data on multiple atmospheric components. GAW promotes data sharing and international collaboration by facilitating the exchange of measurement data, methodologies, and research findings among participating countries and organizations. Moreover, within the GAW program the establishment and maintenance of atmospheric monitoring capabilities in developing countries are supported by the provision of training, technical support, and access to data and instrumentation.

In Kenya, the active GAW stations are the Global GAW station Mount Kenya (WIGOS Station Identifier WSI 0-20008-0-MKN) and the Regional GAW station Nairobi (WSI 0-20008-0-NRB). The earlier Regional GAW station Malindi (WSI 0-20008-0-MLD) was discontinued.

Mount Kenya (0-20008-0-MKN)

Mount Kenya is one of the very few high-altitude observatories in East-Africa (GEO Mountains, 2023) and is among the best-equipped mountain stations in terms of atmospheric composition in the region. The station is classified as a Global GAW station and observes surface ozone and carbon monoxide, the greenhouse gases carbon dioxide and methane, aerosol optical properties as well as supporting meteorological elements. The metadata record of this station can be found at https://oscar.wmo.int/surface/#/search/station/stationReportDetails/0-20008-0-MKN. This record is periodically updated and refined and was thoroughly reviewed in December 2024.

Atmospheric composition data from this station are available through the following data centers (cf. Appendix 1: Available Data):

- World Data Center for Greenhouse Gases WDCGG: since 2004, with gaps
- World Data Center for Aerosols WDCA & World Data Center for Reactive Gases WDCRG: since 2002, with gaps

There is no dedicated data center for meteorological data obtained in the context of GAW. Meteorological data are available through

- World Data Center for Greenhouse Gases WDCGG: since 2020
- Kenya Meteorological Department KMD: since 2002, with gaps
- MeteoSwiss, since 2002, with gaps

Figure 28 thru Figure 31 in Appendix 1: Available Data provide visualizations of the data available from the international data centers up until December 2024.

Nairobi (0-20008-0-NRB)

This station is classified as a Regional GAW station and is also a contributor to the NASA SHADOZ network (Lee et al., 2010; Southern Hemisphere ADditional OZonesondes (SHADOZ), n.d.; Thompson et al., 2017a, 2021; Witte et al., 2017)

Atmospheric composition data from this station are available through the following data centers (cf. Appendix 1: Available Data):

World Ozone and UV Data Center WOUDC: since 1984

Aerosol optical properties have been observed since 2024, these data are still being processed and are available from MeteoSwiss and KMD only.

Meteorological data are available through

- Kenya Meteorological Department KMD
- MeteoSwiss

Figure 32 in Appendix 1: Available Data provides a visualization of the data available from the international data centers up until December 2024.

Malindi (0-20008-0-MLD)

This station is classified as a Regional GAW station and was in operation between 1967 and 2006, first as a radiation station, later as an ozone sounding station. It is closed. Atmospheric composition data from this station are available through the following data centers:

- World Ozone and UV Data Center WOUDC: 1999-2006

Figure 33 in Appendix 1: Available Data provides a visualization of the data available from the international data centers up until December 2024.

Ecosystem GHG flux observations

Continuous ecosystem flux observations in Kenya have only been established in the past decade. First observations took place in Laikipia (Northern Kenya) as well as in Western Kenya within the greater Masai Mara area and around Lake Naivasha. These sites were either operated on a project or campaign mode only and are no longer operational to our latest knowledge. More recent observations were established by the Mazingira Centre of the International Livestock Research Institute (ILRI) in the Kapiti Plains, South Central Kenya, The University of Helsinki in Taita, Southern Kenya and the most recent setup was initiated by Jaramogi Oginga Odinga University of Science and Technology on Lake Victoria (not yet operational). A detailed overview of the existing sites is provided below (Figure 5).

The growth in ecosystem flux observations in Kenya is impressive and far ahead of neighbouring countries. It further shows the demand of such observations for improved understanding of ecosystems in the context of climate change in the region, particularly in relation to mitigation pathways as well as in relation to understanding the adaptive capacity of these ecosystems to climate change and consequently the continuous provisioning of ecosystem services.

The operational status of the ecosystem stations is diverse for the same reasons as found for atmospheric observations. Amongst the key challenges for ensuring continuous observations are the lack of continuous financial resources to maintain staff and instruments and subsequently measurements. Up to today, each of these stations has been funded by individual projects, predominantly competitive scientific funding and have been supported by highly motivated individuals with minimal institutional funding. Similarly, hiring and keeping well-trained experts, both technically and scientifically, to ensure continuous operation of the sites with data quality control and quality assurance checks as well as scientific output has proved to be a challenge. Additionally, such long-term observational sites in Kenya are exposed to a wide range of environmental challenges, ranging from continuous high radiation and extended droughts leading to flash floods, to fires and the hazards of wildlife and livestock. This subsequently leads to more frequent maintenance intervals, sensor malfunctioning or overall failure of instruments. A common threat, especially to semi-automated systems in remote regions are damages due to vandalism and theft. Each of these challenges and threats has to be accounted for. In essence, the future sustainability of these stations under present conditions is highly uncertain.

Figure 5. Active (red) and discontinued (black) eddy covariance stations in Kenya

Western Kenya: Overview of flux stations in the greater Masaii Mara and at lake Naivasha

The International Institute for Geo-Information Science and Earth Observation (ITC), The Netherlands operated two flux towers in Kenya: Naivasha Flux Station and The Mara Flux station.

The Naivasha flux tower was established in 2010, but due to vandalism and breakdown, it became only fully operational in 2011. The tower was located in a shrub-land where wildlife graze inside the Kenya Wildlife Research and Training Institute (KWRTI) in Naivasha. The station operated until late 2021 when it was again vandalized.

The Mara flux station was located inside the Maasai Mara National Reserve in a grassland site used for both wildlife and livestock grazing. The tower was installed in 2017 and operational until a fire incidence damaged the scaffolding and instrumentation.

Naivasha

Established in September 2010, data collection started in January 2011

Eddy covariance flux tower meant for measuring energy fluxes and later on also CO2 and H2O fluxes at 10 Hz. It consisted of a sonic anemometer and an open path infrared gas analyzer. However, the analyzer was only added in 2012 for a short duration of about 3 months (21 March 2012 to 9 May 2012) and later re-installed in 2017 until the vandalism of the entire station occurred in 2021. A large aperture scintillometer was installed for measuring sensible heat flux. Meteorological data included: air temperature, relative humidity, albedo, surface temperature, volumetric water content at 10, 30 and 50 cm, soil temperature installed at t 1, 2, 3, 4, 5, 6, 8, 10 and 12.5-cm depths below the ground. Soil heat flux was measured at 10 cm. Additionally air pressure, radiation and rainfall were measured.

Mara

Established in July 2017, this Eddy covariance flux tower was meant for measuring energy fluxes and later on also CO2 and H2O fluxes at 10 Hz. It consisted of a sonic anemometer and an open path infrared gas analyzer. Meteorological data included: air temperature, relative humidity, albedo, surface temperature, volumetric water content at 10, 30 and 50 cm, soil temperature, soil heat flux was measured at 10 cm. Additionally air pressure, radiation and rainfall were measured. A Cosmic Ray Neutron Probe Sensor (CRNP) was also installed for measuring soil moisture.

The flux station at Naivasha, located at an altitude of 2000 m with coordinates (Latitude: -0.736534, Longitude: 36.450901). The station at Mara, situated at a higher altitude of 1573 m with coordinates (Latitude: -1.493426, Longitude: 35.149226), has been operational from July 2017 till 2019. Further technical metadata of the two stations are given in the table below:

Parameter	Description	Tower 1 (Naivasha)	Tower 2 (Mara)
Canopy Height (m)	Height of vegetation canopy at the site	0.5 -1	<0.30
Displacement Height (m)	Displacement height for wind profile measurement	0.33-0.67	0.2
Roughness Length (m)	Length scale representing surface roughness	0.05-0.1	0.03
Instrument Height (m)	Height of the measurement instruments above ground	5.5	7.0
Gas Analyzer	Type and details of the gas analyzer	LI-7500	LI-7500
Anemometer	Type and serial number of anemometer	WindMaster (Pro) type 1561, Gill Instruments	WindMaster (Pro) type 1561, Gill Instruments

Table 1. Metadata of the GHG monitoring stations in Naivasha and Mara

Kapiti Plains: Overview of flux tower in South-Central Kenya

In Kapiti plains, two greenhouse gas (GHG) monitoring stations were established at the end of 2018 and in early 2019 (Figure 6).

1. Kapiti Research Station and Wildlife conservancy: a typical semi-arid savanna rangeland which is utilized for livestock farming and encompasses a wide range of wildlife

2. Ausquest farm: a minimal tillage large scale cropping enterprise located adjacent to Kapiti Research Station with the same climate and soil type.

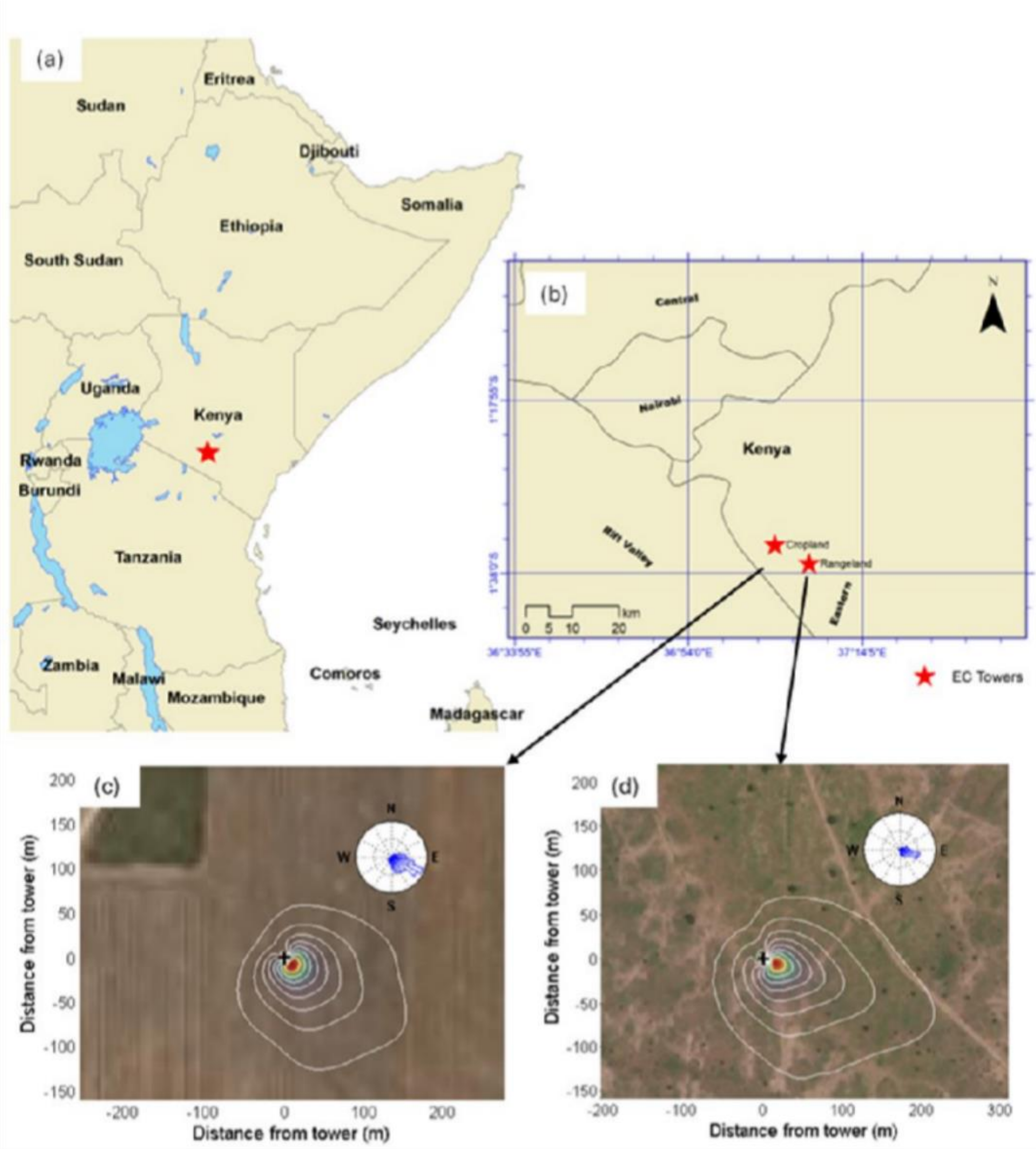


Figure 6. Location of Kapiti Research Station and Ausquest Station in South Central Kenya. Figure from (Odongo et al., submitted)

Kapiti Research Station

At Kapiti, a combination of an open-path infrared gas analyzer (LI-7500DS, LI-COR Biosciences, Lincoln, NE, USA) and a sonic anemometer (Gill Windmaster Pro sonic anemometer, Gill Instruments, Lymington, UK) was employed for measuring CO_2, water vapor, sensible heat, and momentum fluxes. These instruments, set at a height of 4.3 m with a northward offset of 0º, operated at a sampling frequency of 10 Hz. The separation distances from the center of the gas analyzer's sampling volume to the anemometer were -5.0 cm northward, -20.0 cm eastward, and 0 cm vertically. The data acquisition was enabled using an embedded computer (LI-COR Biosciences, Lincoln, NE, USA). Meteorological measurements at this site included relative humidity and temperature gradients, measured at two-point heights of 2 m and 4 m

(Vaisala HMP155 sensors, Vaisala Oyj, Helsinki, Finland). Precipitation was recorded using a tipping bucket rain-gauge (LI-COR TR525m, LI-COR Biosciences, Lincoln, NE, USA) at a height of 1.5 m. Shortwave and net radiation were measured with a net radiometer (CNR 4, Kipp & Zonen, Delft, The Netherlands) installed at a height of 4 m. Photosynthetic Photon Flux Density (PPFD) was measured using a quantum sensor (LI-190R, LI-COR Biosciences, Lincoln, NE, USA) installed at a height of 4 m. All these biometeorological data were stored on a datalogger (Sutron 9210 datalogger, Sutron Corporation, Sterling, VA, USA).

Ausquest Station

At the Ausquest farm, flux measurements in the cropland were conducted using a closed-path CO_2/H_2O gas analyzer (EC 155, Campbell Scientific, Logan, UT, USA) and a sonic anemometer (CSAT-3, Campbell Scientific, Logan, UT, USA) installed at a height of 3.2 m and North off-set at 115 º. The sampling frequency was 10 Hz. The separation distance between the gas sampling tube and the center of the anemometer was 15.6 cm. The flow rate of the sampling system was 6.0 l min^{-1}, with the inlet tube for the gas analyzer measuring approximately 64.5 cm in length and 2.2 mm in diameter. The longitudinal and transversal lengths of the setup were 12.0 and 1.0 cm respectively and the gas analyzer time response was 0.1 s. Meteorological measurements at this site included relative humidity and temperature gradients, measured between two points at heights of 0.4 and 2.0 m (Vaisala HMP155 sensors, Vaisala Oyj, Helsinki, Finland). Precipitation was recorded using a tipping bucket rain-gauge (EML ARG100, Environmental Measurements Limited, NE, United Kingdom) at a height of 2.05 m. Radiation measurements, conducted at a height of 3.5 m, included incoming and outgoing Photosynthetic Photon Flux Density (PPFD) (LI-190 Quantum sensors, LI-COR Biosciences, Lincoln, NE, USA), shortwave radiation (Apogee SP-110 pyranometer, Apogee Instruments, Inc., Logan, UT, USA), and net radiation (NR-lite2 net radiometer, Kipp and Zonen, Delft, The Netherlands). The data acquisition was done with a datalogger (CDM-A116 with a 16-Channel 5V Analog to Input Module connected directly to a CR6 datalogger, Campbell Scientific, Logan, UT, USA).

Taita: Overview of the Flux Towers in southern Kenya

In Taita, two greenhouse gas (GHG) monitoring sites were setup by University of Helsinki and Taita Research Station.

1. Maktau Station is located within a farmland where conventional tillage is practiced
2. Choke Station is located within a shrubland in a conservation area.

Maktau (WSI 0-404-300-060250122AS00001)

Established in November 2018, data starts in December 2018 ; Eddy covariance flux tower installed for measuring energy fluxes as well as CO_2 and H_2O fluxes at 10 Hz. It consists of a sonic anemometer and an open path infrared gas analyzer.Meteorological data included: air temperature, relative humidity, albedo, average surface soil temperature , volumetric water content, electrical conductivity at 10, 30 and 50 cm, permitivity at 10, 30 and 50 cm, air pressure and rainfall.

Choke (WSI 0-404-300-060240116AS00002)

Established in October 2022, hosts

1. **Eddy Covariance Flux Tower** meant for measuring CO_2 and H_2O fluxes. It consists of a Sonic Anemometer and a closed path gas analyzer.

2. **Meteorological data** at a 15-minute time step including: Photosynthetically active radiation (PAR), Net Radiation, Relative Humidity, Rainfall, Air Pressure, Soil Volumetric Water Content, Soil Electrical conductivity and Soil Temperature at 10, 30 and 50 cm.

The data collection method used in Taita is based on dddy covariance theory as detailed by (Burba, 2013) and the processing method is based on published method by Sabbatini et al., (2018)

The flux station at Choke (Tower 1), located at an altitude of 850 m with coordinates (Latitude: -3.6456, Longitude: 38.3572), began operation in October 2022. The station at Maktau (Tower 2), situated at a higher altitude of 1055.6 m with coordinates (Latitude: -3.4258, Longitude: 38.1393), has been operational since December 2018 (see Location Maps below). Both stations are currently active, further technical metadata of the two sites are given in the table below.

Parameter	**Description**	**Tower 1 (Choke)**	**Tower 2 (Maktau)**
Canopy Height (m)	Height of vegetation canopy at the site	4.0	2.0
Displacement Height (m)	Displacement height for wind profile measurement	3.0	1.34
Roughness Length (m)	Length scale representing surface roughness	0.02	0.3
Instrument Height (m)	Height of the measurement instruments above ground	5.5	3.3
Gas Analyzer	Type and details of the gas analyzer	LI-7210 (Serial 72H-0119)	LI-7500DS (Serial 75D-4087)
Analyzer Interface Unit	Type and serial number of analyzer interface unit	LI-7550 (Serial AIU-0176)	Not applicable
Flow Module	Type and serial number of flow module	7200-101 (Serial FM1-0301)	Not applicable
Anemometer	Type and serial number of anemometer	GILL WMP (Serial 223002)	WMPro Sonic (Serial W181710)
Anemometer Software Version	Software version of the anemometer	2329-701	2329-701-01
Logger ID	Identifier for the data logger	AIU-0176	Smart3-00183
Logger Software Version	Software version of the data logger	8.9.0	8.9.0

Table 2. Metadata of the GHG monitoring stations in Choke and Maktau

Lake Victoria: Overview of flux tower in Lake Victoria Basin

The site (Jaramogi Oginga Odinga University of Science and Technology) has only been established at the end of 2024 and is not yet operational. Further details will be updated in OSCAR as soon as these become available.

Manual meteorological observations

While spatially and temporally complete quality-controlled data for key variables is indispensable for the provision of weather and climate services, a decline in the availability of observed data over Africa has been recorded (Dinku et al., 2017). As an example, Figure 7 shows the evolution of African stations reporting to the Global Precipitation Climatology Centre, and Figure 19 shows the dramatic decline of manual rainfall observations in Kenya. Reasons for this include declining investment, social or political conflicts, and challenging topography (Dinku, 2019). Fortunately, some of this decline is offset by transitioning to automatic weather stations.

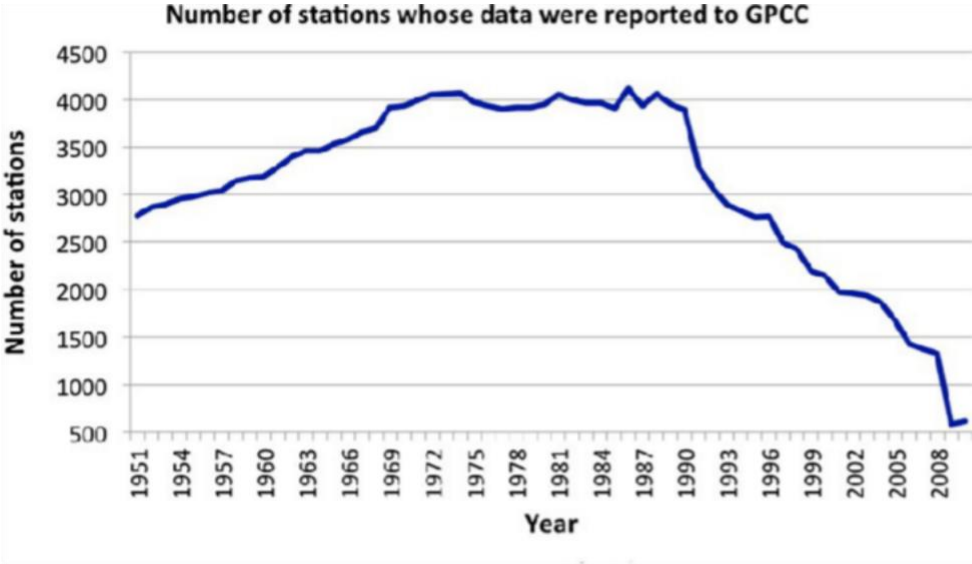


Figure 7. Evolution of African stations whose data were reported to the Global Precipitation Climatology Centre. Figure taken from (Dinku et al., 2017)

Manned stations network of KMD

KMD began its national observation by operating 34 manual synoptic stations. These were manned stations that operated on 24 hours observing weather parameters through registers. The registers would be dispatched every month to a central location for digitization and archival. The Kenya Meteorological Department currently runs 41 manned observatory stations that are staffed between 12-24 hours a day and rely on manual measurements (cf. Figure 8). Of these 41 stations, 14 serve as agro-meteorological stations (staffed 12 hours per day) that are located at or near agricultural research facilities to support agriculture research.

The stations have been equipped with digital instruments for atmospheric pressure, air temperature, and relative humidity (PTU) to replace the mercury-in-glass thermometers and to facilitate the observation of basic weather parameters. In addition, other instrument such as evaporation pans, wind systems, and soil thermometers are employed to measure various meteorological parameters.

Once observed, data at the station level are transmitted to the headquarters servers through the Climsoft software. Climsoft is a software suite for storing climatic data in a secure and flexible manner and for extracting useful information from the data. Climsoft is a free open-source project, licensed under GPL3. It is widely used by National Meteorological and Hydrological Services (NMHSs) of developing countries.

Climsoft, Climate Data Management System (CDMS) is designed to store historical climatic data in computerised form. These data can be used to produce summary reports, maps or diagrams or subsets of the data can be extracted for further processing. (http://www.climsoft.org/g/)

At the KMD headquarters, in its role of the Regional Telecommunication Hub (RTH), KMD Communication centre exchanges data from the Region 1 (RA1) on the Global telecommunication system, Regional telecommunication system and National Telecommunication system using the TRANSMET circuit. Data received through the Climsoft also undergoes quality control and is archived in the KMD servers. This data supports the operational function of the department in its mandate of provision of weather and climate information service.

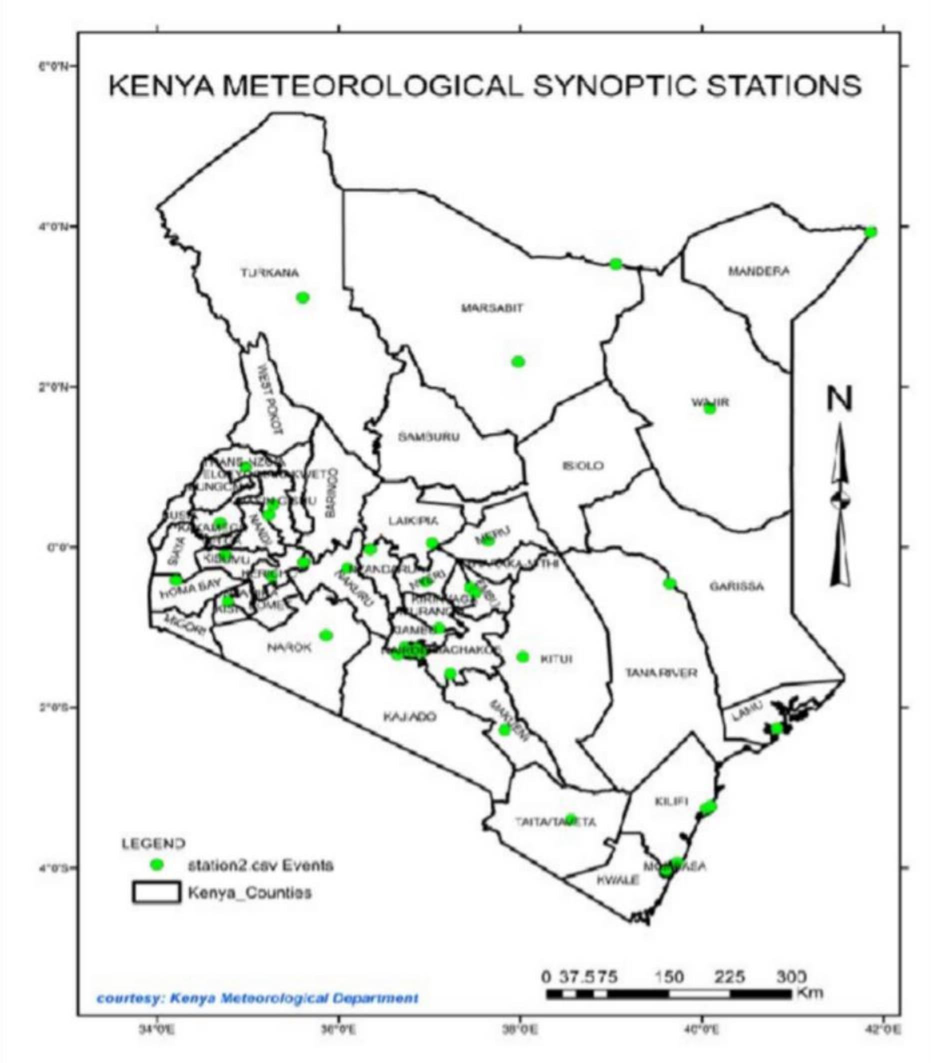


Figure 8. Synoptic, fully equipped manned stations currently operated by KMD.

Manual precipitation stations

The earliest and oldest weather observation monitoring in Kenya is that of precipitation. From as early as the last century, there's evidence of rainfall monitoring and observation across the country. These early stations were manned. The observations was made in inches and the monthly totals would be documented in registers. KMD inherited registers from more than 2000 such rainfall stations, data which has been rescued, and archived at KMD (cf. Figure 9).

In 1960 rainfall cards were introduced for the monitoring of daily cumulative rainfall. The cards would be distributed every year to all the rainfall stations. The set included a cumulative annual card that would be filed at the station and a pre-stamped cards that documents daily rainfall and at the end of the month the observer was simply required to drop the card at the post office for delivery to KMD headquarters where the data would be digitized and the card archived.

Each station was given an identifier made up of seven digits. The first four digits indicate the longitude and latitude under which the country lies. the last three digits are a continuing sequence from the last registered station.

For efficient operations of the rainfall stations, KMD was required to provide the rain gauge and measuring cylinder, support training of the volunteer observer and submit annual assessment of the stations operations.

Figure 9. Monthly rainfall totals from Narok rainfall station from 1946

Automatic Weather Station Network

Automation of data collection in KMD was first envisioned in the KMD Strategic plan of 2013-2017 and involved procurement of an initial set of 36 automatic weather stations (AWS) that were installed at all KMD manual stations. The purpose was for the stations to complement the data from the manual stations and also support the validation of the automatic observed data.

There are currently 625 AWS in Kenya, with only half of them operated by KMD. Given the area size of Kenya, this translates to an average of 1 automatic station for every 650kmsq, which considering the diversity of geographical features is not sufficient to support weather and climate information.An ideal situation would be to have an AWS for every 50kmsq Besides the increased spatial coverage, the advantages of such AWS networks include the availability of data in near real time, as AWS are usually equipped with data loggers and telecommunication systems that enable continuous data transmission. The automatic reporting occurs at mostly very fine temporal resolutions (around 15 minutes, on average).

The KMD manages a heterogeneous AWS network from different initiatives as depicted in Figure 10 (Faniriantsoa and Dinku, 2022). In the following, the individual networks are introduced in more detail.

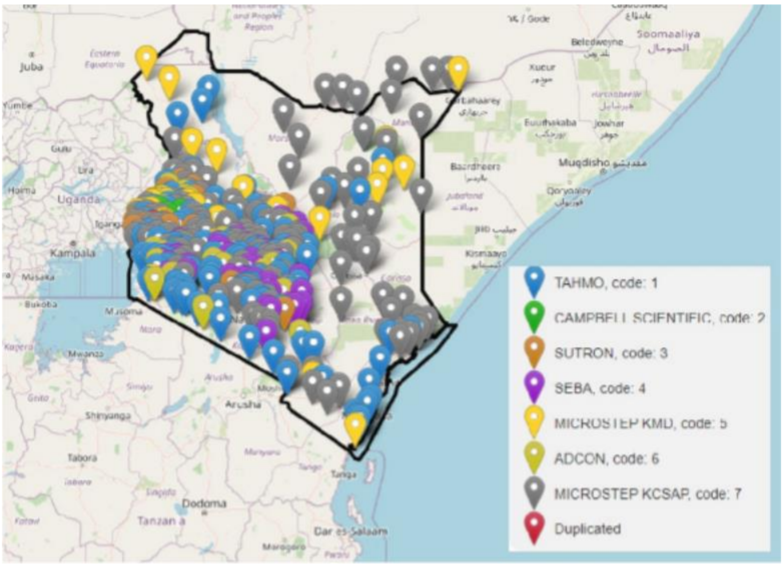
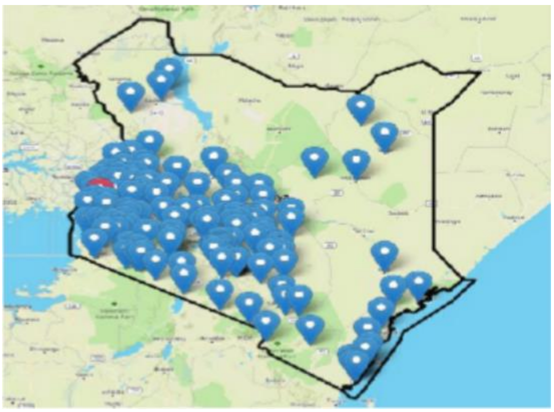


Figure 10. Overview of automatic weather station networks. Source: modified from (Faniriantsoa and Dinku, 2022)

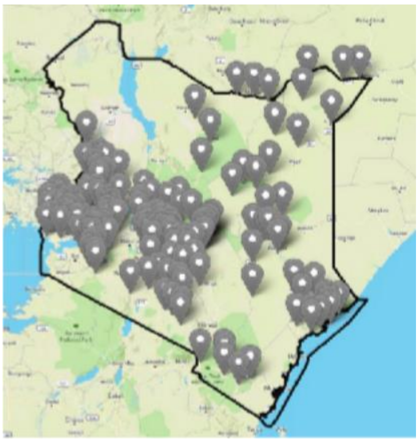
Trans-African Hydro-Meteorological Observatory (TAHMO)

About	The idea behind TAHMO is the development of a dense network of hydro-meteorological monitoring stations in sub-Saharan Africa (Trans-African Hydro-Meteorological Observatory (TAHMO), no date). For this purpose, 20,000 cost-effective and robust stations will be or have been installed and operated by the initiative. The first station was installed in 2012. Most AWS are located at local schools and universities so that lecturers can use the data in their lessons (School-2-School and University-2-University program).
Scope	TAHMO plans to install 20'000 stations in sub-Saharan Africa. In Kenya currently 132 TAHMO stations are operated
Spatial distribution	

Technical details	• **URL**: https://tahmo.org/ • **Data Access**: Data is made available to NMHS first. For government and scientific use the data is free. For commercial use of the data (incl. development of new services) a fee depending on geographical coverage and level of exclusiveness of use within a sector is incurred by TAHMO. • **Funding**: TAHMO has diverse funding partners including Horizon 2020 Europe Union Funding for Research & Innovation, WMO, The World Bank, United States Agency International Development USAID, Global Resilience Partnership and Netherlands Organisation for Scientific Research. • **WMO Compliance**: TAHMO instruments meet or exceed all WMO standards. However, as these are compact AWS, the elevation above ground of precipitation and wind measurements cannot comply with WMO siting regulations. • **Sensors**: The TAHMO network consists of MEM stations by the Meter Group. They were developed with the goal to become optimal in terms of high-quality measurements and cost-efficiency. 12 weather sensors are packaged into a single compact device. • **Example station**:  **Figure 11:** A TAHMO station. Source: https://www.kcsap.go.ke/installation-agro-weather-stations.

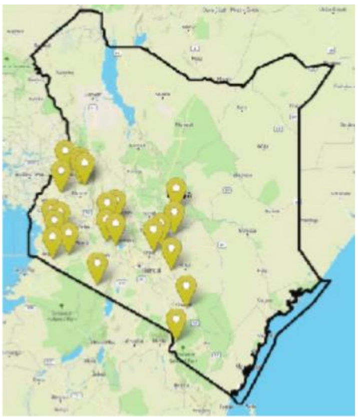
Kenya Climate Smart Agriculture Project (KCSAP) – MicroStep-MIS

About	The KCSAP is a project of the Government of Kenya supported by the World Bank. It was implemented from 2017-2022 under the framework of the Agriculture Sector Development Strategy (ASDS) and National Climate Change Response Strategy (NCCRS). In August 2022, 154 AWS (120 climatic, 18 agro-meteorological stations, 17 hydrological stations) built during the KCSAP project were commissioned and handed over to the KMD.

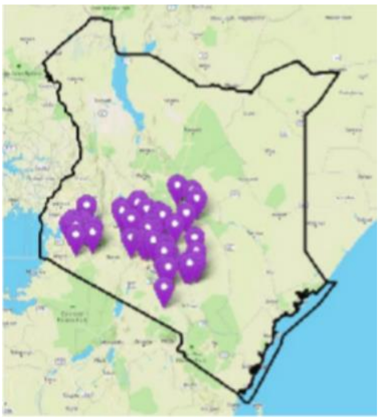
Spatial distribution	 24 out of the 47, counties are currently covered by KCSAP.
Technical details	• **URL**: https://www.kcsap.go.ke/ • **Funding**: The project budget is a total of USD 279 million. USD 250 million is financed by The World Bank and USD 29 million is contributed by the Government. • **Sensors**: MicroStep-MIS stations. • **Example station**:  **Figure 12:** Photo of a MicroStep-MIS installation. Source: https://www.kcsap.go.ke/installation-agro-weather-stations

KALRO - Kenya Agricultural and Livestock Research Organization

About	Supplied by Agriculture and Climate Risk Enterprise ACRE Africa (earlier Kilimo Salama: "safe agriculture" (insurance for farmers). 78 stations in Kenya (source: https://slideplayer.com/slide/10618769/)

Map	
Technical details	• **Stations**: manufactured by ADCON Telemetry

3D Printed Automatic **Weather** Stations (3D-PAWS)

About	3D-Printed Automatic Weather Station (3D-PAWS) is an innovative approach to creating cost-effective, customizable, and accessible weather stations using 3D printing technology. The 3D-PAWS (3D-Printed Automatic Weather Station) is an initiative by the University Corporation for Atmospheric Research (UCAR) and the US National Weather Service International Activities Office (NWS IAO), with support from the USAID Office of U.S. Foreign Disaster Assistance (OFDA). The project began in 2023 and has managed to fabricate and install the AWS in most of the 41 KMD Manual stations site both as a parallel observation system to the manual one and also for data validation purposes.
Map	

Technical details	• URL https://3dpaws.comet.ucar.edu/  **Figure 14.** 3D-PAWS station

Related programs and initiatives

Enhancing National Climate Services (ENACTS)

ENACTS is an initiative launched by the International Research Institute for Climate and Society (IRI) aimed at strengthening the capacity of national meteorological and hydrological services in developing countries to collect, analyse and disseminate climate-related data and derived information products (Dinku et al., 2017). The major activities of ENACTS include improving the availability and quality of climate data, enhancing the access to climate data, information products, and services relevant to the needs of the public and promoting the widespread use of climate information services. Currently, ENACTS is implemented in over 20 African countries (including Kenya) (cf. Figure 15).

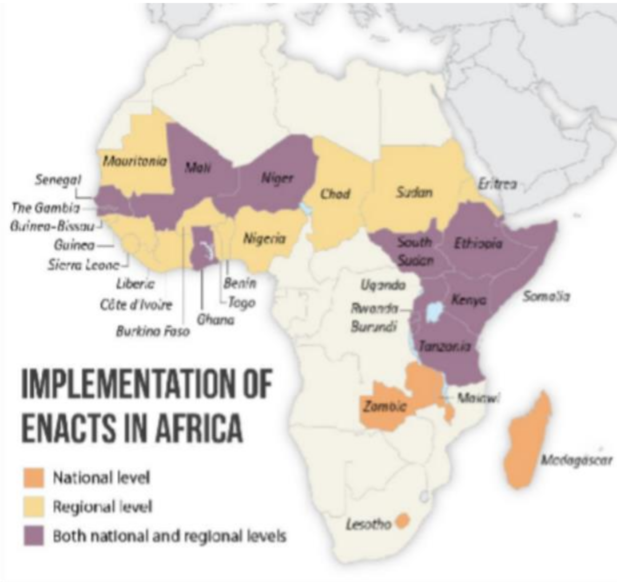


Figure 15: Implementation of ENACTS in Africa. Source: https://iri.columbia.edu/resources/enacts/.

Within the framework of ENACTS, various tools have been developed to realise the aims.

The **Climate Data Tool (CDT)** is a software tool developed with the target to support the NMHS with the management, analysis and visualization of climate data. By offering features like facilitated data management, quality control, data analysis, visualization and reporting the capacity of climate services is aimed to be enhanced. The CDT **Maproom** (Grossi and Dinku 2022) is a portal for decision-makers, researchers and practitioners working in climate-sensitive sectors. It aims to bridge the gap between climate information providers and end-users by making climate data more accessible, understandable and applicable. The Maproom serves as a central hub for accessing and visualizing climate information and data collected and processed by the NMHS. Both, historical climate information as well as seasonal climate forecasts, are accessible on the Maproom. KMD's Maproom (CDT) is available at http://kmddl.meteo.go.ke:8081/maproom/ (cf. Figure 16).

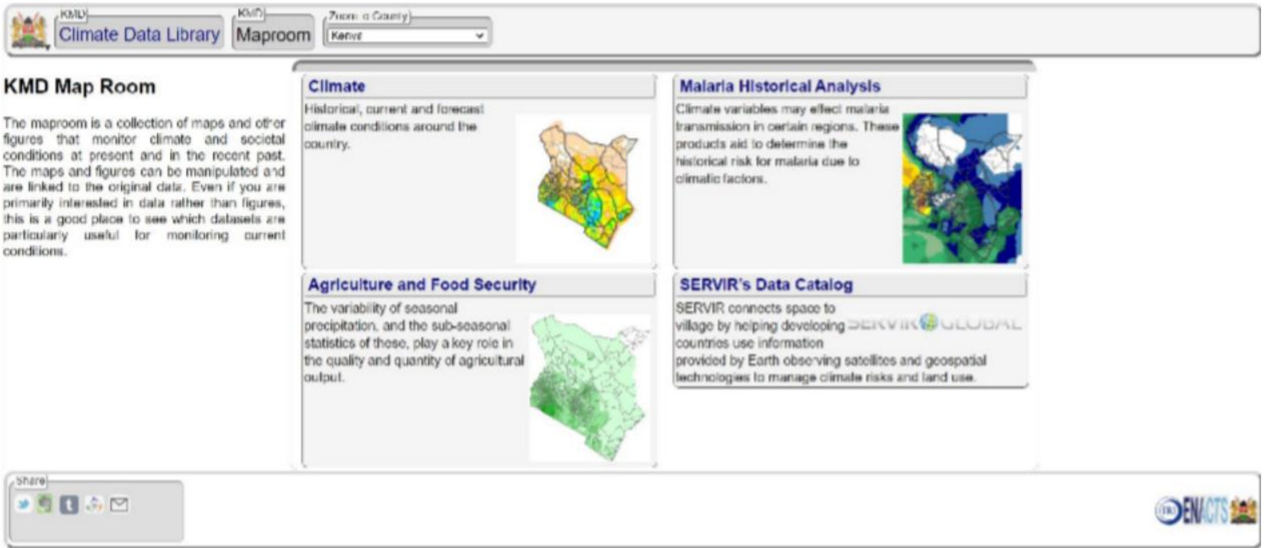


Figure 16. Screenshot of the KMD Maproom (http://kmddl.meteo.go.ke:8081/maproom/)

The **Automatic Weather Station Data Tool (ADT)** is a software tool developed to automate the processing and analysis of AWS data to optimize the management and utilization of this data by the NMHS (Faniriantsoa and Dinku 2022). The tool contains functionalities on data quality control, data processing, data visualization and data access and sharing. Moreover, the tool stores metadata (station name, unique identifier, latitude, longitude, elevation, available sensors, type of sensors, height of each sensors above ground, history of change of sensors, meteorological variables observed, units of the measurement, temporal resolution, periodic maintenance, calibration of sensors) of the AWS. KMD's ADT is available at http://196.202.217.194:8081/ .

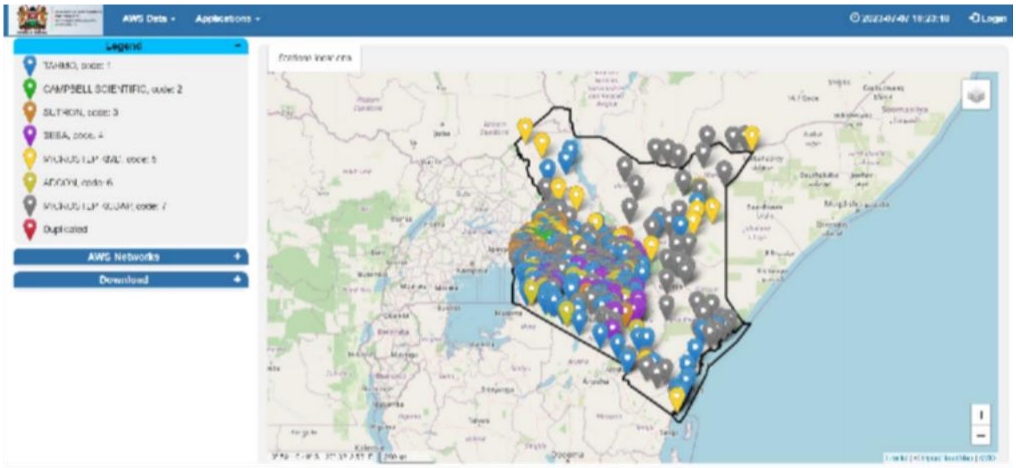


Figure 17. KMD's Automatic Weather Station ADT portal at http://196.202.217.194:8081/

Weather and Climate Information Services (WISER) programme

WISER is a programme established 2015, funded by UK Aid and managed by the Met Office, with the aim to deliver transformational change in the quality, accessibility and use of weather and climate information services at all levels. Numerous projects have emerged from the WISER programme, some of which focus on Kenya.

The aim of **WISER Western Kenya** was to develop and deliver decentralised services of KMD in 4 counties (Kakamenga, Siaya, Kisumu and Trans Nzoia). KMD, CARE Kenya and Met Office were involved in the project. Through the project decision making was facilitated and risks minimised at county to household level by increased and better use of weather and climate information.

The main target of the **Developing Risk Awareness through Joint Action (DARAJA)** project was the improvement of weather and climate information services focusing on urban informational settlement communities in Nairobi (Kenya) and Dar es Salaam (Tanzania). An example for DARAJA's engagement is the training of media partners since Radio and TV were identified as preferred channels for communicating information on weather and climate. Trainings included support on how to interpret weather and climate information and to provide impact related advice in an easy-to-understand format. Moreover, the provision of weather and climate information through Social Media (WhatsApp, Facebook) was enhanced.

The **Coastal Resilience and Improving Services for Potato Production in Kenya (CRISPP)** project aimed to develop a set of co-produced climate information services which improve the dissemination and impact of weather and climate information for households in Kenya's coastal region. The project was a cooperation between the KMD, the Met Office and the Global Climate Adaptation Partnership (GPAC) Kenya. They summarized their impacts in numbers as follows: 4 new and improved forecast products that meet the user needs, 51 new organisations using weather and climate information to improve decision making and over 300’000 end users with improved access to weather and climate services.

TWIGA Initiative

Between 2018 and 2021, the Transforming Water, Weather and Climate Information Through In-situ Observations for Geo-Services in Africa (TWIGA) initiative aimed to transform weather, water and climate data into value-added information services (TWIGA-H2020, n.d.). TWIGA received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No. 776691. The project facilitated the development of geoservices for communities in sub-Saharan Africa. The outcome of the project was a platform, where satellite and sensor data are freely available to users.

Transformative Environmental Monitoring to Boost Observations in Africa (TEMBO)

The main objective of TEMBO, which is the follow-up project of TWIGA, is to close the environmental in-situ data gap in Africa (Transformative Environmental Monitoring to Boost Observations in Africa (TEMBO), n.d.). The projects build on recent sensor technology to make measurements cost-efficient. On the other hand, services in the areas of flood early warning systems, reservoir management and agricultural information are developed. The project has received funding from the Horizon Europe Programme (2021-2027) under grant agreement No. 101086209. KMD is one of the numerous project partners.

Climate Services and Related Application Programme (ClimSA)

ClimSA (https://www.climsa.org/) is a programme that supports eight different regional climate centres in African, Caribbean and Pacific developing countries in technical and financial aspects as well as in infrastructure and capacity building for improving the access and use of climate information in decision making processes at all levels. The initiative has a M€ 85 funding from the 11th European Development Fund. One of the expected outputs of the initiative is a knowledge platform to exchange best practices.

Future Climate For Africa (FCFA)

Within FCFA, the HyCRISTAL project focused on the integration of hydro-climate science into policy decisions for climate-resilient infrastructure and livelihoods in east Africa. The project was implemented between 2015 and 2021. In Kenya specifically, the project supported the co-production of decision-relevant climate information and enabled on-going dialogue between providers and users of this information. For this, pilot projects focusing on urban Water, Sanitation and Hygiene systems, rural livelihoods, tea production and lake transport infrastructure were conducted.

Data assessment and analysis

Manual meteorological observations

Manned stations

Manned stations are equipped with a complete set of meteorological instrumentation following WMO standards. According to Figure 18, the volume of data received from the 41 manned stations in Kenya is not optimal and remains below 100%. The reasons for this vary, but include

- Delayed replacement of instruments. The procurement systems are unable to factor urgent repairs and maintenance
- Poor telemetry systems. Transmission of data is highly dependent on reliable internet. Downtimes with no local data storage will occasionally interrupt data transmission.
- Security concerns. A part of the KMD network operating in the northern part of the country occasionally encounter security concerns and are forced to downgrade their operations from 24-hr to 12-hr observations

These manned stations remain important for climate science and 13 of them share their data globally on the WMO Global Telecommunication System (GTS, now WMO Information System WIS2.0). These data are important in the development of datasets with global coverage, i.e. CHIRPS Rainfall Estimates from Rain Gauge and Satellite Observations. The manned stations provide ground truth of the Automatic Weather stations as well as satellite data.

The KMD observation network remains a key asset in the exercising of its national mandate. The support and maintenance of these stations remains a prioritized national development budget item.

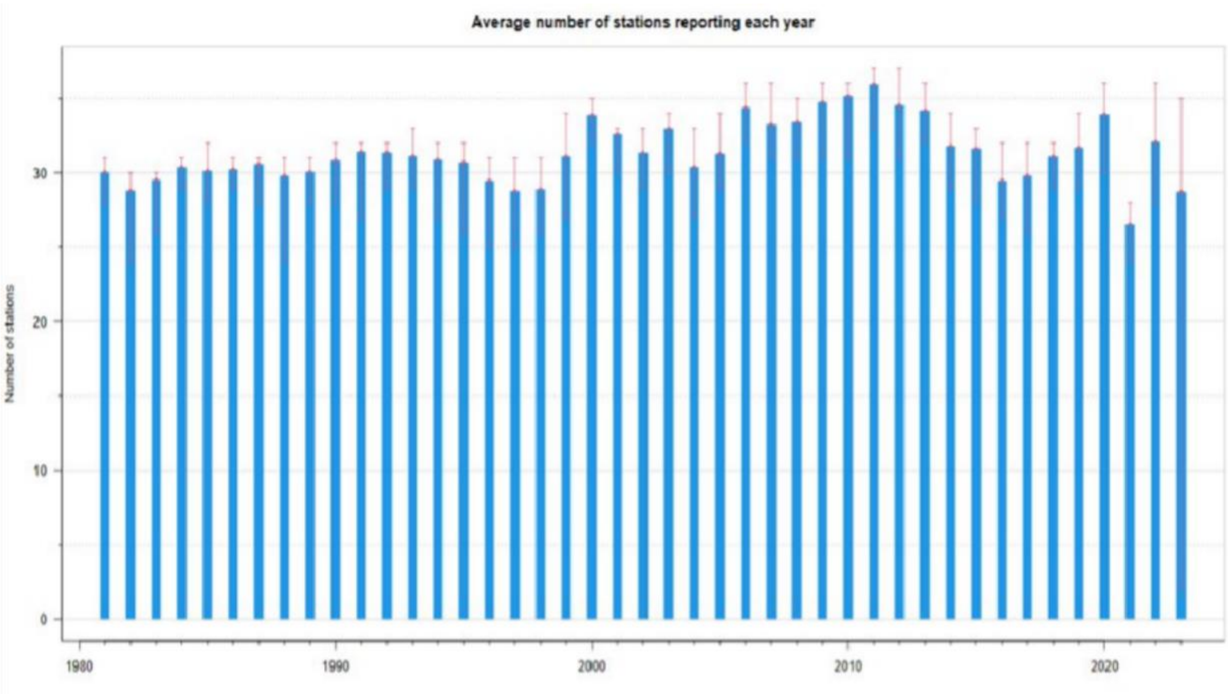


Figure 18. Manned stations reporting data to KMD.

Manual precipitation stations

As documented for the whole of Africa (cf. Figure 7), KMD has also experienced a tremendous decline in the number of officially active rain-gauge stations (cf. Figure 19), to the point where really only just a few are left and reporting. This gradual decline of rain-gauge stations has several reasons, but is mostly due to budgetary constraints in supporting the station network, lack of incentive and then a strategic shift towards automation. Key organizations that need weather (e.g., rainfall) data have continued to make these observations routinely to support their own organizations' mandate. Such organizations included: Kenya Forest Service, Kenya Agricultural Research Institute, Kenya Wildlife Service, Administrative offices such as Police posts, primary, secondary and tertiary institutions. Lack of clear data sharing protocols likely led to the reduced transmission of data to KMD. This has resulted to various institutions monitoring and archiving their own datasets pointing towards an essentially needed research infrastructure.

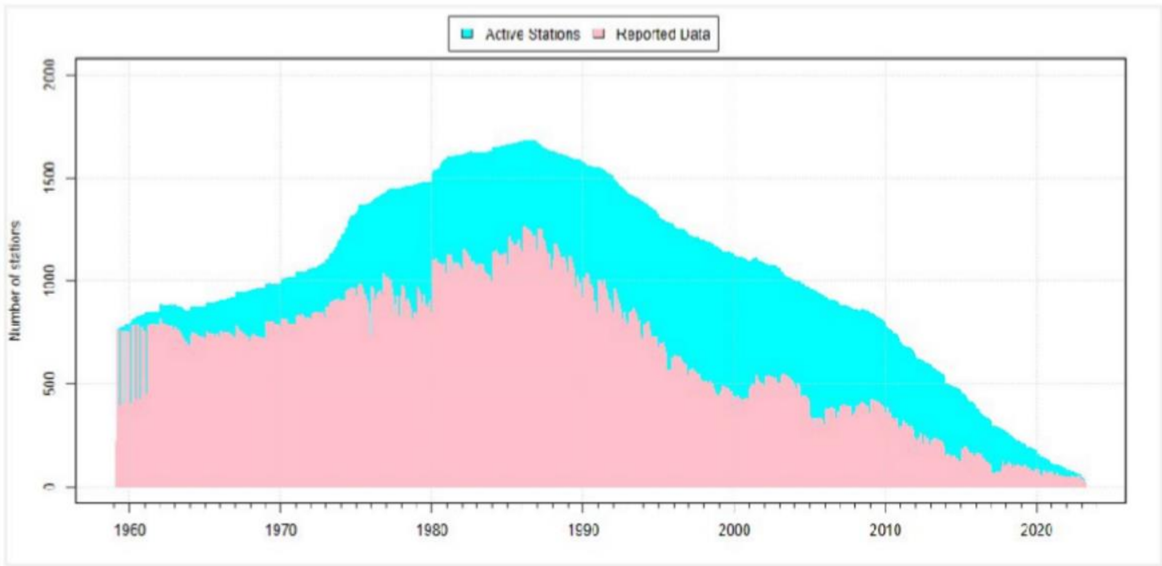


Figure 19. The number of manual rain-gauge stations in Kenya is in sharp decline since the mid 1980s. Some of this is decline is offset by the development of automated weather station networks. Source: KMD

Solar radiation measurements

KMD has operated radiation measurements and has submitted data for a number of stations and varying periods to the World Radiation Data Centre (WRDC). An overview is given in Appendix 1: Available Data: Tabular overview of available data. Shown in Figure 37 is the temporal evolution of the network. After a decline since the 1990s, today, 15 radiation observing stations are being operated throughout the country.

Automatic meteorological observations

KMD, through its Strategic Plan 2013-2017, embarked on an automation of her observation network. The first phase saw the installation of 36 Automatic Weather stations within the premises of the manual stations for validation purposes. This new venture had the advantage of increasing the frequency of observations for a number of observed parameters. The Strategic Plan 2018-2022 saw the advancement of this strategy. Through budgetary allocations and collaborations, KMD has since continued to improve its station network and offset the decline in capacity through the installation of automatic weather stations (cf. Figure 19).

Automatic weather stations also provided the advantage of direct ingestion into the data servers, bypassing the need to digitize observed data. While errors in transmission of observations are thus minimized, a new challenge with these automatic rain gauges is the absence of daily manual intervention. For example, if debris blocks the gauge, the reported amounts of precipitation can quickly become incorrect. This will often go unnoticed and represents a high risk for the quality of service for weather as well as climate applications.

Ecosystem greenhouse gas flux observations

Ecosystem greenhouse gas flux data are processed directly in the field since stations are equipped with embedded computers. However, additional data post-processing and the inclusion of a wide range of data QA/QC are needed. Data are then usually shared in available repositories (i.e. Fluxnet) and depending on the chosen data policy, freely available. The directly-in-the-field-processed data allow for remote evaluation of the measurements and are key to ensuring continuous data collection and quality. Potential troubles with instrumentation identified through remote data QA/QC checks can thus be detected and fixed. The open access data sharing policies allow for maximum use and greatest impact of the data for the benefit of society.

Atmospheric composition observations and services

Nairobi

Since 1996, the Nairobi ozone soundings have been part of the WMO GAW program and a contribution to the NASA SHADOZ program (cf. Figure 20). Numerous publications have demonstrated the importance of the SHADOZ network, and Nairobi is an important part of it, given its location on the equator. The observations primarily serve the validation of satellite products (Lee et al., 2010; Thompson et al., 2017a, 2021) characterizing the evolution of the stratospheric ozone layer, in support of the Montreal Protocol.

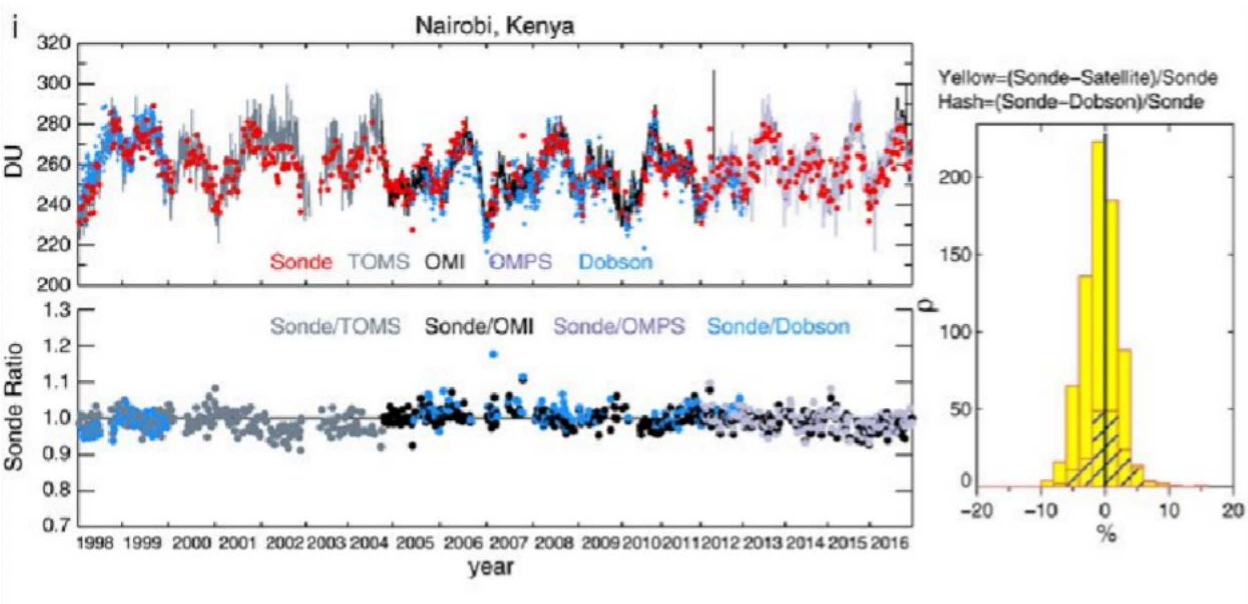


Figure 20. Comparison of sonde, total ozone and satellite products for Nairobi. Source: (Thompson et al., 2017b)

More recently, the station has also been used to host surface ozone and aerosol measurements, in support of WMO GAW and with an increasing focus on air quality and health related services.

Mt. Kenya

As described above (section Mount Kenya (0-20008-0-MKN)), the Mt. Kenya GAW station provides unique atmospheric composition measurements in the region. Since 2020, we have continuous measurements of carbon dioxide, methane, carbon monoxide, and surface ozone with high temporal resolution. These data can be used to investigate regional characteristics of the gases such as seasonal and diurnal variability. Furthermore, the measurements provide ground truth that can be used to validate satellite observations or atmospheric composition models. The following two examples highlight the importance of Mt. Kenya GHG measurements for modelling validation and for the region as a whole.

Figure 21 presents hourly averaged measurements at Mt. Kenya from 2020 to 2023 for the four mentioned gases and their seasonal variability. Besides the clear increase for CO_2 and CH_4, the figure shows region-specific variability in the seasonal cycle. The seasonal cycle of CH_4, for example, clearly reflects the hemispheric influences, with negative peaks when the ITCZ crosses the station (around May and October) and highest values when the influence of northern air masses is highest (approximately November to

February). Such observations are invaluable to validate regional changes in GHGs and their regional variability within a changing climate. The figure also illustrates the good agreement to CAMS modelling data, suggesting that the measurements are highly valuable for model validation in that region.

Due to its high altitude and central position on the African continent, measurements at the Mt. Kenya station are representing a large region. This is illustrated in Figure 22, showing the good agreement between CO measurements at Mt. Kenya and fire activity in the whole region.

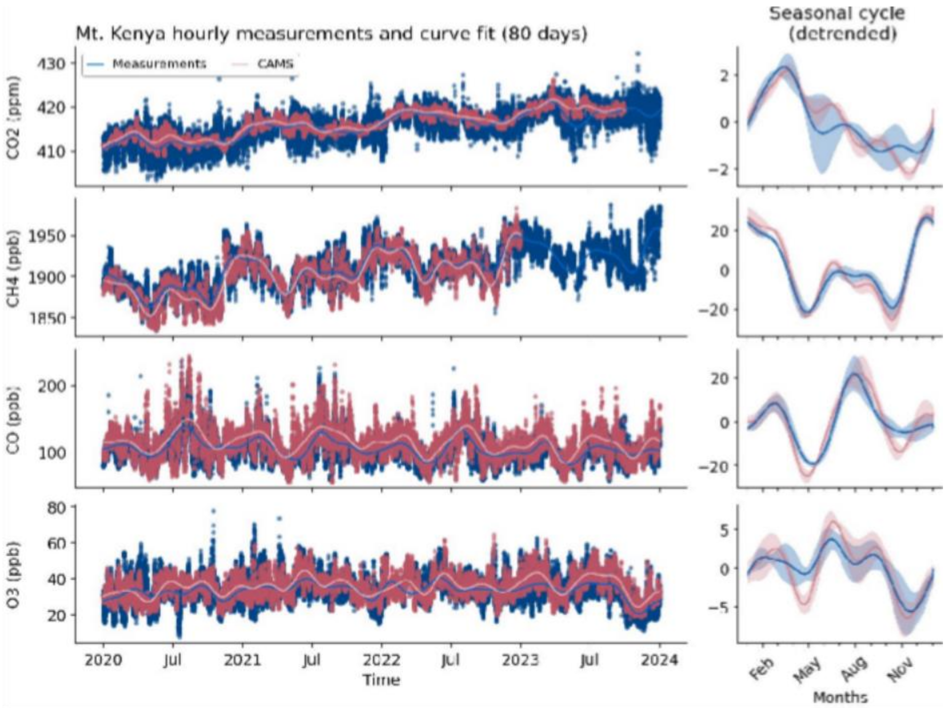


Figure 21. Hourly measurements of CO2, CH4, CO and O3 at Mt. Kenya (blue) and 3-hourly CAMS modelling data at a selected level (red). The brighter lines show a curve fit to the data using a smoothing of 80 days.

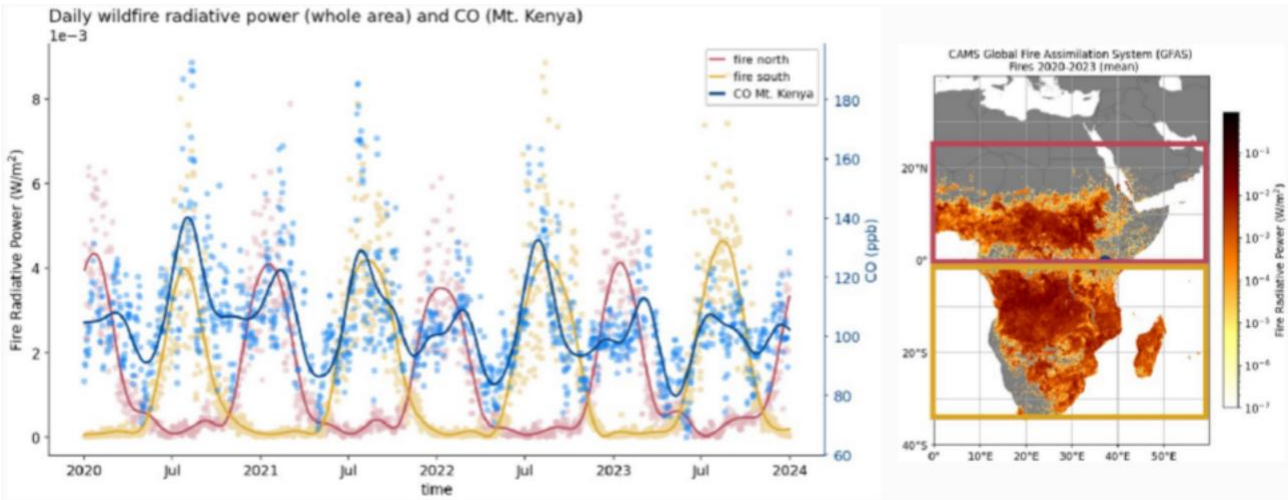


Figure 22 Fire radiative power from the GFAS product for regions north (red) and south (yellow) of the Mt. Kenya station. The time series of CO measured at Mt. Kenya is shown in blue.

The trace gas measurements at Mount Kenya are complemented by optical aerosol observations. The low wavelength dependence in the absorption indicates the presence of black as well as brown carbon

(Baumann, 2024). With regard to the SAE and the SSA, it can be said that the particles on MKN tend to be large and more scattering. In the future, the characterization of the particles and the possible causes must be investigated in more detail using other methods, as there are still many uncertainties. However, overall, the available observations from MKN demonstrate elevated values for SSA, the scattering and absorption coefficient compared to other high altitude measuring stations. This is most likely due to the overall higher particle load in the equatorial African atmosphere as a consequence of wide-spread biomass burning, both anthropogenic and natural.

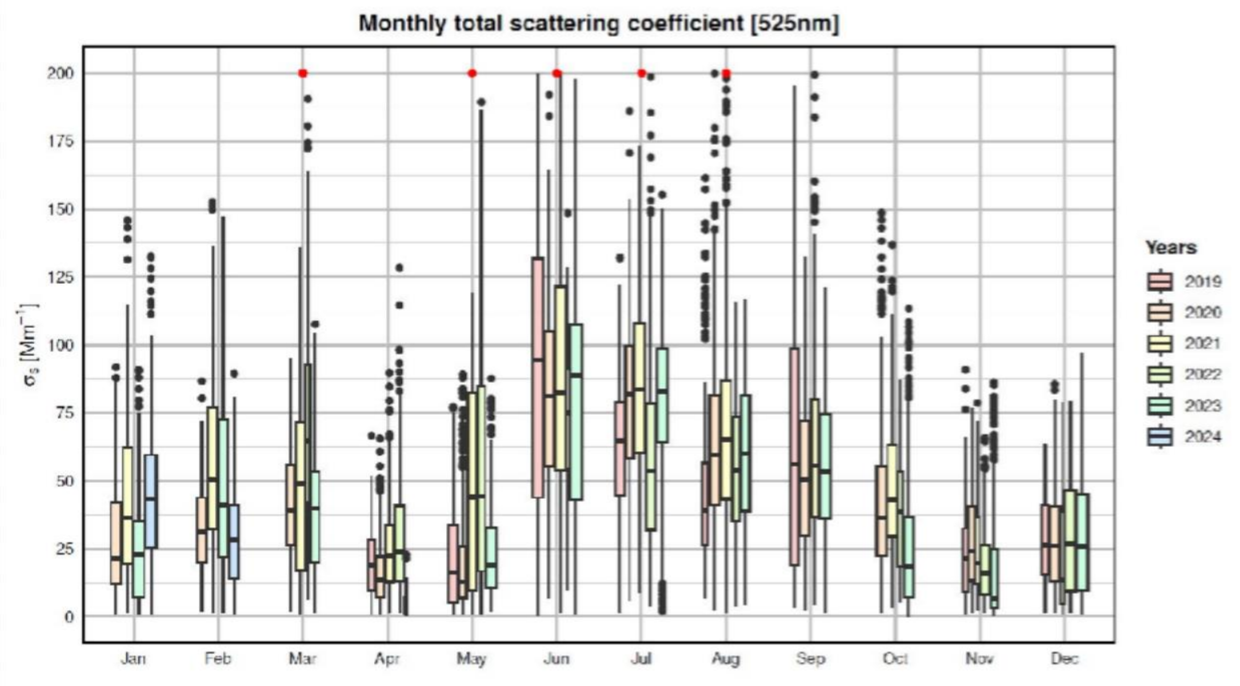


Figure 23. Monthly boxplots for the total scattering coefficient at 525 nm developed for each year. The boxplot statistics are based on hourly mean values.The width of the boxplots corresponds to the number of available data points.The dots represent extreme values, whereas those in red indicate those outside the range shown. Source: (Baumann, 2024)

Air quality monitoring in urban environments

Stockholm Environment Institute (SEI), in collaboration with the United Nations Environment Programme (UNEP) and the Kenya Meteorological Department (KMD), has undertaken significant efforts to enhance air quality monitoring and inform policy development in Kenya. The Air Quality Drivers for sub-Saharan Africa (AQD-Nairobi), was implemented between 2017 and 2018 to identify the factors influencing personal and community exposure to air pollutants in Nairobi. The project deployed various air quality sensors to assess pollution sources and levels. The data collected will provide valuable insights into the chemical composition of Nairobi's air, which is crucial for formulating effective mitigation strategies. Additionally, the project targeted local communities through citizen science initiatives, enabling residents to monitor air quality and understand their exposure to pollutants (West et al., 2019).

By integrating air quality sensors into KMD’s existing meteorological infrastructure, the Department’s ability to track air pollution trends in real-time and provide more comprehensive environmental data for decision-making has improved. A notable achievement of this strategy has been the integration of air quality monitoring at weather stations located at Kenya’s six international airports. This initiative enhances pollution surveillance in critical transportation hubs, ensuring a more data-driven approach to mitigating air pollution risks in high-traffic areas.

These collaborative efforts have not only enhanced the technical capacity for air quality monitoring in Kenya but also provided critical data to inform policy decisions aimed at improving air quality and public health. The integration of scientific research, community engagement, and policy development exemplifies a comprehensive approach to addressing air pollution challenges in urban settings. The UNEP-SEI partnership continues to play a vital role in advancing air quality governance in Kenya, fostering scientific research, and supporting policy development for cleaner air and healthier communities (cf. https://www.sei.org/about-sei/press-room/kenya-meteorological-department-begins-analysis-of-air-pollution-after-sensor-installed/).

Similarly, the capacity for air quality monitoring (ozone, particulate matter) was enhanced in the context of the Swiss-Kenyan GAW collaboration. In a project co-funded by the Swiss Academy of Sciences' Atmospheric Chemistry and Physics Commission, another 3 IQAir AirVisual sensors for particulate matter and CO2 observations were deployed at KMD's Nairobi Headquarter, in the city of Bomet and in the vicinity of a tea factory in Mogogosiek in 2023 (cf. https://www.iqair.com/ch/profile/vhu3die-f). Before deployment, these sensors were operated for several weeks in Switzerland, collocated with reference instruments to enable a solid assessment of their calibration and performance (cf. https://github.com/joergklausen/airvisual/blob/main/analysis.ipynb). At the KMD Headquarter in Nairobi, the sensor is collocated with reference instruments that should facilitate a long-term performance assessment of this particular 'low-cost' sensor in an urban environment. Collection and analysis of these data is ongoing.

These advances in deployed equipment for urban air quality monitoring provide important opportunities, however, they also increase the operational burden on the KMD. Even more than AWS, the instruments deployed need regular calibration and maintenance, as well as life-cycle replacement. The total cost of ownership is likely much higher than originally anticipated, and adequate use of the data (especially data of so-called 'low cost' sensors) requires a high degree of technical and scientific competence that is presently not sufficiently available.

User requirements and services

Stakeholder survey

An online survey was developed to document and assess weather, climate and atmospheric composition services using and/or providing such information via the platform SurveyHero (https://www.surveyhero.com/). The survey was set up to request agreement with the collection and use of name and organization of the respondents, in alignment with the EU's General Data Protection Rules (GDPR). According to GDPR Art. 4 (7) the KMD acted as the "controller" of the survey, whereas MeteoSwiss was the "processor" of the survey (according to GDPR Art. 4 (8)).

Whenever adequate, the questions were multiple choice with pre-populated answers for the respondents to choose from (multiple choice questions where a single choice had to be taken, checkboxes with the opportunity to choose multiple answers and linear matrices for evaluation). In all other cases, stakeholders had the opportunity to share their experiences in more detail via a text box. Most questions were not mandatory so that participants had the chance to participate voluntarily for each question. The exceptions were questions on whose answers further questions were based on.

The questionnaire started with the same general questions for all stakeholders (about organization, sector, area of interest, etc.). Thereafter, a distinction between stakeholders using and stakeholders providing weather, climate and atmospheric composition information was made. Stakeholders doing both (using and providing) all questions were made available. The questions for stakeholders using information contained general questions about the usage (purpose of using this information, decisions based on this information, use cases, type of information, information access, lead time, importance, etc.), the evaluation of the used information (accuracy, adequacy, timeliness, clarity, satisfaction, availability, suggestions for improvements), the willingness to pay for such information and specific questions to the usage of air quality information. Stakeholders providing information received general questions about the provision (type of information provided, to whom information is provided, how/ how often is information provided) and questions about a network if they had established or operate(d) one. The full questionnaire including responses can be found in **Appendix 2: Stakeholder Survey**.

Stakeholders with interests in energy, hydrology, agriculture, health, seasonal forecasting and now-casting were identified mainly by KMD, with some suggestions put forth by the other pilot partners. The stakeholders were contacted via e-mail co-signed by the general director of KMD and MeteoSwiss. For this, a KADI survey email address was created (kadi-survey@mail.icos-cp.eu). The survey was widely disseminated to 111 stakeholders in mid-July 2023. The deadline for response was set to three weeks after receipt of the invitation. After 3 weeks, a reminder with an extension of the deadline by 2 more weeks was sent. Stakeholders identified at a later stage of the pilot still had the opportunity to participate in the survey (this was the case for 57 stakeholders).

The stakeholder survey was followed up with a face-to-face validation workshop attended by 31 individual survey respondents and 25 additional participants.

Survey results

Not all of the 106 respondents of the survey completed all questions. The user-oriented section was completed by about 65 respondents. Of the respondents, 26 identified themselves as data providers. Based on the identity of the respondents, government organizations remain the highest consumer of climate information (Figure 25 A). Of course, this result may be biased due to the fact that a government organization, specifically KMD, was also responsible for compiling the list of stakeholders who were subsequently addressed.

The user perspective

There were varied responses on the type of climate data and information that the respondents used. Emerging uses include that of model data as well as remote sensed data which is currently not shared by KMD (cf. Figure 24). This points to the emerging need and use of regional and global data sets.

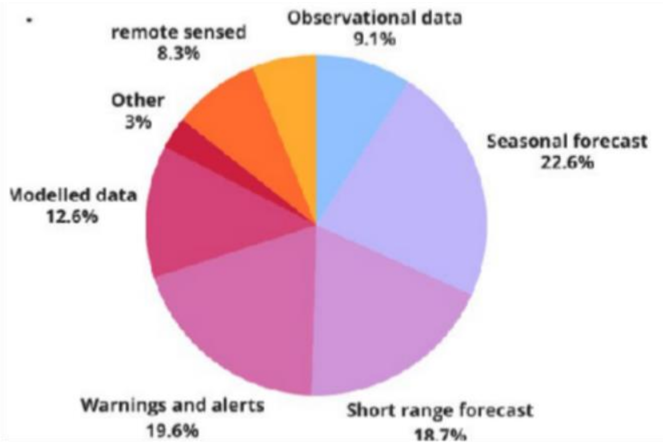


Figure 24. Type of information used according to the stakeholder survey

General responses on weather, climate, and atmospheric composition information

Weather, climate, and atmospheric composition information are used across multiple sectors for planning, management, and decision-making (Figure 25 C). Dissemination to the public and targeted user groups and research were to two pre-dominant uses cases. In infrastructure and engineering, it informs the design of roads, highways, bridges, and water infrastructure while ensuring regulatory compliance. Forestry and agriculture rely on this data for forest management, tree planting preparation using rainfall data, and fire management based on temperature trends. It supports disaster management by aiding in early action planning and anticipatory responses. The energy sector uses weather forecasts to manage energy demand and optimize renewable energy generation. In education and research, it plays a role in environmental conservation, academic studies, and data validation. Aviation benefits from this information for air navigation services and operational safety. Governments use it for informed decision-making at the county level, ensuring effective policy implementation. Additionally, it is shared with farmers to improve agricultural planning and productivity. Overall, weather and climate data support sustainability, safety, and efficiency across industries.

An improvement of weather, climate, and atmospheric composition information can be achieved through enhanced accuracy, timeliness, and accessibility. There is a need for more frequent updates, including weekly climate reports and hourly weather updates, to improve reliability and early warning systems. More localized data, including additional point/station observations and improved resolution, would help reduce the generalization of forecasts. Accessibility should be improved by providing data in simpler language, making it visually appealing, and disseminating it through apps, social media, and local media channels. Real-time sharing and better interoperability, including FAIR principles (improved Findability, Accessibility, Interoperability, and Reuse of digital assests) and web APIs, would enhance data usability. Specific user needs, such as tailored information for different sectors and clearer forecasting icons and terminology, should be addressed. There is also a demand for more marine and atmospheric pollution data, as well as improved collaboration between stakeholders to ensure co-implementation of projects. Free and easier access to data, including automated weather station outputs, would aid planning and decision-making. Additionally, forecasts should be available during national holidays and should highlight specific areas of impact. Overall, improvements should focus on making data more relevant, accessible, and actionable for diverse users.

Easier integration of weather, climate, and atmospheric composition information into decision-making processes requires improved accessibility, accuracy, and timeliness. Many respondents emphasized the need for real-time data sharing, automated weather stations, and advanced data integration systems for seamless use in decision-making. Accessibility improvements include open access portals, FAIR data principles, web APIs, and digital formats such as NetCDF and raster/vector data. Clearer communication through simpler language, improved terminology, visually appealing presentations, and local dissemination via social media, SMS, and traditional media would enhance usability. Users also highlighted the importance of affordability, with calls for free or low-cost weather data for infrastructure planning and agriculture. Reliability, consistency, and sector-specific tailoring of data—such as irrigation planning and carbon cycle monitoring—are crucial. The availability of targeted updates, including region-specific forecasts and impact-based information, would enhance decision-making efficiency. Training on data interpretation, terminology, and modern analysis tools would empower users to apply the information effectively. Collaboration between organizations, formalized through partnerships or MOUs, would facilitate data sharing and co-implementation of climate projects. Overall, decision-makers require timely, user-friendly, and actionable weather and climate data to optimize planning and response strategies.

To better fulfill their mandates, respondents require additional observations and products that enhance accuracy, relevance, and accessibility. Many highlighted the need for more granular, real-time, and long-term climate data, including soil temperatures, riverine flood forecasts, and extreme event predictions. Improved atmospheric composition monitoring, including air pollution levels and greenhouse gas emissions data, is essential for environmental and health-related applications. Marine and coastal data, such as sea surface temperatures, sea level rise, tides, and wave data, would support ocean monitoring and mangrove forest management. Sectors like agriculture and infrastructure require historical and predictive climate data to optimize decision-making, including agro-ecological modeling, crop suitability analysis, and climate-resilient infrastructure planning. There is a demand for financial risk assessment data, including granular datasets for stress tests and scenario analyses. Renewable energy stakeholders need detailed wind profiles, turbulence data, and solar radiation measurements for optimizing energy production. Some respondents emphasized the need for improved forecast communication, including better terminology, tailored advisories for specific communities, and multi-channel dissemination strategies. Integrated modeling tools combining meteorological and carbon cycle data would aid in tracking carbon fluxes and climate impacts. Overall, enhanced accessibility, modernization of data collection methods, and more tailored, sector-specific forecasting would significantly improve decision-making across various fields.

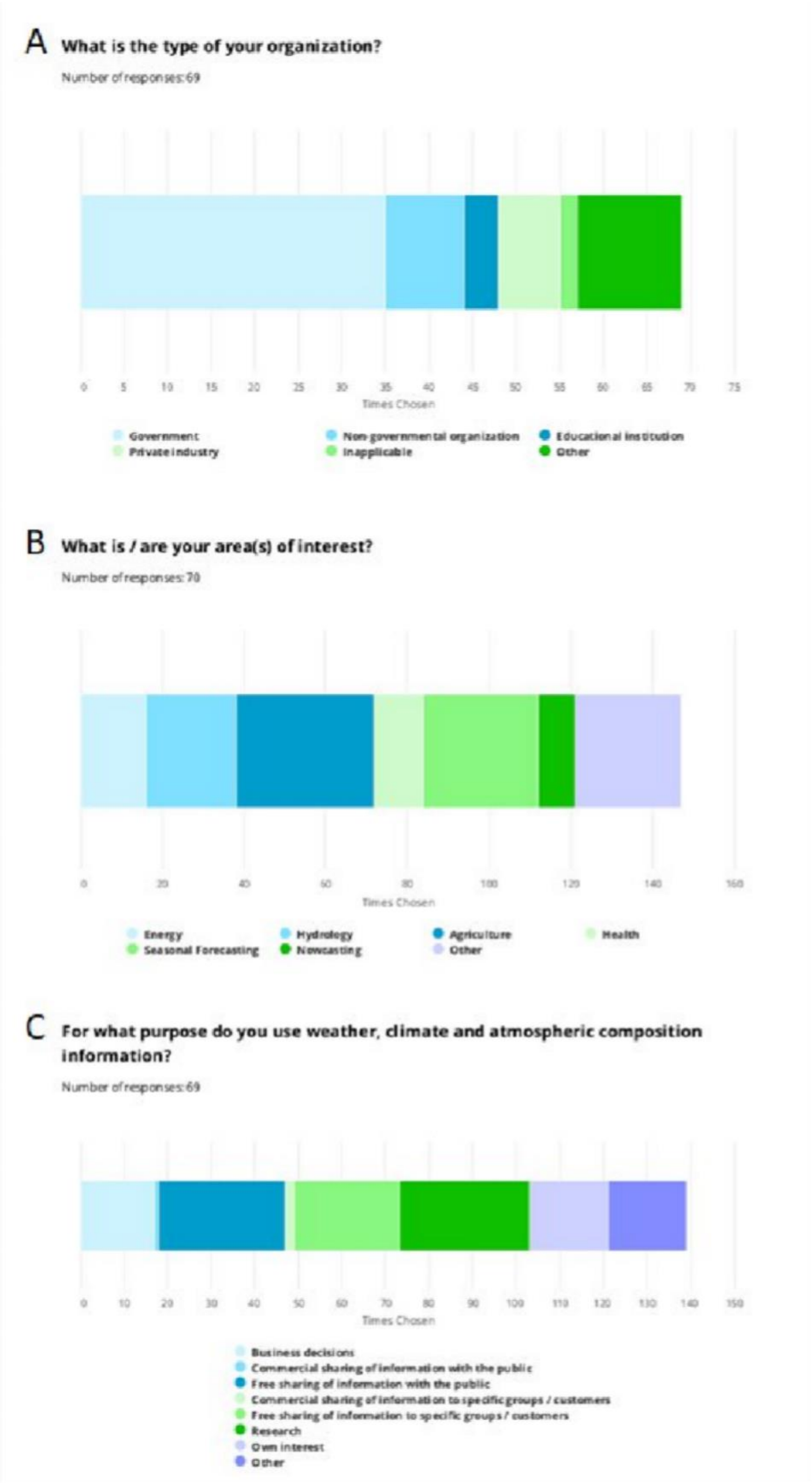


Figure 25. High-level questions and responses from the online stakeholder survey.

With a view to long-term sustainability of existing and future services, users were also asked to range their willingness to pay for weather, climate and atmospheric data and information. Not unexpectedly, this , willingness to pay for climate information remains moderate to very low (Figure 26 A). Of those who are willing to pay, private customers and companies represent 56% of the user base (Figure 26 B). It is very unclear how robust this result is, but it may open up avenues for partial cost recovery. It can be assumed that the willingness to pay for customized services and value-added products is markedly higher than for the basic (observational) data, though.

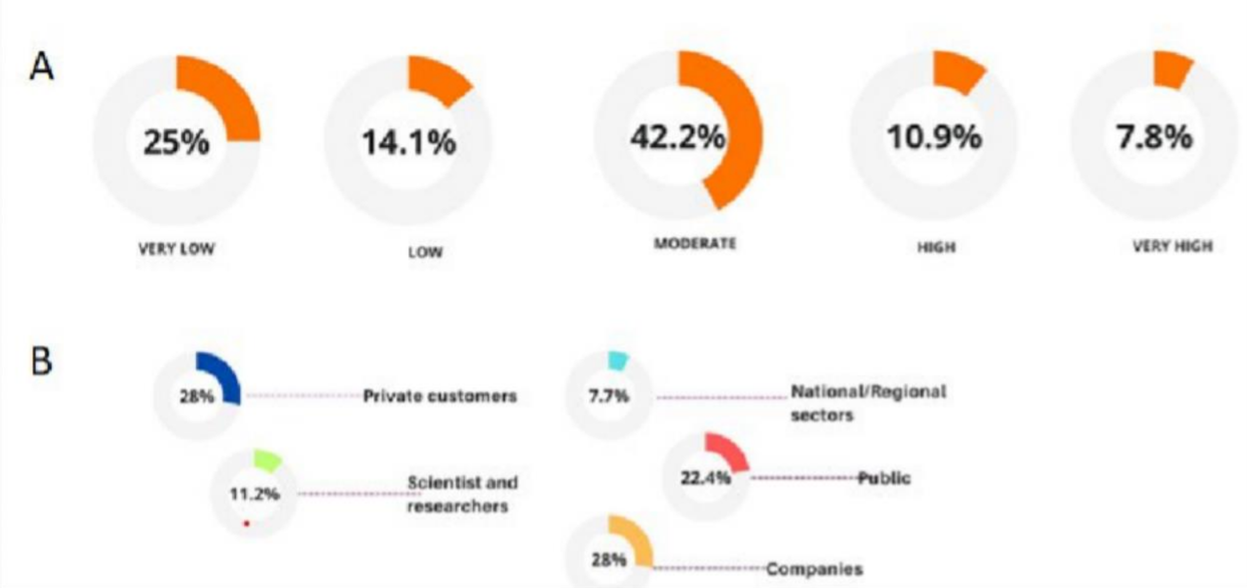


Figure 26. Willingness to pay for climate information (A) and sectoral differentiation of those willing to pay (B). source: Appendix 2: Stakeholder Survey

Specifics on air quality information

Air quality information is used for a variety of purposes across different sectors, including research, policy development, compliance monitoring, and environmental management. Many respondents rely on air quality data to assess greenhouse gas emissions, estimate carbon sinks, and support Kenya's commitments under the Paris Agreement. Research institutions use air quality information to study localized pollution phenomena, monitor climate change impacts, and develop integrated hazard maps. Organizations involved in infrastructure and construction monitor air quality to ensure their operations do not contribute to excessive pollution, particularly during material extraction and roadworks. In the energy sector, dispersion modeling is used to assess the impact of geothermal power plants on local air quality. The agricultural sector utilizes air quality data to evaluate the effect of pollutants on irrigation water quality, tea production, and vegetation health. Some respondents highlighted the importance of air quality information for early warning systems, public awareness campaigns, and resilience planning. Financial institutions and consultants use air quality data for risk assessments and compliance with environmental regulations. Additionally, air quality monitoring informs urban forestry efforts, helping determine tree species best suited for air purification. Compliance with international standards, such as ICAO Annex 16 on civil aviation emissions, was also mentioned as a key use case. Overall, the data plays a crucial role in decision-making across multiple domains, from environmental conservation to industrial regulation and climate adaptation planning.

On a scale from 1 (not important at all) to 5 (very important), the timeliness of this information was gauged important to very important (4.4, standard deviation: 0.8) (cf. Appendix 2: Stakeholder Survey).

The provider perspective

The survey was addressed mostly to stakeholders outside KMD. The responses received were useful, but clearly do not reflect a holistic view on data provision of weather, climate and atmospheric information in Kenya. At present, KMD is by far the most relevant provider of such information.

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Lessons learned and Conclusions

Lessons learned from dissemination and collaboration activities

Dissemination of climate information

Timely dissemination of weather observations is essential in decision making. The KMD has improved its dissemination capabilities through use of emerging technologies including social media. It is also continually increasing its user base through the website, use of short messaging services and portals such as Maproom (see Section Enhancing National Climate Services (ENACTS)). The KMD also releases an annual "State of Climate" publication that seeks to document a comparative analysis of a year's performance versus the climatological normals. This publication aims to incorporate a study of as many weather parameters as possible.

However, the data policy of KMD at present is not an open data policy which prevents easy data sharing with private or other data providers outside KMD. Moreover, most of the data collected by KMD qualify as 'core data'. For these, a restricted data policy is in disagreement with the WMO unified data policy. Numerous studies have shown that open data policies improve the FAIRness of data and increase their socio-economic value (cf. Figure 27).

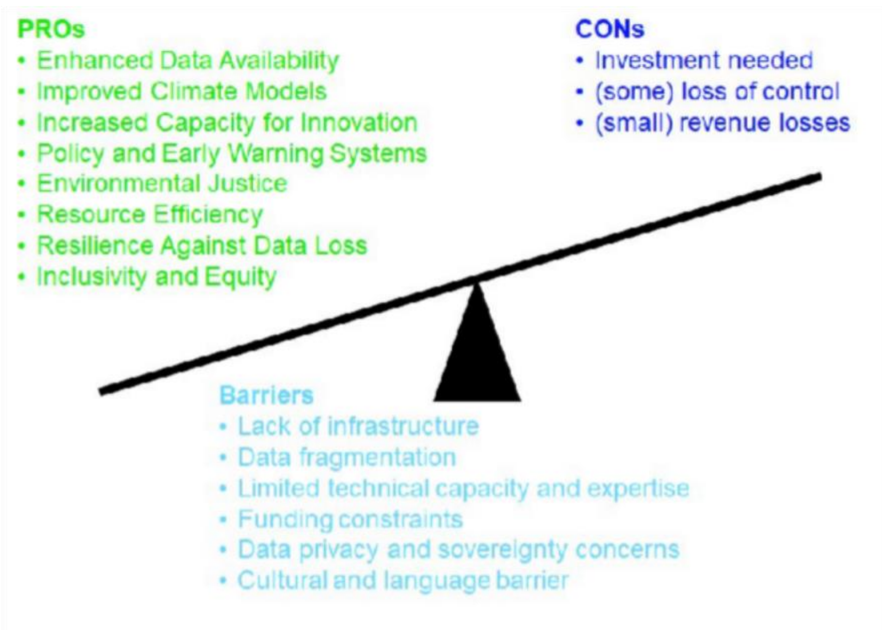

Figure 27. On balance, the pros of FAIR (improved Findability, Accessibility, Interoperability, and Reuse of digital assets) data sharing clearly outweigh the cons. Source: (Klausen et al., 2024)

Collaborations

KMD understands that climate is a cross-cutting topic with linkages to social and economic dimensions. With a main mission to improve the uptake of national climate services, the department prioritizes coordination and engagement mechanisms between countries, actors and stakeholders along the country's climate services value chain. Over the years, there have been successful collaborations with organizations and through projects focussing on observations networks and monitoring systems, user interface platforms, research, modelling and prediction, climate services information systems, and capacity building. The long standing collaboration between MeteoSwiss and KMD is a success story of benefits accruing from partnerships.

National Framework for Climate Services

Kenya Meteorological department, through its mandate is documenting effects of climate change through the monitoring of weather parameters and production of forecasts. This has become a crucial role given the threats and the negative impacts of climate variability and change that risk stifling sustainable development for the country. The role of stakeholders in partnering to co-designing climate information is crucial now more than ever. For effective coordination, KMD with the support of WMO, GOK and stakeholders developed the National Framework for Climate services (NFCS). The NFCS provides institutional mechanism to coordinate, facilitate and strengthen collaboration among national institutions to improve the co-production, tailoring, delivery and use of science-based climate information and services, particularly in the climate sensitive sectors including agriculture, livestock and food security, Disaster Risk Management (DRM), health, among others . The Cabinet Memo on the NFCS was approved in 2024 and the launch is planned for 2025.

Robust and efficient atmospheric observations as available for Mt Kenya are a collaborative effort. KMD has over the years leveraged on the support of the international and regional agencies for technical and financial assistance. The enactment of the National Framework for Climate Services including the costed action plan confirms the Government's commitment to supporting the entire value chain of climate information services.

Lessons learned from meteorological observations

Climate information depends on monitoring and analysis of climate data.

There have been marked improvements on the KMD station network with the inclusion of Automatic Weather Stations (AWSs) complementing the manual station network. KMD is also partnering with its stakeholders in efforts to improve the station network. The aim is to have at least 2400 automatic weather stations by 2030. An improved station network will among others

- Improve the accuracy of forecast products,
- Enable the monitoring and analysis of all weather parameters,
- Support diverse decision making and research of emerging issues.

Advancing the use of AWSs has already greatly improved the network of atmospheric observations. This, though has not been without challenges. Challenges experienced from when KMD embarked on the strategic decision to automate its observations are multifaceted; both technical and administrative. Most privately held AWS sites did not adhere to the recommended setup by the World Meteorological Organization (WMO) and lack skilled personnel to handle the maintenance and calibration of AWS.

Given the diverse AWS systems and networks, arising from the installation of various types of AWS from different vendors and stakeholders, there has been an issue of conflicting data sharing protocols leading to insufficient useability of the observed data. Multiple AWS systems from different suppliers gather data in different formats and use different servers for storage.

Other issues include inadequate calibration, limited availability of spare parts, inconsistent maintenance due to a lack of expertise in AWS station maintenance, and inconsistent instrumentation. As to the information on the KMD observation network, its exact and current operational status is still not clearly known. Some of the components of the observation network are non-functional or obsolete and may require repair or replacement. AWS could be non-functional due to a variety of issues, ranging from minor to major in severity. Minor issues encompass insufficient airtime data bundles, inappropriate IP address pointing, faulty batteries, impaired or fractured connections, sensors, and solar panels. These can be rectified by changing the required spare components and resetting the system. Major problems, such as inadequate security, improper siting, and faulty data loggers, may necessitate a higher financial investment, perhaps including the need to relocate.

A complex procurement process, which presents difficulties in the drafting of specifications, is an obstacle, especially for procurements within project initiatives. Insufficient or non-existent allocation of funds for operation and maintenance are a serious impediment for long-term quality-assured data services.

The introduction of the 3D-PAWS AWS addresses some challenges, as they are fabricated in-house, using recycled material, with trained technicians, converting the function of KMD from a procurement agency to an operational entity. Initial field tests of these low-cost AWS are promising. However, 3D-PAWS AWS serve a limited number of use cases, and it is not yet proven if they can be considered a replacement for the more commercial AWS on the market in terms of long-term viability, accuracy and precision.

Lessons learned from ecosystem greenhouse gas observations

Monitoring GHG emissions in four contrasting ecosystems – farmland (Maktau) and shrubland (Choke), rangeland (Kapiti), cropland (Ausquest) – has been ongoing since 2018. A wide variety of successes and challenges occurred across the four observation sites. A snapshot of these are provided here.

Successes:

1. Pioneering GHG Monitoring in East Africa: Establishing flux towers in under-monitored regions is a significant milestone, filling a critical gap in global datasets.
2. Strong landowner partnerships: Cordial relationships with landowners have ensured equipment security. Sharing rainfall data has further strengthened these collaborations.
3. Capacity Building: Recruitment and training of Kenyan personnel in flux tower maintenance, repair, and data analysis is ongoing.
4. International Recognition: Efforts are under way to publicize the stations and integrate them into global networks like Fluxnet and ICOS, enhancing their visibility and impact.

Challenges:

1. Solar Power Outages: Prolonged cloudy periods challenge even well-designed solar systems, leading to unforeseen data gaps.
2. Damage by nature: Wild animals, such as elephants in Choke, damage instruments like lysimeters and flux station fences, often using them as scratching posts.
3. Poor Internet Connectivity: Remote locations lack reliable connectivity, complicating real-time monitoring and data archiving.
4. Frequent Physical Visits: Regular site visits are necessary for maintenance and repairs, increasing logistical demands.

5. Limited Local Expertise: Kenya lacks experienced field technicians for handling eddy covariance flux towers, creating a skills gap.
6. Vandalism & theft: Instrumentation was damaged by individuals out of curiosity (cables in the soil) and theft (particularly during the COVID-19 pandemic when less field visits were possible). This led to data gaps and reinvestment in instrumentation.
7. Data Gaps and Gap Filling: Rainfall pulse-driven ecosystems pose significant challenges for gap-filling due to non-linear relationships between fluxes and environmental variables, restricting the study of critical timelines.
8. Sensor Calibration: Sensor maintenance requires international shipping for calibration and repairs, while the unavailability of standard calibration gases locally adds to the difficulty.
9. Extended Downtime: Prolonged instrument breakdowns result in data losses that cannot always be resolved through gap-filling.
10. Publishing Challenges: High-impact journals often prioritize data from globally recognized networks like ICOS or FLUXNET, making it difficult to publish findings from isolated sites. Moreover, publishing data from 1-2 sites is difficult yet field measurements and field data analysis (gap-filling studies) are needed to advance the data processing routines for arid ecosystems and the subsequent understanding of the functioning of the ecosystems.

Lessons learned and recommendations for future monitoring:

1. Ensure long-term funding and give planning security to the employed staff - similar to atmospheric observations
2. Continuously train staff beyond simple technical fixes but to understand the purpose and importance of the measurements
3. Prioritize station security, especially in remote areas, by situating them in secure locations and maintaining strong relationships with landowners.
4. Implement cloud-based data storage to prevent data loss.
5. Budget for local capacity building for installation, maintenance, and data analysis, ensuring local expertise.
6. Adhere to international standards in station setup, data collection, and analysis methods.
7. Use a hybrid power system combining mains electricity and solar for reliability.
8. Encourage the employed staff to analyse the data themselves, introduce them to the community and network of climate change scientists.

Lessons learned on capacity building for long-term observations

Long-term surface-based measurements are needed for understanding atmospheric and ecosystem behaviour in the tropics, and they are invaluable complements to satellite observations. To resource them is a perennial struggle.

Capacity development and knowledge transfer has to be continuous, often multi-decadal, and equitable to address requirements and secure sustainable operations. In many developing countries, academic education is often too theoretical, with a lack of providing practical experience. The reason for this may be found in outdated pedagogical concepts, but all too often, the reason is more mundane: a lack of financial resources to buy equipment, combined with a fear of destroying it during its use. One result of this is an almost impermeable barrier between technicians/operators (don't touch data) and scientists/ meteorologists (don't touch instruments). This severely limits the capacity of an organization to maintain long-term observations, and/or to move beyond simple technical support functions towards data/science-related tasks.

Experience has shown that a number of recurring factors determine the success or failure of building up sufficient capacity in an organization (or country) to sustain long-term monitoring. The success factors include

- a firm mandate of the organization for the activity, e.g. for greenhouse gas or air quality monitoring, ideally based on some national legislation. If this is not the core activity of the organization, a solid commitment of higher management is mandatory.
- a base level of financial/human resources to access and maintain infrastructure. It is important to realize that total-cost-of-ownership includes life-cycle replacement of equipment (depreciation).
- motivated, sufficiently trained staff, and the organizational processes to ensure a sound hand-over when rotating staff to avoid loss of existing scientific and engineering capacity
- solid partnerships involving mutual commitment with like-minded, experienced organizations. Engagement with several stakeholders for operations and scientific exploitation, and clear statements of ambitions and expectations, roles and responsibilities help provide stability and foster relationships of mutual trust. Reliance on a single foreign organization for funding is a high-risk and should not be the long-term perspective.
- open data sharing with clear rules of conduct and quid-pro-quo reciprocal exchange of data and services increase data use and with it, the quality and value of the information. In many countries, publicly funded data are still restricted and part of revenue streams, although many studies have shown that this is rarely economical and the benefits of open data outweigh the cons (cf. Figure 27). To overcome this severe impediment, national regulations and revenue models of government agencies must change.

On the flip-side, obstacles for the long-term success of capacity building are easily identified and include

- lack of consumables and/or spare parts
- lack of a dedicated budget line, and/or lack of financial authority for operators
- hierarchy issues within the organisation
- unclear responsibilities within an institution and among the partners
- (long-term) commitment of the partners to the operations
- missing mandate in/of the organisation for scientific analyses, preparation of elaborated products, services etc.
- insufficient technical and scientific know-how, fluctuation of staff
- difficulty of engaging young talents and to keep them engaged on a long term
- distance to the headquarters (especially for remote monitoring locations)
- language/jargon barriers (use of different terminologies)

Conclusions

This report highlights the essential role of long-term observations and the need for research infrastructures, open data sharing, institutional capacity, and international partnerships in strengthening climate and atmospheric services in Africa. The key conclusions include:

1. **The Role of National and International Partnerships:** Sustainable atmospheric, climate and ecosystem observations and services that foster socio-economic development must rely on national partnerships. International projects like KADI can stimulate existing and trigger new partnerships and direct collaboration among national and international institutions. Successful collaborations, such as those between MeteoSwiss and the Kenya Meteorological Department, illustrate the benefits of international cooperation in building capacity and improving climate services. However, excessive reliance on external funding poses a risk to the long-term sustainability of climate observation networks.
2. **The Need for Research Infrastructures**: Long-term atmospheric, climate, and ecosystem observations are crucial for effective climate and ecosystem services. Additional services that emerge from long-term continuous observations include training opportunities for young and experienced researchers and technicians. Similarly, the stations and data are often the base for gaining academic qualifications (MSc, PhD etc.). Furthermore the stations are platforms for intensive courses such as summer schools that aim at generating a critical mass of well-trained experts that are indispensable for long-term sustainable operations. Today, Africa lacks a well-integrated and sustainable environmental research infrastructure, leading to fragmented data collection efforts and limited understanding of critical climate processes.
3. **Challenges in Open Data Sharing**: While open data policies have been shown to enhance the FAIR (Findable, Accessible, Interoperable, and Reusable) principles and increase the socio-economic value of climate data, many national meteorological services still enforce restrictive data policies. This hinders collaboration amongst governmental institutions and academia and the co-development of climate services for the benefit of socio-economic development.
4. **Institutional Capacity and Sustainability**: Effective climate observation requires stable funding, trained personnel, and infrastructure maintenance. However, climate monitoring efforts and services face difficulties due to resource shortages, affecting the reliability and continuity of observations and other challenges such as staff rotation or loss, lack of technical expertise, and inadequate institutional frameworks.
5. **Policy and Coordination Efforts**: The development of frameworks like Kenya's National Framework for Climate Services (NFCS) is a positive step toward better coordination among stakeholders. Such frameworks help facilitate data sharing, improve service delivery, and align national climate policies with international standards.
6. **The Nexus of Climate, Air Quality, and Health**: Air quality is a critical but often overlooked component of climate and health research. Initiatives like the UNEP-SEI partnership in Kenya demonstrate how integrating air quality monitoring into meteorological networks can enhance pollution surveillance and inform public health interventions. Expanding such efforts across Africa will be vital for improving the availability of relevant datasets, mitigating air pollution risks and addressing climate-related health impacts.
7. **Importance of Equipment Calibration, Maintenance, and Renewal**: Ensuring high-quality atmospheric and climate data requires regular calibration, maintenance, and timely replacement of ageing or faulty instruments. Many observation networks in Africa suffer from inadequate

calibration, inconsistent maintenance, and limited spare parts, leading to data gaps and inaccuracies. A lack of financial planning for life-cycle equipment replacement further jeopardizes data continuity.

8. **The Need for Reference Instrumentation Alongside Low-Cost Sensors**: While low-cost sensors and innovative technologies like 3D-printed automatic weather stations (AWS) and compact air quality sensors offer promising alternatives, they are not a substitute for high-precision reference instrumentation. Low-cost sensors require rigorous validation and often do not provide the necessary long-term stability and/or sensitivity. Thus, their integration should complement, rather than replace, traditional monitoring networks to ensure reliable long-term climate and air quality data.

In summary, strengthening climate, atmospheric and ecosystem services in Africa requires substantial investment in observation and research infrastructures, policy changes to promote open data sharing, capacity-building efforts, and sustained international partnerships. Addressing these gaps will enhance the region's ability to respond to climate challenges and support sustainable socio-economic development.

KADI

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Appendix 1: Available Data

Tabular overview of available data as of December 2024

World Data Centres (WDCs) for Atmospheric Composition serve as central repositories for vast amounts of data related to aerosols, reactive gases, greenhouse gases, and atmospheric trace gases. These specialized data centres play a crucial role in collecting, curating and disseminating atmospheric composition data from various monitoring networks, satellite observations, and research projects across the globe. In the following, the available data for Kenya in the WDCs is summarized.

Data centre	Variable(s)	Contributor	Availability	Station	Miscellaneous
World Data Centre for Greenhouse Gases (WDCGG)	CO_2, CH_4, N_2O, SF_6, $^{13}CO_2$, $C^{18}O_2$, CO	KMD, NOAA	2004-Jan. 2011	Mt. Kenya (MKN)	event-based
	CO_2, CH_4	KMD, Empa, MeteoSwiss	2020- 2023	Mt. Kenya (MKN)	1h resolution
World Data Centre for Aerosols and Reactive Gases (WDCA, WDCRG)	CO, O3	KMD, Empa, MeteoSwiss	June 2002 - May 2006, 2019-2023	Mt. Kenya (MKN)	1h resolution
	p, RH, T, wind direction, wind speed	KMD	June 2002-May 2006	Mt. Kenya (MKN)	1h resolution
	2-methylbutane, 2-methylpropane, ethane, n-butane, n-pentane, propane	KMD, NOAA	June 2006 - June 2011	Mt. Kenya (MKN)	12d resolution
	aerosol_light_backscattering_coefficient, aerosol_light_scattering_coefficient, p, T	KMD, PSI, MeteoSwiss	2015	Mt. Kenya (MKN)	1h resolution
World Radiation	Global Radiation,	KMD	1966-1993	Mandera, Kitale,	

Data Centre (WRDC)	sunshine duration			Nakuru, Narok	
			1965-2003, 2006-2007	Lodwar	
			1973-1993,1998,2006	Eldoret	
			1964-1994	Garissa	
			1967-1993	Kisumu	
			1967-1974	Nanyuki	
			1965-1973	Muguga	
			1964-1993	Nairobi / Dagoretti Corner	
			1969-1993, 1995-1998, 2000, 2003, 2006-2007	Nairobi / Kenyatta Arpt	
			1971-1980	Lamu	
			1967-1990	Malindi	
			1964-1968, 1973-2003, 2006-2007	Voi	
			1964-1983, 1990-1993	Mombasa / Moi Arpt	
	Global Radiation, diffuse Radiation	KMD	2002-2007	Mt. Kenya (MKN)	Hourly, daily, monthly
World Ozone and Ultraviolet Radiation Data Centre (WOUDC)	Total Ozone	KMD	1984-1999, 2005-2012	Nairobi	daily
	Ozone Sonde	KMD	1996-2017		weekly
	Ozone Sonde	KMD	1999-2006	Malindi	event

	UV Irradiance Broadband	KMD	2017-2020		
Climate Monitoring and Diagnostics Laboratory (NOAA-CMDL)	CO_2, CH_4, CO, H_2, N_2O, SF_6, $d^{13}C(CO_2)$, $d^{18}O(CO_2)$		December 2003 – June 2011	Mt. Kenya MKN	
	CH_3Cl, C_2H_6, C_2H_4, C_3H_8, C_3H_6, i-C_4H_{10}, n-C_4H_{10}, i-C_5H_{12}, n-C_5H_{12}, n-C_6H_{14}		February 2006 – June 2011		
	C_6H_6, C_7H_8, C_5H_8, C_2H_2		September 2008 – June 2011		
Southern Hemisphere ADditional OZonesondes (SHADOZ)	Ozone profile	GAW Ozone program, KMD	1998-2023	Nairobi	weekly

Graphical overview of available data

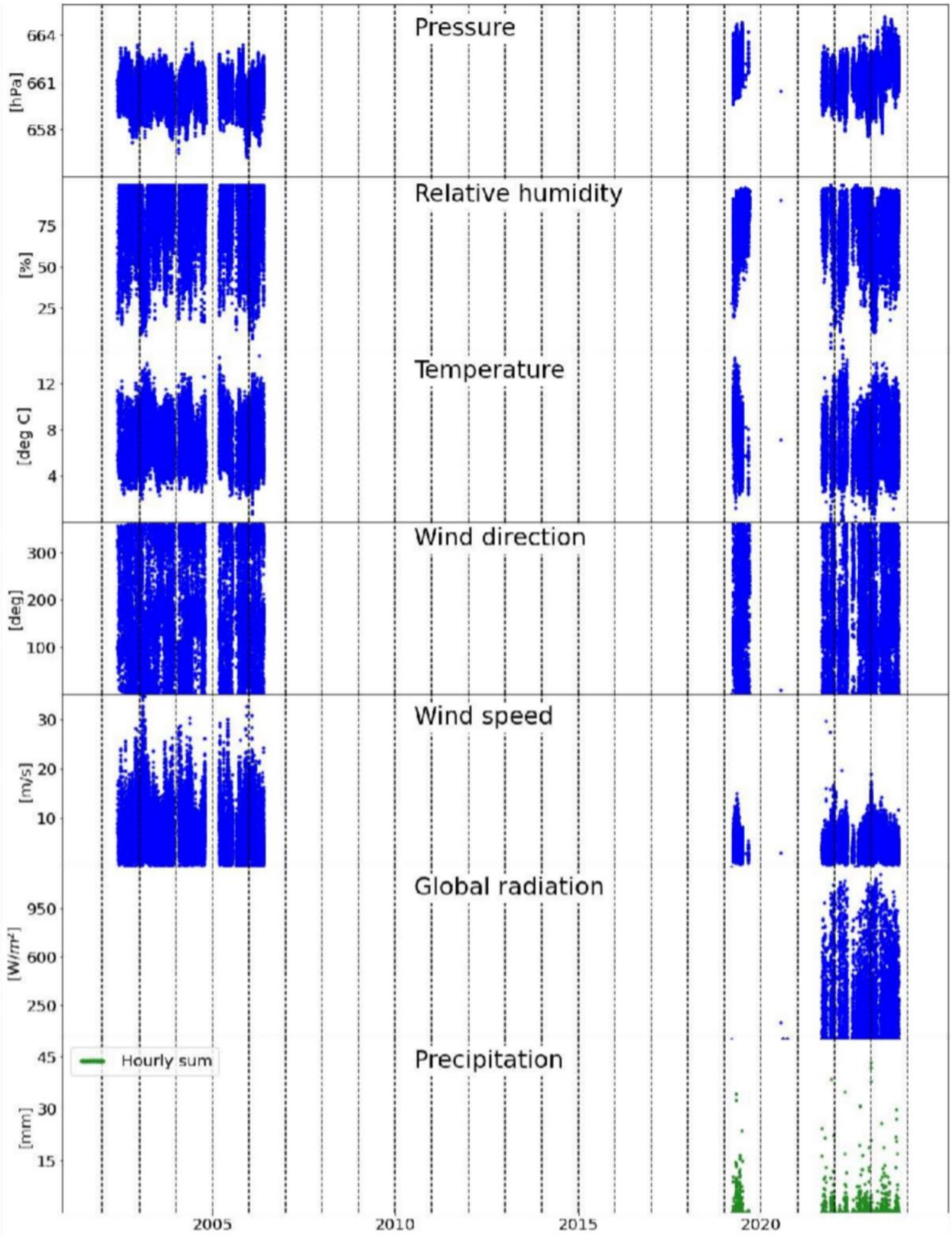


Figure 28. Meteorological data available from Mount Kenya (up until 2023)

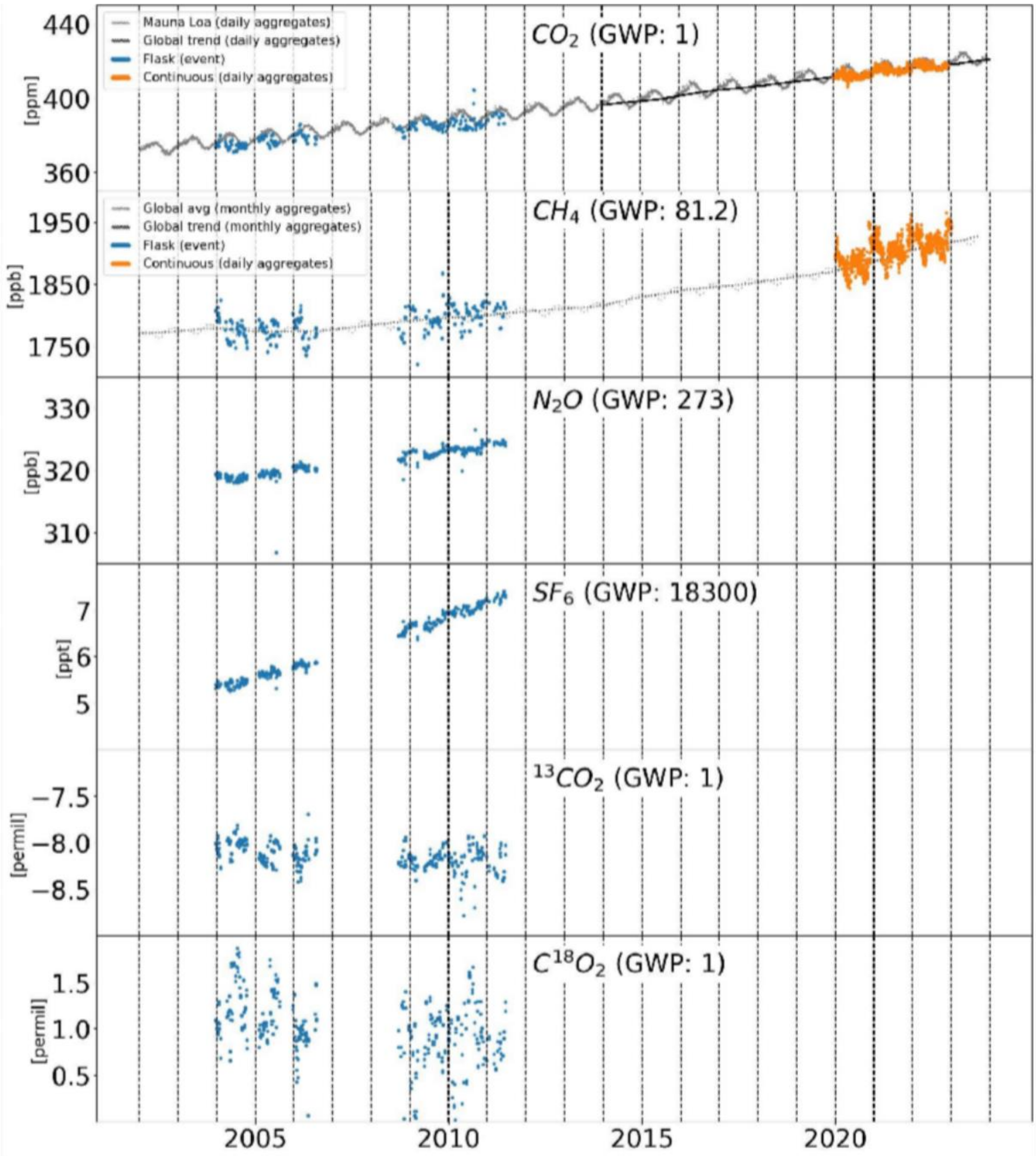


Figure 29. Greenhouse Gas measurements available from Mount Kenya (up until 2023)

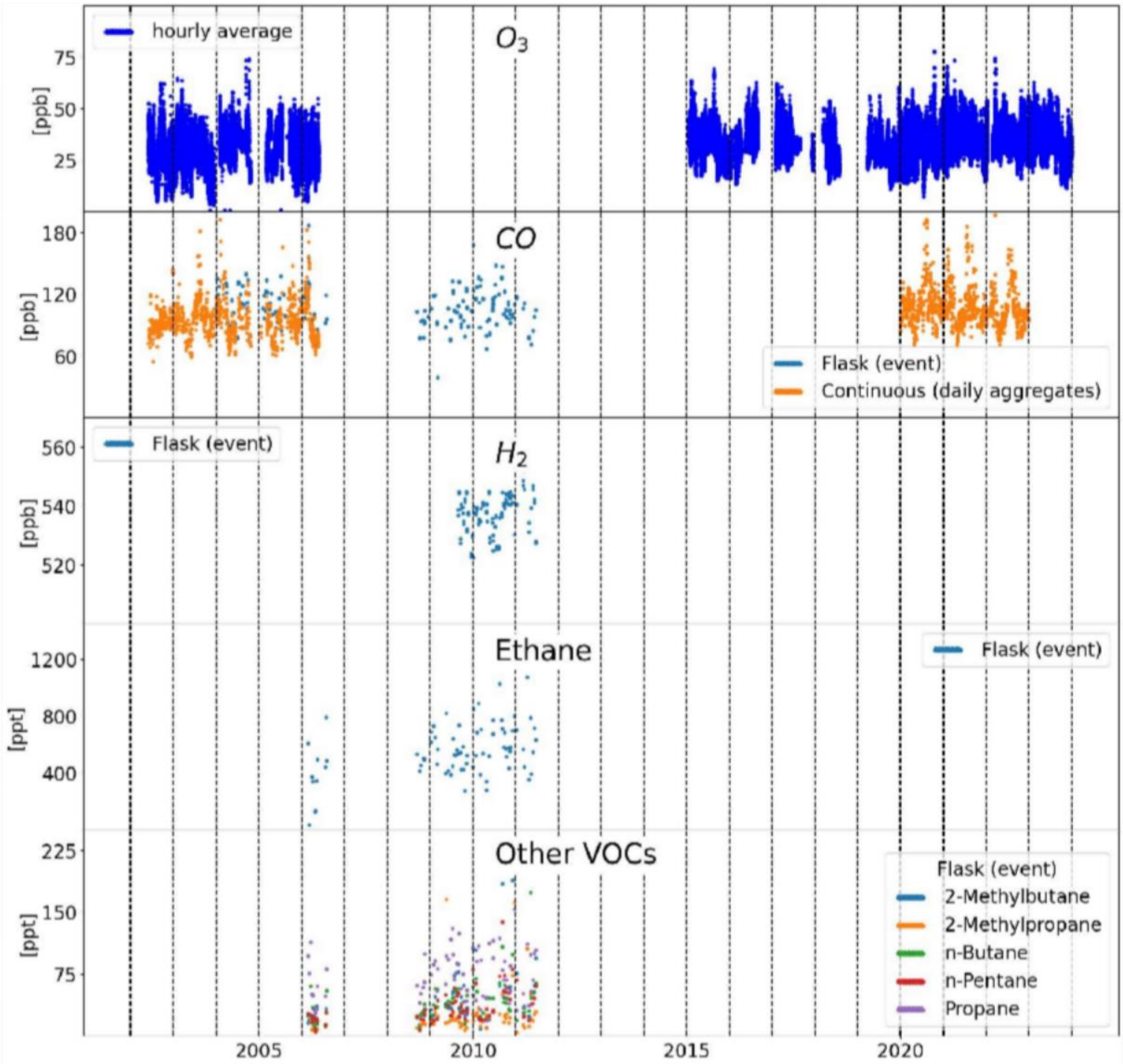


Figure 30. Reactive gas measurements available from Mount Kenya (up until 2023)

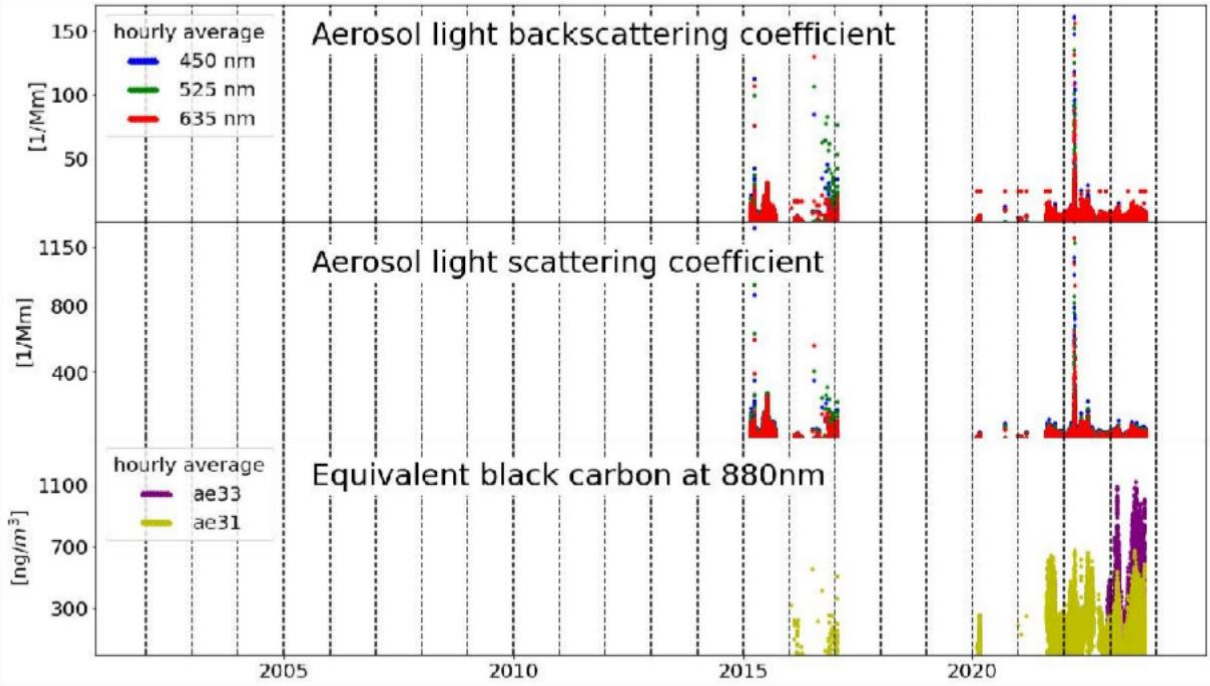


Figure 31. Aerosol optical properties from Mount Kenya GAW station (up until 2023)

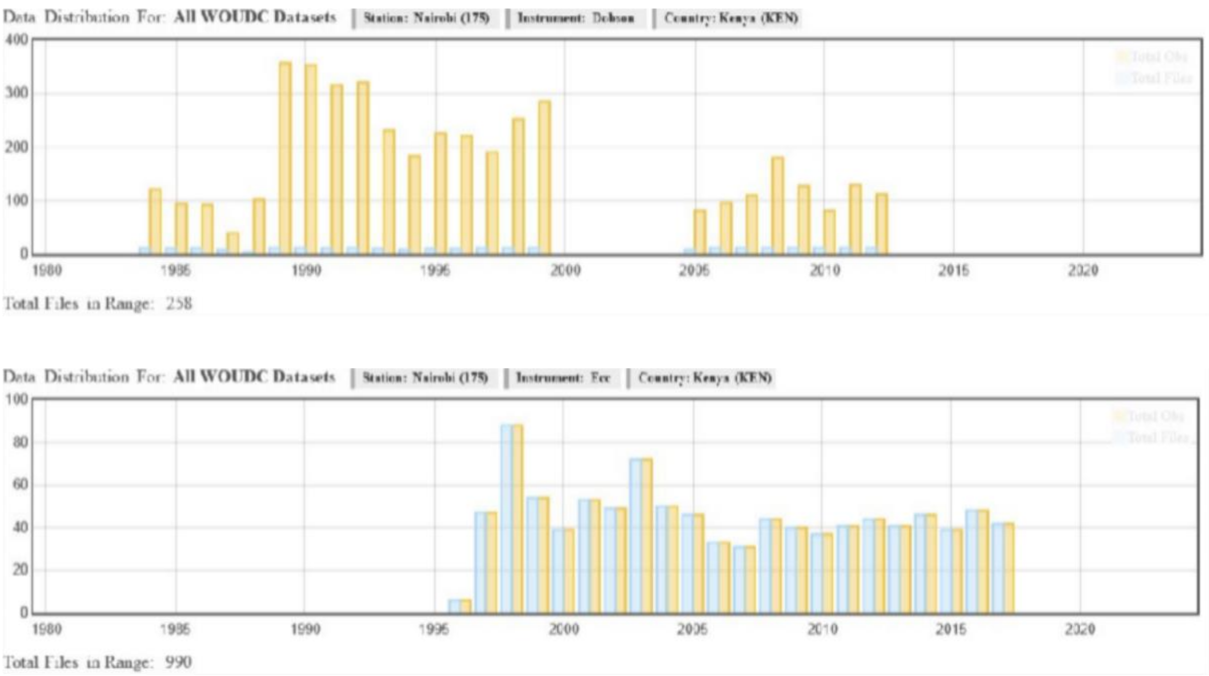


Figure 32. Overview of data from Nairobi GAW station. Source: WOUDC (NB: Data submissions for the period after 2012 are still being processed by the WOUDC, and the figures do not adequately reflect what is available) (yellow: total number of observations; blue: total number of files)

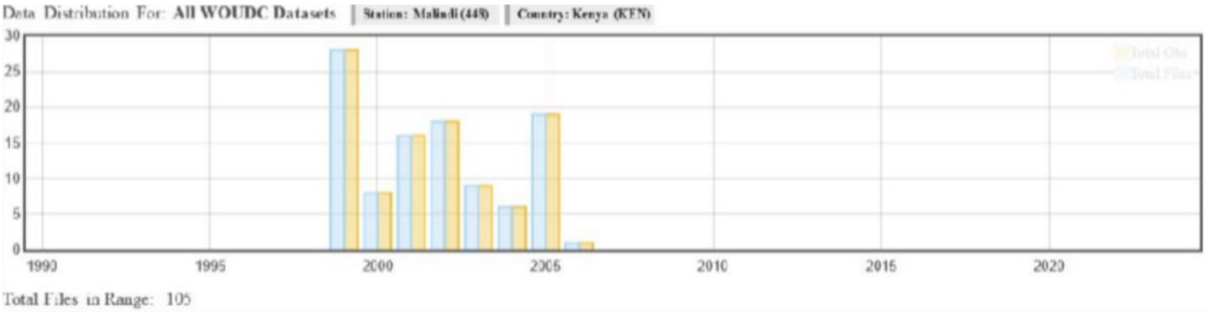


Figure 33. Overview of data from Malindi GAW station. Source: WOUDC (yellow: total number of observations; blue: total number of files)

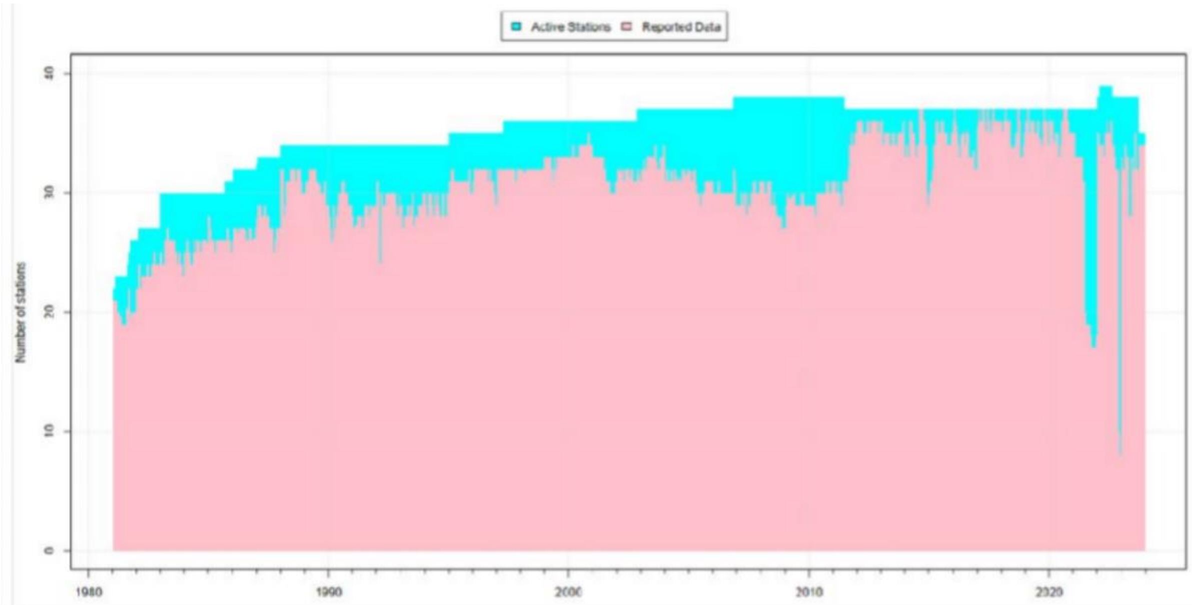


Figure 34. Number of manual stations reporting wind speed and direction

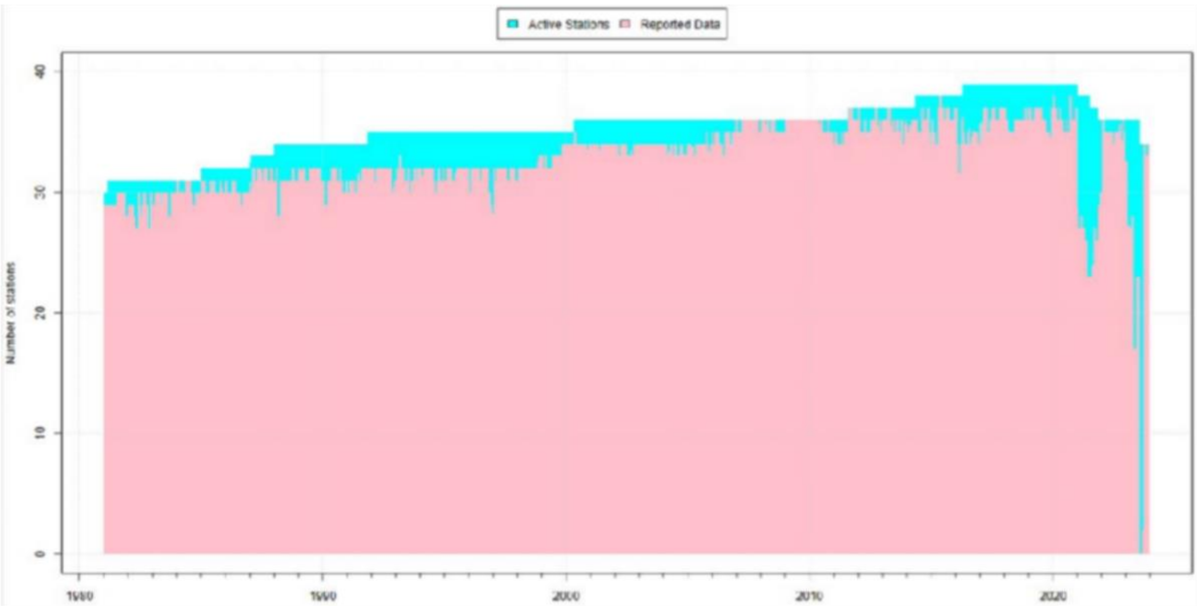


Figure 35. Number of manual stations reporting relative humidity

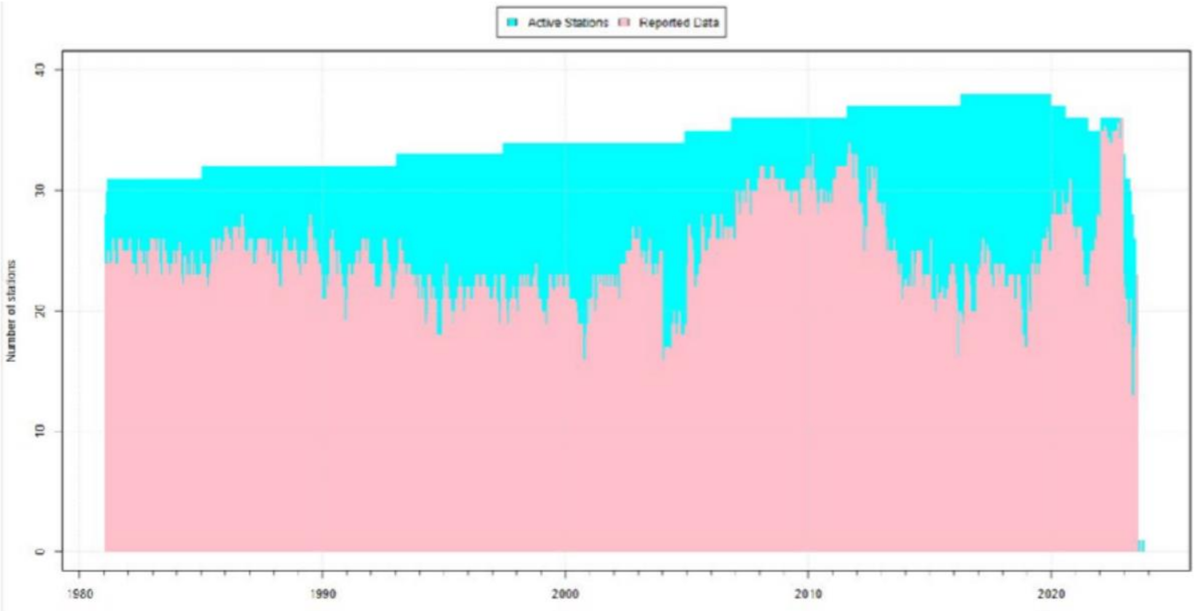


Figure 36. Number of manual stations reporting evaporation

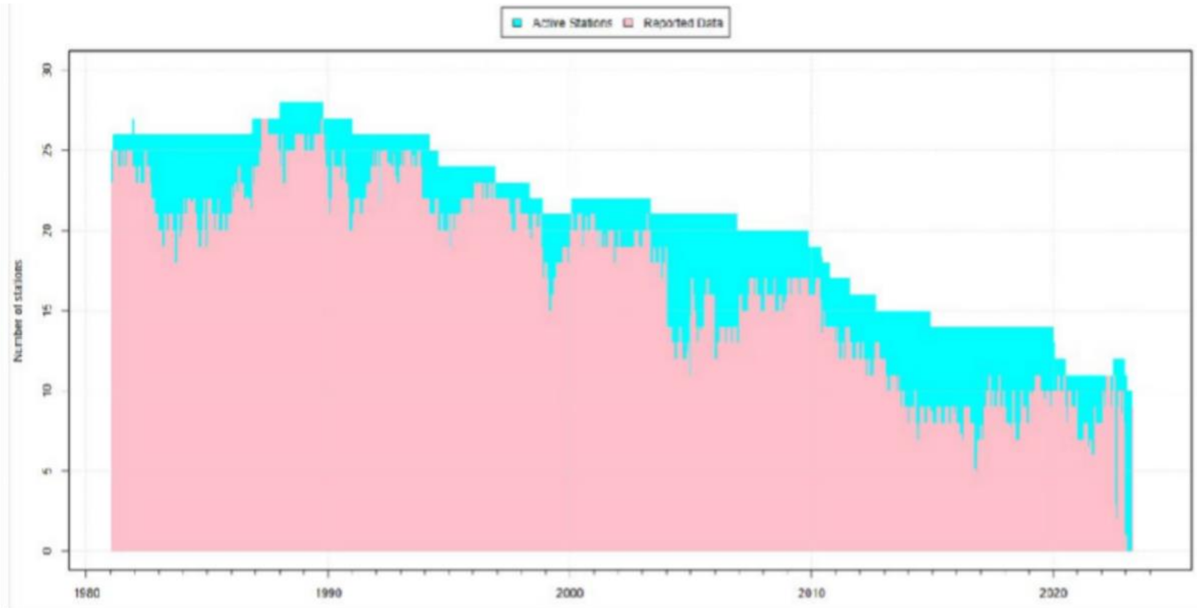


Figure 37. Number of manual stations reporting total downward radiation

Figure 38. Number of manual stations reporting atmospheric pressure

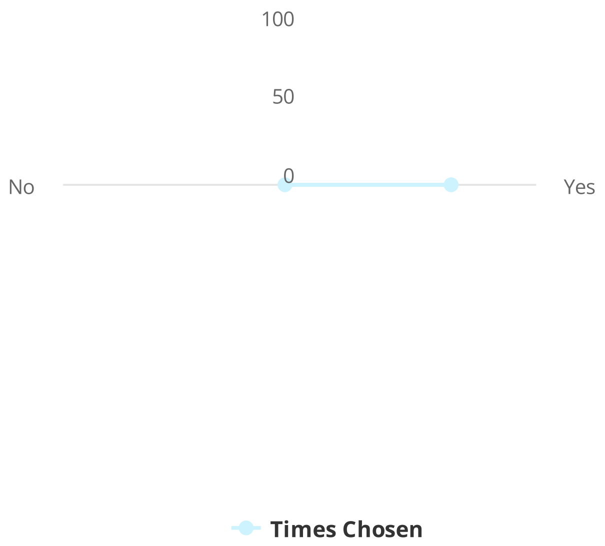
Appendix 2: Stakeholder Survey

[separate pdf]

KADI survey WP2 Pilot 4

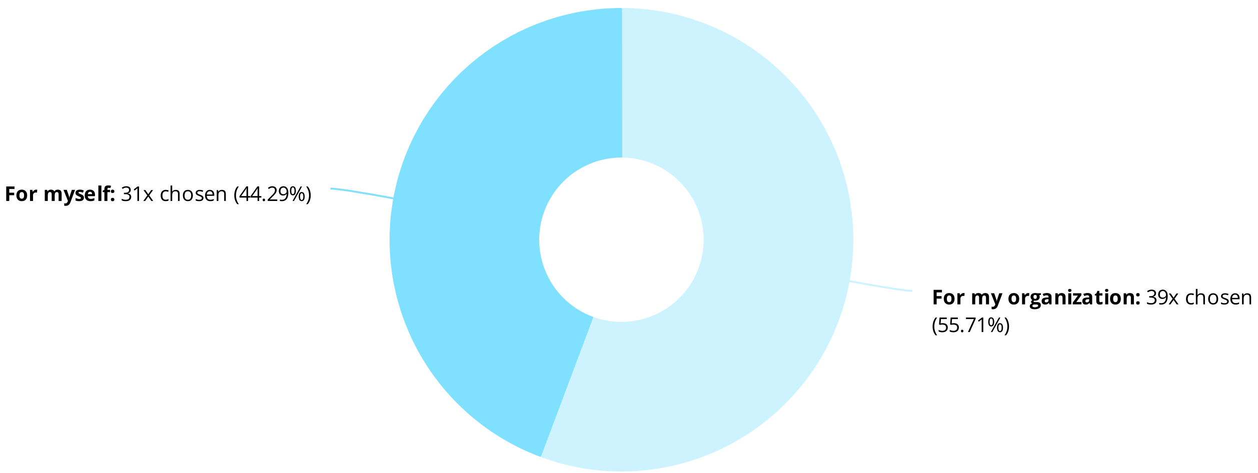
Declaration of informed consent

Number of responses: 106



Are you taking the survey on behalf of your organization or for yourself?

Number of responses: 70



What is your name?

Number of responses: 69

Text answers:

Erick K Kigen

nanda

Marcus Ndwiga

Nelson Amos Mutanda

Ayub Manya

Daina Mathai

Dominic Kiyeng

Emily

Githaiga Mercy Njoki

Peter Sirayo

Anthony Mwanthi

samuel Tama

Minaywa Laboso

Christopher Otieno

Mary mairanga

Prisca Okila

James Kirika

Muthomi Munyua

MERCELINE OJWALA

ZACHARY Misiani

Zachary Kimutai Maritim

Daina Mathai

Franklin Opijah

Anderson Kehbila

Frankline Rono

Dr. Catherine Mbaisi

Irene Cheptum

Osoro Kennedy

Catherine Ndinda K. N.

Catherine Ndinda

Jactone Mboya Agwa

Gabriel Wambugu

Terer Joan

Myself

Ruth Kisabuli

Iddah Wawiye

irene kisingu

Wilson Maina

William Ndwiga

Eunice Maina

Philip OSANO

Evanson Kibe Waceke

Jactone Mboya Agwa

Ewart Julius Komunga

Jane N. Reuben

Alexander Kememwa

wesley ooga

WAIRIUKO LEONARD WACHIRA

SAMUEL OKOTH ONDDNG

MICHAEL MULWA

Philip

Iddah A. Wawiye

Muthomi Munyua

Aziza Hussein

Francis

Calvin

Lydia Mwithiga

DR. ELLY YALUK, PhD.

John Marvin Ayara

Evans Ogochi

Dylan

Julius Muindi

Rose Lekalesoi

Vincent Odongo

Francis Mwangi

stephen muchiri

Beatrice Otieno

Mirriam Chebungei

John Ngugi Kigomo

What is the name of your organization?

Number of responses: 68

Text answers:

Nzoia Sugar Company Ltd

n/a

N/A

National Drought Management Authority
Ministry of Health
Kenya Marine and Fisheries Research Institute
KeNHA
Muungano
Kenya National Highways Authority (KeNHA)
Kenya Forest Service
ICPAC
Safaricom PLC
The Baobb Fruit Company Ltd
Weather Mtaani
Sign of Hope
Coffee Research Institute
Kounkuey Design Initiative
Weather mtaani
University of Nairobi
DIRECTORATE OF RESOURCE SURVEYS AND REMOTE SENSING
KRCS
The Nature Conservancy - TNC

Kenya Marine and Fisheries Research Institute
University of Nairobi
Stockholm Environment Institute
Regional Centre for Mapping of Resources for Development (RCMRD)
National Environment Management Authority
Geothermal Development company
Pamoja FM
State Department for Roads
State Department for Roads
Nairobi City County
Water Resources Authority (WRA)
Ministry of irrigation
Intergovernment
Pearl dairies
Kenya Forestry College (Kenya Forest Service)
SAFARICOM PLC
Drum-beat Afrika Ltd
Adega Farm
Kenya Forest Service

Stockholm Environment Institute (SEI)
Mtaani Radio
Nairobi City County
MOALD State Department of Agriculture
Ministry Agriculture and Livestock Development
Pamoja FM Radio
ministry of health
NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY
Ministry of Water, Sanitation & Irrigation
Kenya Forest Service - Kenya Forestry College
University of Nairobi
N/A
Makini School
Mediae, iShamba
NetZero Consulting
State Department of Irrigation
Ministry of Energy
Kenya Civil Aviation Authority
Ministry of Energy and Petroleum

Ministry of Water Sanitation and Irrigation

Samburu County Government

International Livestock Research Institute

Kenya Civil Aviation Authority

EAFF

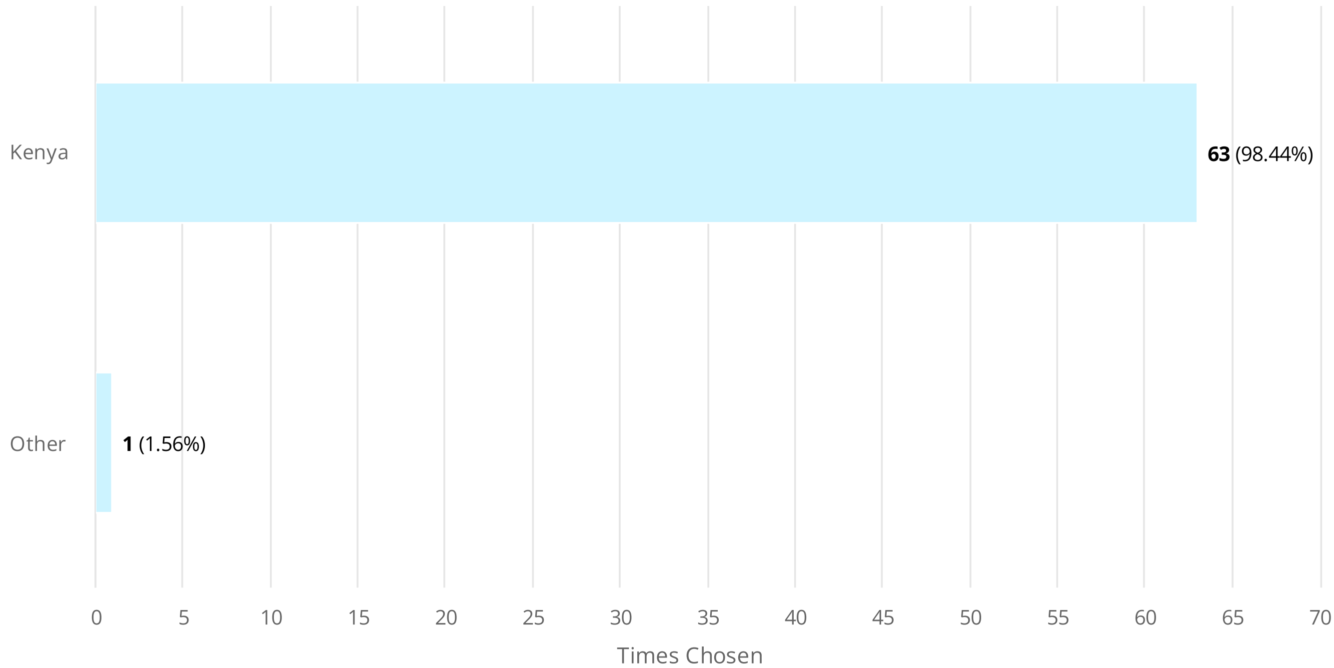
Brookside Dairy Ltd

ministry of water, sanitation and irrigation

Kenya Forestry Research Institute

In which country are you / your organisation based?

Number of responses: 64

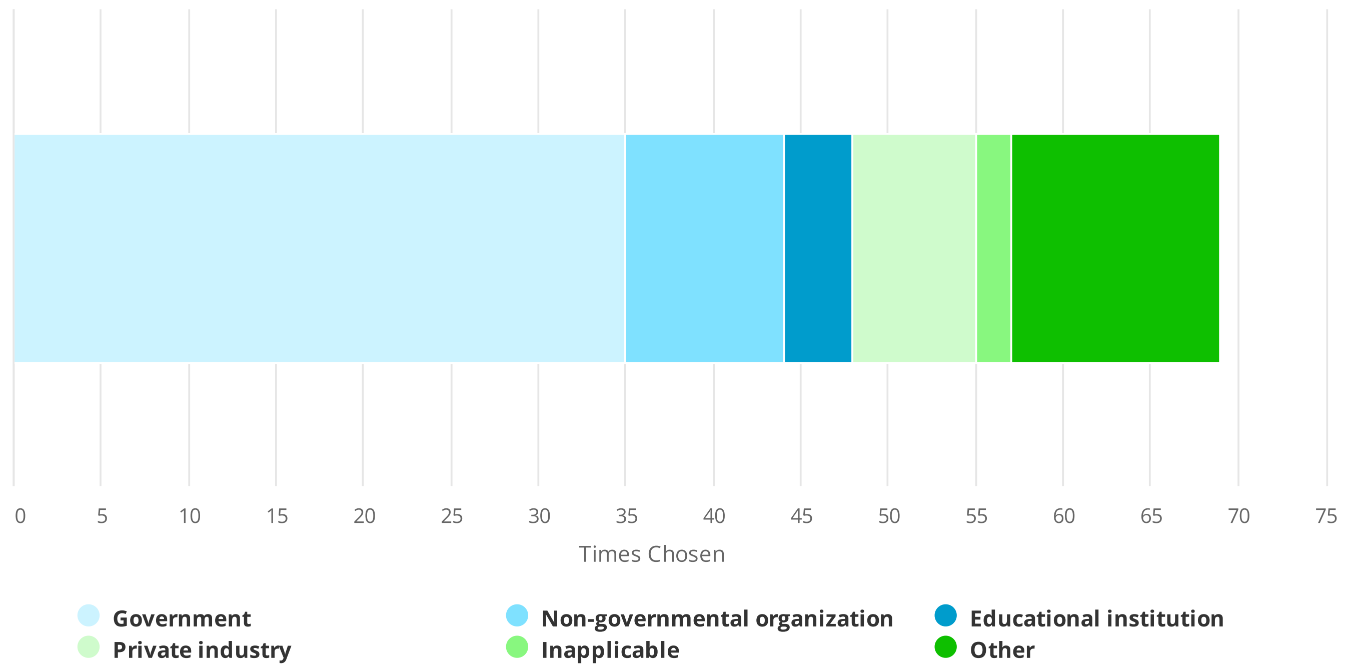


"Other" text answers:

Other

What is the type of your organization?

Number of responses: 69



"Other" text answers:

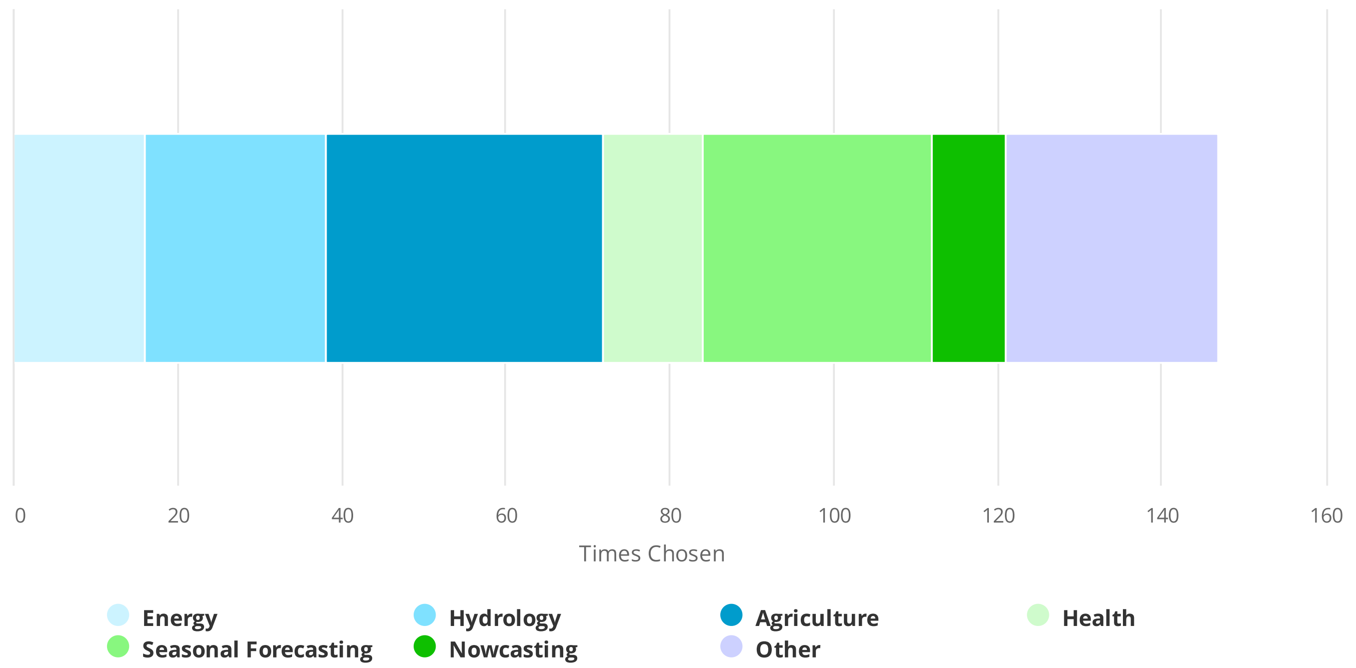
- Government Agency
- Integovernmental
- Community based organisation
- Community based Organization
- Inter-Governmental
- Community Media
- Inter-governmental
- Other
- Research instititute
- Media

Consulting

FARMER ORGANIZATION

What is / are your area(s) of interest?

Number of responses: 70



"Other" text answers:

Marine and Fisheries
Infrastructure
Other
Forest related
Telco/ ICT
Other
DRR, Humanitarian response
daily and weekly weather forecast
Translation and desemination
Structural Engineering

FOREST AND OTHER LANDUSE

Coastal and Marine Research

Weather and climate modelling and prediction

Air quality

Highways

GHG emissions standards

Forestry activity preparation

TECHNOLOGY

Media Research / Media Production

Environment and Forestry

Disaster Management

Environment

Education and Environmental conservation

academic

All sectors climate data for financial institutions

Forestry

Who is your contact person at the Kenya Meteorological Department KMD or at your national weather and climate service?

Number of responses: 52

Text answers:

Christine Mahonga

Christine Mahonga

Christine Mahonga

Chris Kiptum

Pamela Muange

Christine Mahonga

Christine

Priscah

Christine

Joyce Kimutai

Christine Mahonga

Christine Mahonga

Christine Mahonga

Christine Mahonga

Christine Mahonga

Christine Mahonga

Christine

Mrs. Christine Mahonga

CHRISTINE MAHONGA

Forecaster on duty
Christine Mahonga
Director KMD attention Christine Mahonga
Christine Muhonga
Ms. Christine Mahonga
Christine Mahonga
Christine Mahonga
Andrew Njogu
Christine Mahonga
Christine Mahonga
Christine Mahonga
CHRISTINE
Christine Mahonga
Christine Mahonga
Christine Mahonga
Kennedy Thiongo; Patricia Nyinguro; Joyce Kimutai
Nill
M/S Mahonga
Christine Mahonga

NCOF

Patricia Nying'uro, Climate Scientist

Patricia Nying'uro

CHRISTINE MAHONGA

Director, KMD

Ms Christine Mahonga

Christine Mahonga and Andrew Njogu

Christine Mahonga

Mr. Fredrick Etemesi

Christine mahonga

County Director of Meteorology (Samburu County)

Patricia Nyingoro

Customer care office

Dr. Muita

If we may reach out to you for further questions, please enter your e-mail or phone number.

Number of responses: 68

Text answers:

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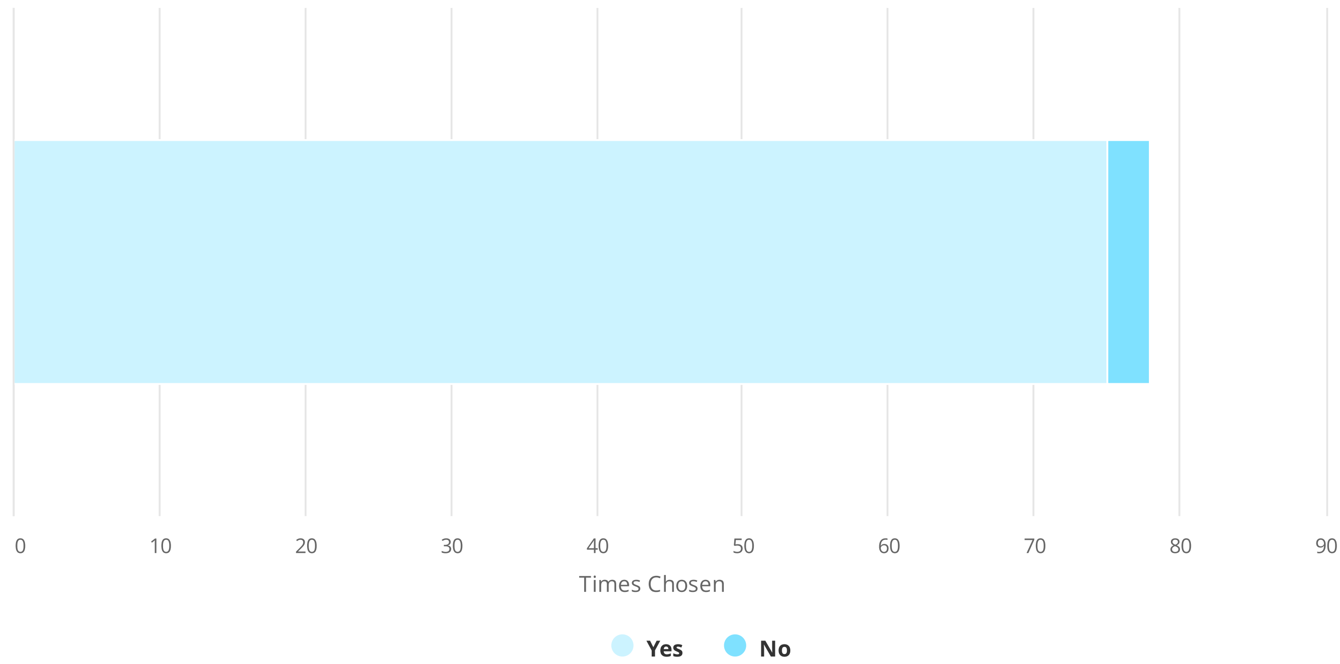
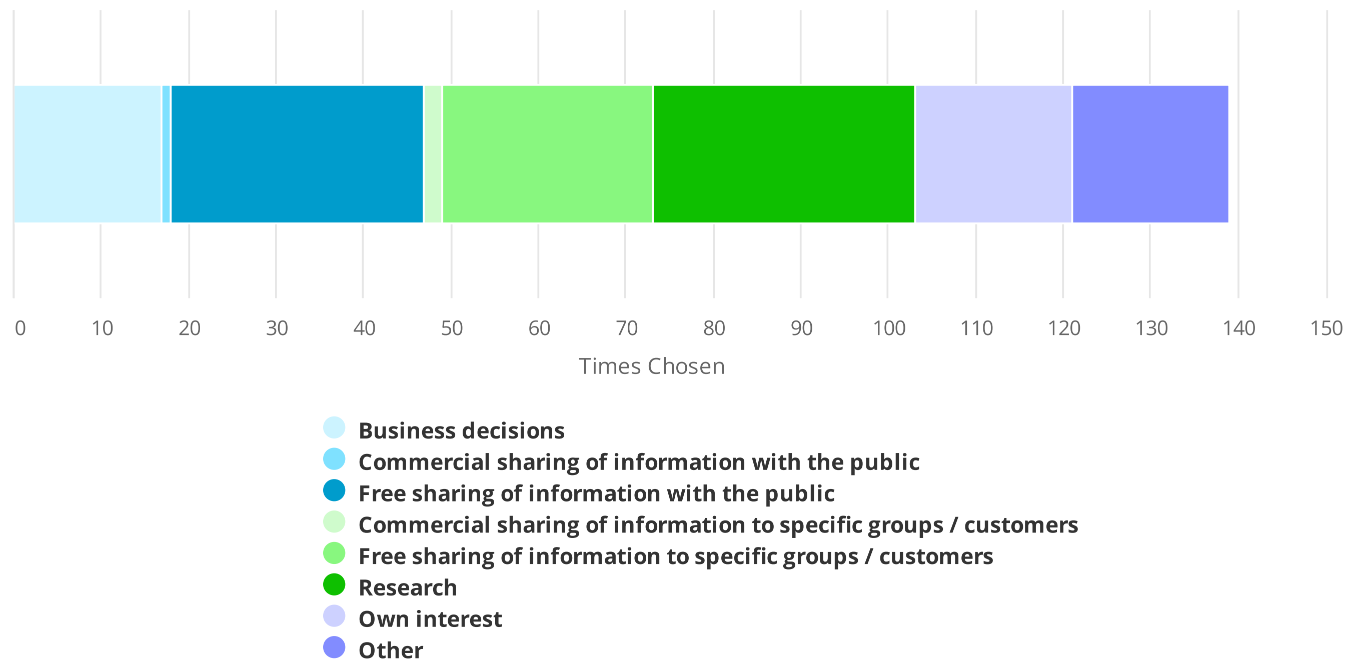
Do / did you use weather, climate and/or atmospheric compostition information?

Number of responses: 78



For what purpose do you use weather, climate and atmospheric composition information?

Number of responses: 69



"Other" text answers:

- Design of roads and highway structures
- Forest related management purposes
- Developing Early Action Plans/Anticipatory Actions
- Bridge Design
- DATA VALIDATION
- Design of infrastructure (Highways and bridges)
- Use climate and atmospheric composition information for design of Highways and Bridges
- Agriculture
- Compliance
- Educational purposes/ Forestry activity preparation

Rainfall data for Tree planting preparation , Temperature data for forest fire management

Disaster Management

Education, environmental conservation

Energy Sector: The energy sector uses weather and climate data to manage energy demand, especially heating and cooling. Renewable energy sources like wind and solar power rely on weather forecasts to predict energy generation and optimize energy production.

For provision of air navigation services

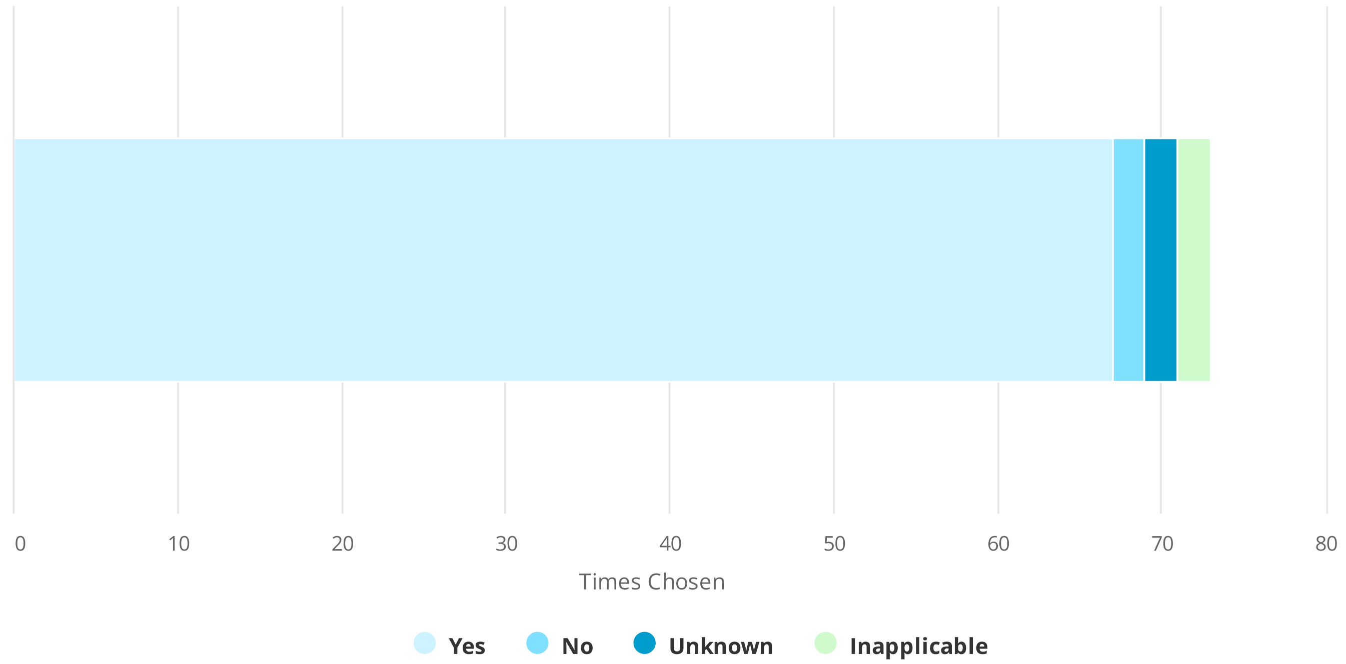
Water infrastructure project designs

For decision making at the county

Share with farmers

Do you take decisions based on this information?

Number of responses: 73



What kind of decisions are supported by the information that you use?

Number of responses: 63

Text answers:

Our cane planting operations are majorly guided by weather patterns.
Harvesting and transportation of sugarcane from farms are also planned based on weather condition

Planning on whether to meet engagements that involve some kind of commute and I would like to know the weather for the day so I can prepare aptly

Drought early warning reports for the country

In the epidemiological regions, which are prone to malaria infections, we monitor climate data to support the prediction of a malaria outbreak. Decisions that are made in such situations are to organise interventions including purchasing requisite materials

Impacts of climate on the local fisheries communities, adaptation and mitigation strategies.

Discharge capacity of a particular stream/river crossing a particular road section will enable me design the appropriate drainage structure.

During design phase of a proposed road/bridge with regards to the construction methodology and the choice of drainage infrastructure.

We use rainfall forecast information to plan for tree planting activities across the country.

At personal level, I utilized KMD climate information for agricultural planning.
At institutional level, we utilize KMD information for integration with other sources/member states to provide regional monitoring of weather over East Africa.

Rain and flooding information, helps choose travel route or dressing code.
weather forecasts helps in farming and planning.

When about to book a vacation, i need a weather update so i can plan activities around the weather or decide whether or not to travel to a certain destination.

We disseminate weather information in informal settlement.

Using rainfall forecast and rainfall performance to develop trigger models to guide early actions before a hazards occurs

Advisory to farmers on coffee and crops planting

advise and action to be taken, early warnings,

- Travel
- Clothing
- Travelling routes.
- What to eat and drink

I would use a wind map to design structures.
I would use lowest and highest isotherms for bridge design.

PART OF ATTRIUTE DATA I THE GEERATED GEOSPATIAL DATASETS
NEED FOR CLOUD DATA TO AID DATA COLLECTION PROCESS USING AIRCRAFTS.

Anticipatory Actions...

(1) Marine Spatial Plan and Zoning of the Ocean Space including policies for each zoning category (2) Planting season (3) Advising Pastoralists on grazing (holistic grazing) plans

Planning for coastal and Marine spaces.
Near future impacts of climate-related hazards to local communities.

Decision on which proxy data is useful for regional applications

Weather and climate data such as the air quality used as part of other data sets to develop integrated spatial maps among other knowledge products. In direct decisions. Decisions on the hazard's, invasive species, crop pests and diseases' maps are made disaster risk planners, and responders, etc

1. When to undertake activities - work related or personal -travel or hold hold field activities.
2. Agriculture- when to plant, type of crops to Plant
3. In my work- the information informs me on what type of messages and information to share with relevant stakekolders
4.

Planning of activities

Cautionary measures in the informal settlement

Updated Hydrological data encompassing rainfall data, river flow data, intensity duration frequency(IDF) curves , flood map and wind map data required for roads designs and design of drainage structures and bridges .
Weather forecast summaries are required for scheduling of operations during road works construction phase and decision making in road sector.
Daily maximum and minimum air temperatures are required for selection of bituminous products for bituminous surface treatments for specific area.

The information helps in preparation of water channels and solid waste management to avoid clogged drains thus resulting into flooding and destructive situations

1. Designing a research objective for developing climate resilient tea varieties.
2. Helps in designing fertilization schedule/regime for plants eg if climate information suggest excess rains decision has to be made on fertilizer application style.

WRA and KMD have a joint Flood Forecasting and Early Warning System (FFEWS) for Nzoia sub basin in Lake Victoria North Basin, Kenya.
We have an MoU where WRA provides hydro data and KMD provides meteorological data. The application can be accessed via https://wimes.meteo.go.ke/#/welcome

Decisions on irrigation farming preparations so as to carry out the activities on the appropriate time and also on when it is more suitable to establish more irrigation schemes on an effort to attain food security

nhhjjkk

Compliance decisions
Risk management of climate risks
Safety and health management
Environmental management for air quality monitoring, water quality monitoring, waste management.
Conservation efforts

We are able to schedule when to prepare for tree planting in the field as well as to plan our seedlings production to enable the seedlings attain the right size for planting by planting season. The information is also used to determine the on set of the dry season that enables us prepare for the fire season. The information help us undertake research on plants and their ecological zones. We also use the data for training.

1.Financial projections for the organization

2.Customer service and delivery-Early preparedness for extreme weather conditions affecting the supply of electricity in our base stations help us to deploy backup solutions for the same to ensure our network is not affected.

Film Production Scheduling of shoot days and making of movement orders.

Agricultural

1.The moisture building guides on the best planting season for good survival rate
2. The Forest fire readiness is guided by temperature data and so early warning purposes
3. The use of satellites data for mapping of land cover land use use and forest cover is guided by temperature data (seasonality data)

Policy development
Early warning
Data analysis for research
Science advice

When I got weather update, I share as it is to my listener on caution to take before leaving in their houses incase weather man predict heavy rainfall in some hours

When we get timely weather forecast and it gives indication that we expect rain above average my organization uses this to clear the drains clear water ways and desilt small rivers passing through Nairobi, we also conduct public awareness to people living in slums and low lying areas to evacuate before the rains, this decreases possibility deaths when it floods in their neighborhood

The seasonal forecast information for both MAM and OND is used to develop agricultural weather Advisories with sector specialists and the stakeholders communities in a participatory process referred to as PSP all over the counties.
Weather warning alerts are used to convince those living in weather disaster places to relocate such as landslide prone areas

The information informs the processes of the agricultural value chains

We share weather and climate information with our audience (radio) which in turn helps them to make decisions on their daily activities. Our audience include business people, school children, women and jua kali sector workers.

ZZZ

to plan my planting and harvesting schedule

I use the information from weather forecast to make decisions on when to plant and what type of crops to plant.

Policy Direction

The information that we collect enables us plan for when to raise our seedlings for the rainy season as well as to determine when to declear fire risk season. Students are also educated on how to use the different equipment for weather measurement.

The university wanted to develop a wind map for the design of structures in Kenya.

before we take students out for camping and outdoor activities

When you advise on planting seasons and calendar

To inform design of projects and plan logistics for project implementation

In the Renewable Energy Generation Weather forecasts are essential for renewable energy sources such as wind and solar power. For instance, the prediction of wind speed, solar radiation, and cloud cover enables operators to optimize energy production and distribution.

Additionally, in Energy Storage, Weather forecasts support decisions related to the charging and discharging of energy storage systems, which help stabilize the grid during fluctuations in renewable energy generation.

1. Deciding on the Runway in use at an airport from time to time using current weather information.
2. Passing/relaying the current/forecast weather information to pilots and flight dispatchers for purposes of route planning and flight scheduling.
3. Use of long-term weather phenomena to make decisions on establishment of airports and development of existing ones.

The information dictates the type of means of transport I'll prefer towards may areas of visit say work, market, business etc.

Design of dams infrastructure we need long term rainfall data, evaporation and for flood forecasting we need nowcasting information

- The type of seeds to give to the farmers and pasture species to plant
- For preparation of food distribution and water trucking activities to the community in case of pending drought
- Emergency preparedness incase of floods
- For construction of roads and bridges
- It also informs the budget allocation to the departments in the county

Flight Movements decision and Planting season

1. when to plant
2. what to plant
3. when to harvest
4. mitigations to make e.g. insurance, post harvest management, plant protection etc

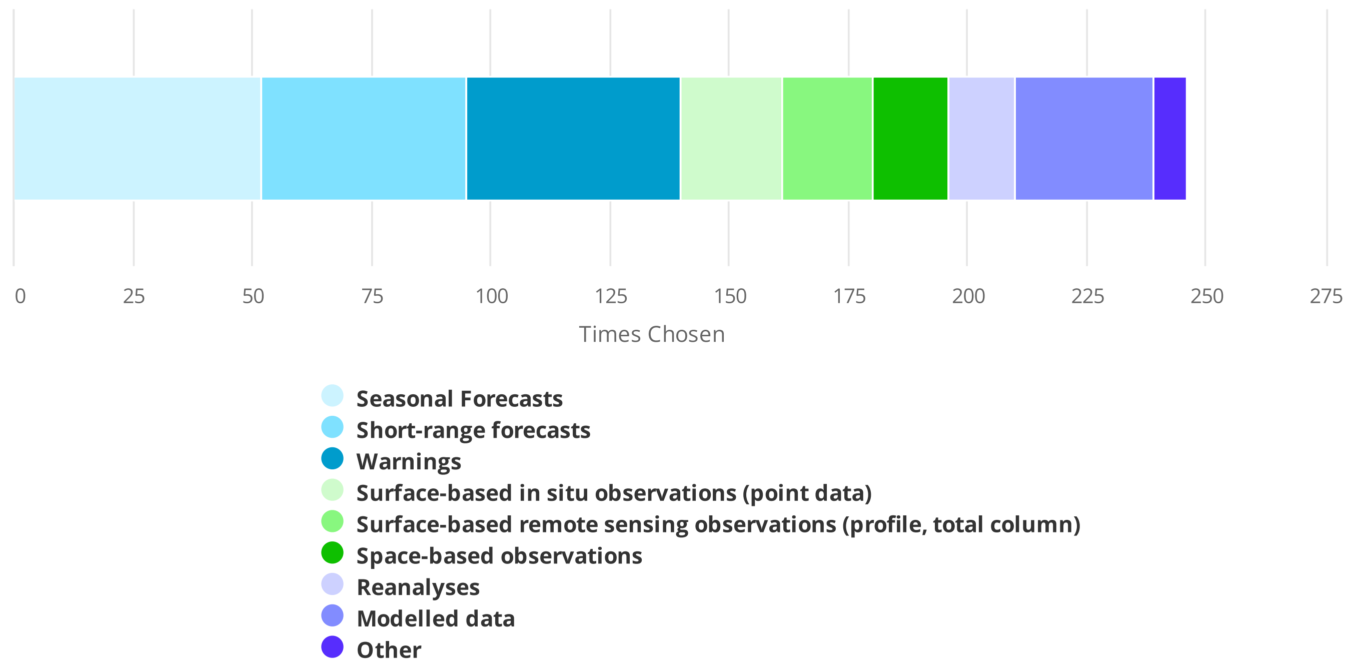
The monthly and seasonal forecasts are particularly useful in advising farmers on management issues such as: Tilling/land preparation for fodder establishment, proper animal housing to avoid disease and improve hygiene especially during wet weather, feeds conservation for future use, water harvesting, disease control by collaborating with other stakeholders to initiate programs against diseases such as foot & mouth disease or even Rift Valley fever.
For business the information is useful for addressing milk collection accessibility challenges especially during wet weather, for planning for transport, storage & to determine levels of milk production.

Give information to my family members for readiness of any season change and prepare for farming activities including planting season readiness.
Planning field related activities and exercises relating to my work
Discussion in various social media platforms

Forest fire research, tree species site matching, forest biomass modeling

What kind of weather, climate and atmospheric composition information do you use?

Number of responses: 64



"Other" text answers:

Nowcasts

daily and weekly forecast.

Nairobi county five day forecast

Other

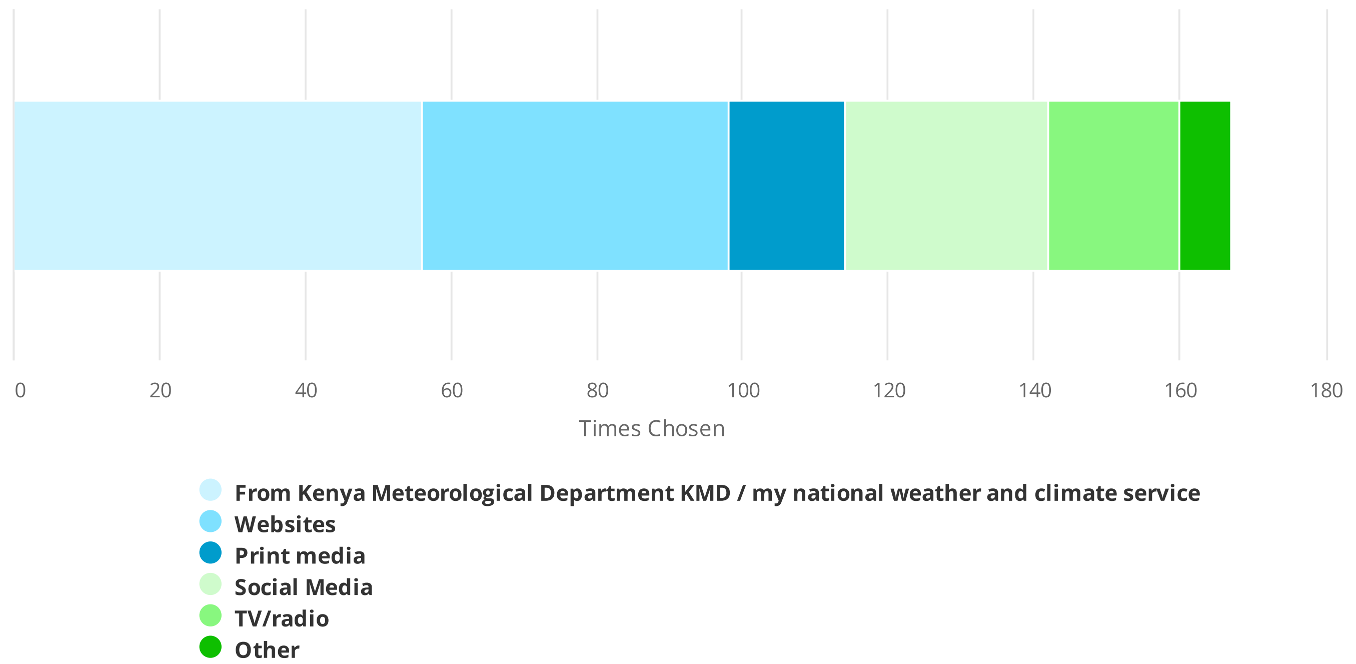
Quantitative precipitation forecast from WRF required

Other

All for financial sector climate risks assessments

How do you access the information?

Number of responses: 65



"Other" text answers:

Emails

Research Articles

Own data

Shared via FTP and the the WIMES application

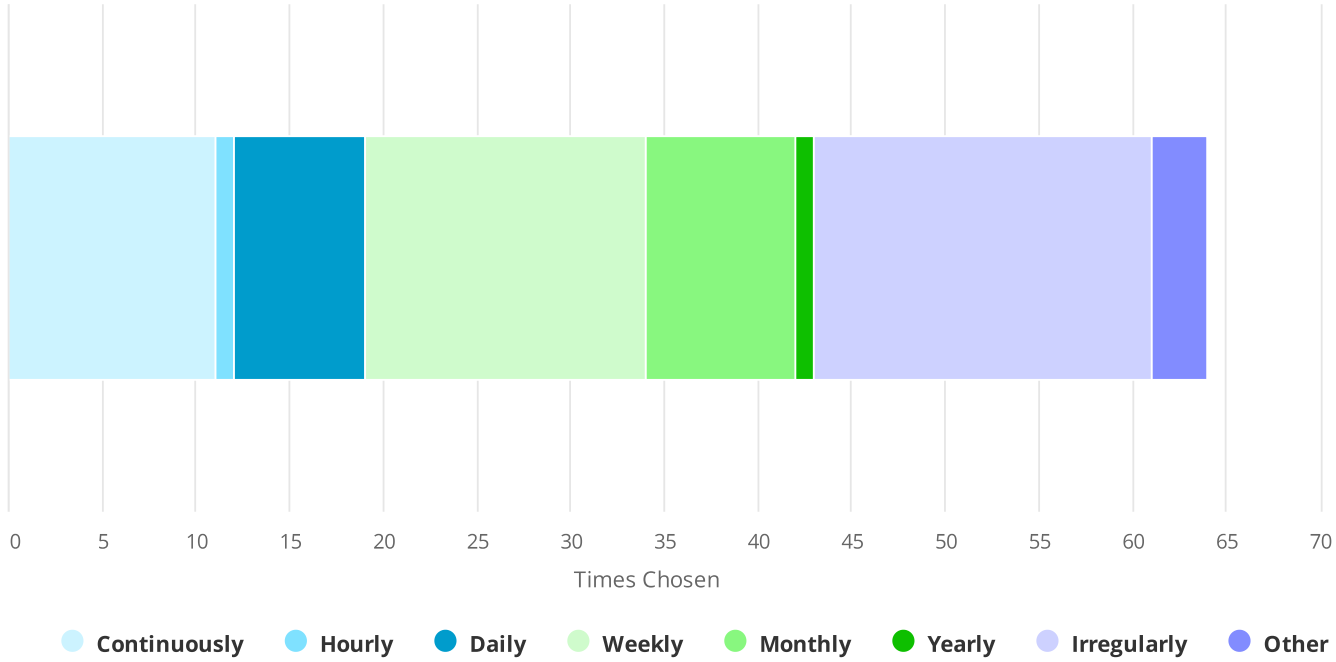
Scientific publications.

Channels established between KMD and KCAA through Letters of Agreement

weather apps; insurance companies

How often do you receive / access the information?

Number of responses: 64

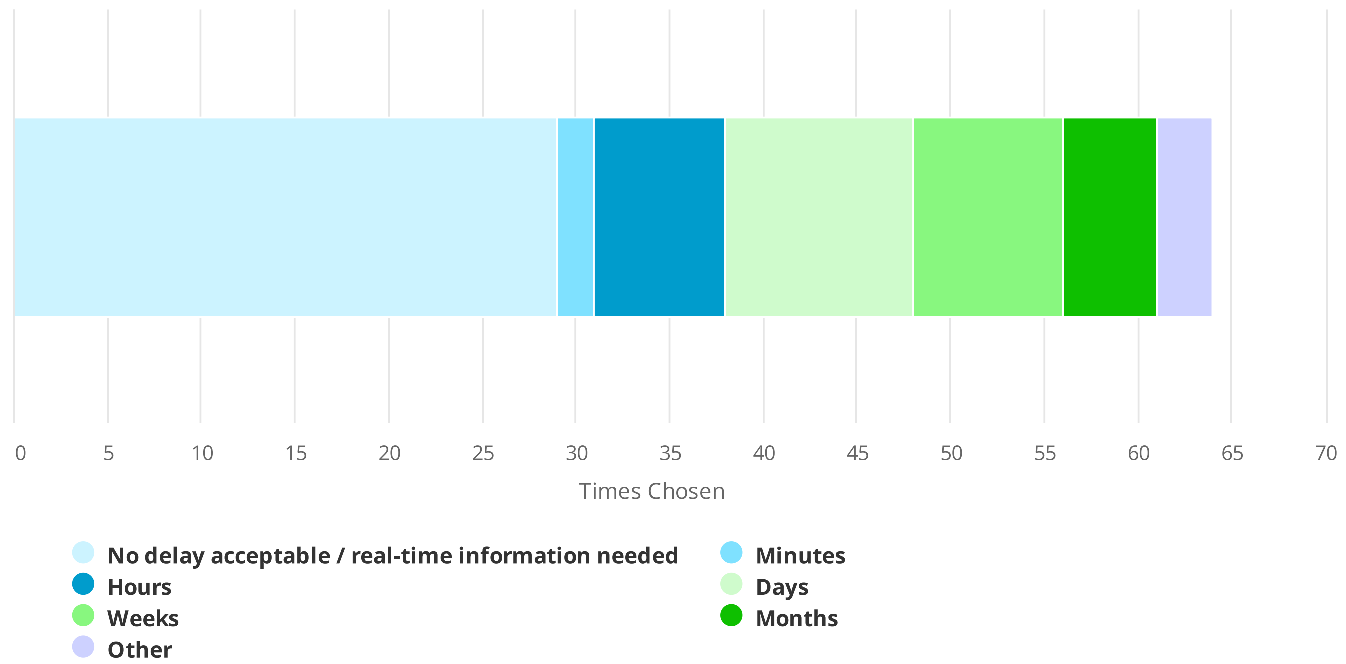


"Other" text answers:

Need basis
Need basis
Long-term and short-term data

What is the acceptable lead-time (delay) of this information you receive?

Number of responses: 64



"Other" text answers:

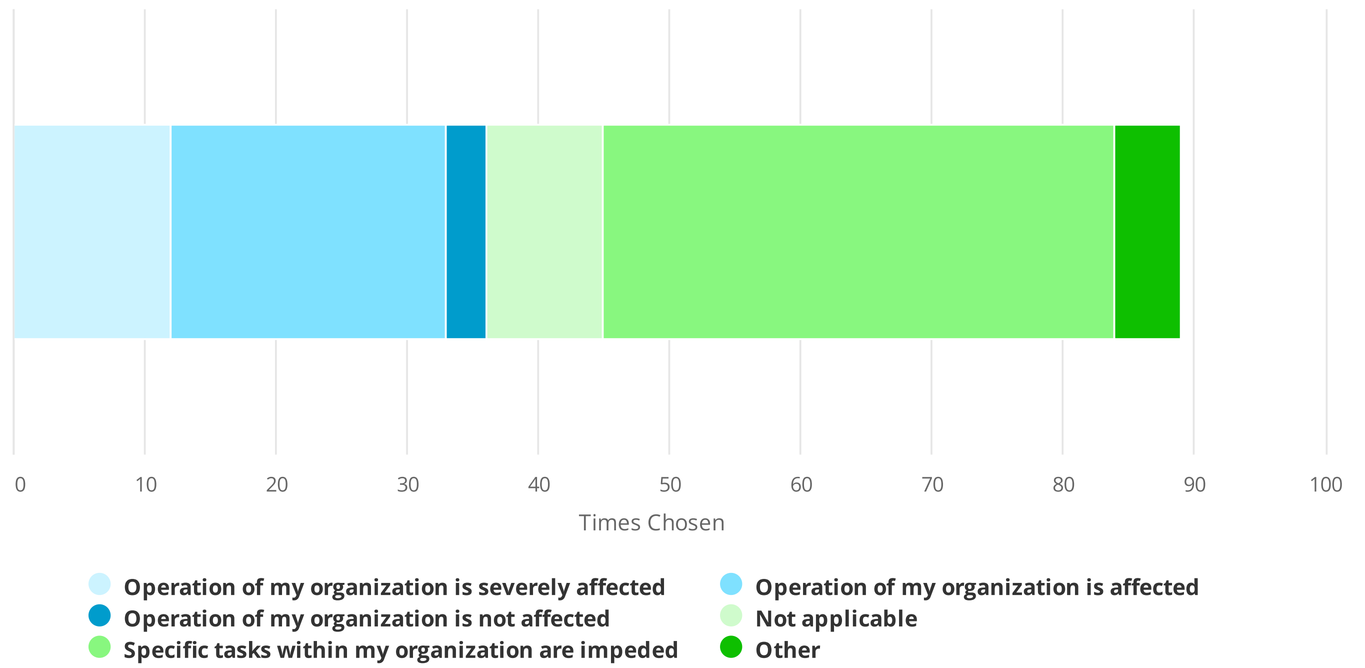
Data that need reanalysis such as generation of IDF curves requires time to generate. Spatial data obtained on real time

Reliable data needed

depends - weekly, daily

What are the consequences if you do not have access to this information?

Number of responses: 65



"Other" text answers:

Consequences felt in communities where we conduct research

My travel is affected

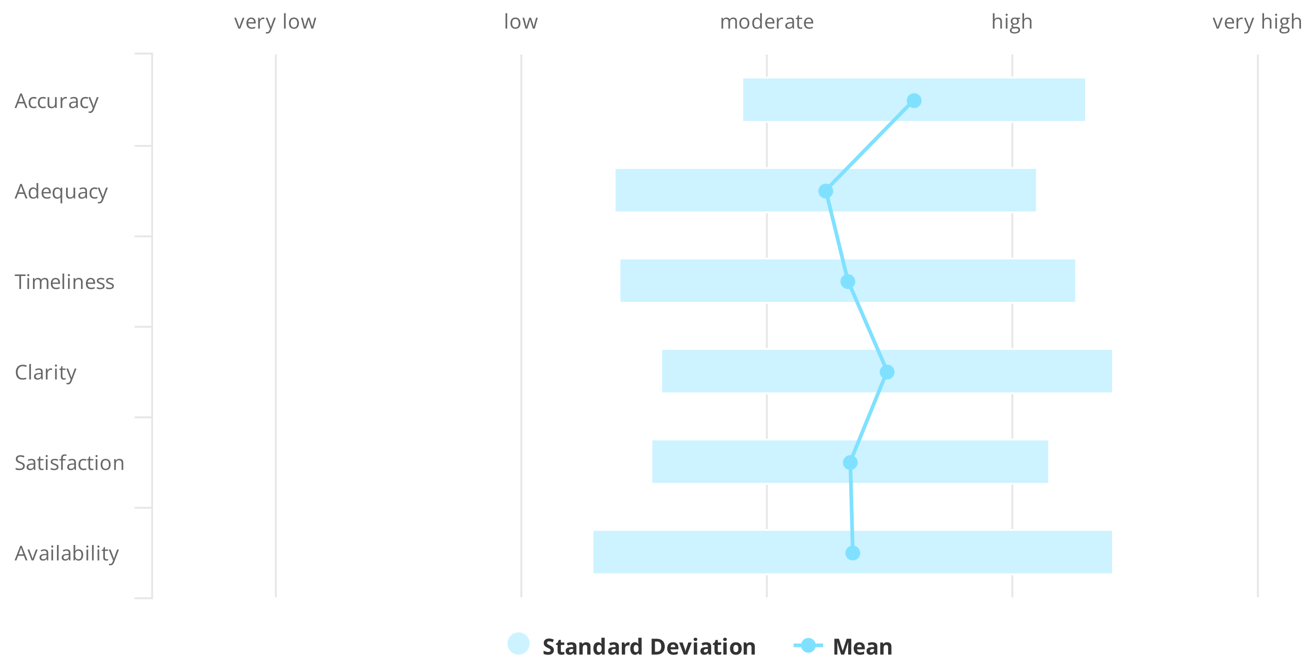
Information is often required for teaching purposes

There will be an information deficit from some of our listeners. A gap that is so crucial at this time.

Aircraft operations are severely affected.

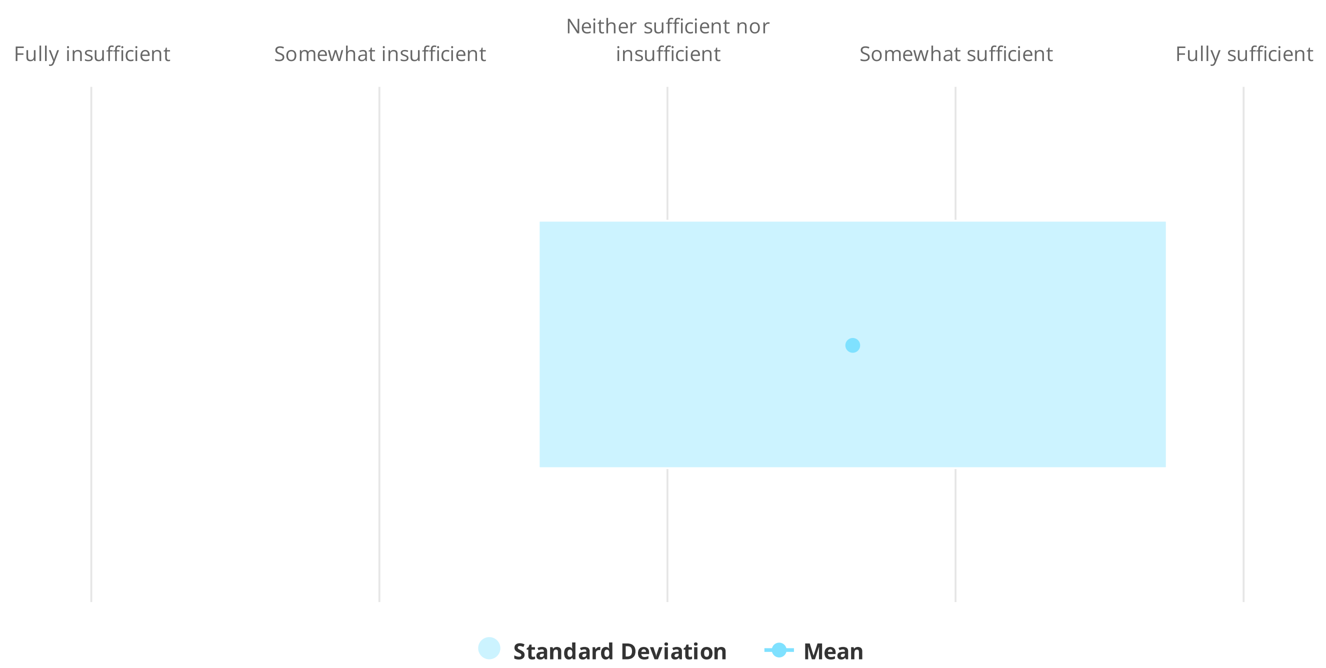
What is your rating of the weather, climate and atmospheric composition information used by your organization in terms of accuracy, adequacy, timeliness, clarity, satisfaction, availability?

Number of responses: 64



Is the weather, climate and atmospheric composition information received sufficient for your sector or organizational needs?

Number of responses: 64



In case you answered with “somewhat insufficient” or “fully insufficient”, what can be improved?

Number of responses: 30

Text answers:

Remote sensing monitoring products for example SPI

There is minimal marine/ocean-based information to help in sufficient monitoring of phenomena caused by the ocean systems.

We need to have climate updated every week

Improve on reliability and timeliness of the information.

We require to also give emphasis on daily and weekly forecasts for the dry season, especially in terms of temperature, humidity and wind speed and direction, as this will help in giving early warning for potential occurrence of forest fires

Availability of more point/station observations

Information access that is not technically presented but palatable and easily accessible through an app or on social media. Information that is not scientific such as millimeters of rain but visually appealing explanation of forecasts that include feels, wind conditions, not daily but also morning afternoon and night weather conditions.

The time line of information should be hourly incase the weather partans changes.

- Include specific areas that are going to be impacted.
- Improve on Icons and terminologies being used for the community and others to understand.
- Ensure also to be sharing forecast during national holidays also.

Ease of access to data in a more interoperable or rather based on FAIR principles of data sharing.

Atmospheric pollution data is hardly available

The resolution could be improved

Need for enhanced collaboration and co-implementation of projects. Need for specific MOU's that clearly highlights mutual benefits. Need for weather and climate information providers to package and avail different information products tailored to the needs of the user. Need for data availability over web APIs.

Sometimes the information covers a large region and it is therefore generalised

Enable easy accessibility of some of your data.

Realtime sharing

N/A

The FFEWS system QPF (WRF) outputs which i a Kenya specific QPF. This is currently not available in the system and hence the system is using global data sets instead (GFS rainfall forecast)
We also intend to extend our collaboration to other flood prone areas in Kenya other than the Nzoia basin and hence the availability of WRF rainfall forecast will be vital.

Data collected from the automated weather station that is located at Kenya Forestry College Londiani is not relayed black to us on time and when it is actually needed.

Clarity and adequate time to prepare sufficiently.

More accuracy in weather forecasting is always more helpful.

Nothing to be changed.

Information needs to be broken to simpler language for the very local farming communities and disseminated using local radio or TV channels for wider reception.
Climate information services should be benefited by all actors in a value chain,from the input supplier,agro producer,trader.transporter,processor to the consumer

More comprehensive data is required apart from just the rainfall data. It would be nice if we could get sufficient information on all the parameters collected from the AWOS weather station here at Kenya Forestry College at a more regular interval for better planning of our activities.

Allowing free access of the data.

timely and the graphs,avoid repeating information

Timeliness in reporting

- Lack of in situ data in samburu county to inform more on weather, climate and atmospheric composition due to lack of instruments and synoptic stations
-

N/A

- merging of weather data to make sense
- better tailoring of information to sector
-

What would make it easier for you to include weather, climate and atmospheric composition information in decision-making processes in your organization/department?

Number of responses: 61

Text answers:

installation of automatic weather stations to speed up weather data collection.

Delivery of information in an easily understandable language for easy interpretation of the data given.

Shairing of county specific products

Improve on terminology for ease of use by members

If data was easily accessible based on FAIR principles of data sharing for effective integration with other data and in adjusting for response plans for the communities.

The importance of the information

By getting the information early and without fail

Ensure there is adequate funding to acquire and incorporate this information in decision making process.

Prior planning and inclusion of climate experts into decision
making processes.

Availability of data and information on all facets, and their implication in forest management

Availability of forecast information on digital formats (e.g. netcdf/raster) on dedicated online platforms

accuracy, timely and more detailed data

Accessibility, accuracy and visual appeal of data disseminated.

Accurate information from KMD

Easy access to data

Having the data always

Plan work and daily activities well and achieve them.

Available means of disseminating the forecast e.g social media and use of sms to the people that I share the information to.

I would prefer if I could see all the available data that KMD has and then judge on what amount of data I need. It would also be nice to download data from the KMD website, for example, by filling a form and making payment through convenient means such as M-Pesa and get the data in an MS Excel Spreadsheet.

I would also not like to pay for the data though since I am a tax-paying citizen.

IF THE DATA IS AVAILED IN RASTER AND VECTOR FORMAT

Simple explanation on about the forecast

Open Access Portal

Weather and climate data is easily included; atmospheric composition data should be available on a regular basis.

N/A

Clear MOU's that emphasize mutual benefits. Data availability over web API's. Project co-implantations

If this information can be available in a format that can be used to help me make an informed decision...on what to do, when to do. Help in planning for future anticipations

Timely availability of the required information

Give an enriching data on the same

Availability of free/ Low cost updated weather data for roads and bridge designs

Reliability, accuracy and consistency of the information

Provision of the said WRF to the Nzoia application for FFEWS (https://wimes.meteo.go.ke/#/welcome)

Availability of the data and clarity of the data

Availability of data at affordable rates.
Training on how to interprete climate data and terminologies used.

To have regular weather from the AWS located at Kenya Forestry College, relayed to us on more regular basis.

Automation of weather information access and transmission

Dissemination of information more widely so we have more departments, more sectors, aware of expected climate, weather and atmospheric composition information.

Accuracy and timeliness.

The information and data sharing as per the organisation need is paramount for effective use of the climate/ atmospheric data

The timeliness and availability of the data when requested
Data sharing through a MoU or partnership agreement with Kenya Forest Service

Regular availability of data

Through collaboration of disamination of weather to members of public

it be made available

Enhanced Accessibility
Timeliness of the information
User friendly to all consumers of CIS information

Use of simpler language in dissemination of the information from the meteorologists

with weather updates am in a position to fore plan, the kind of the crop to plant and the the measures should be taken in the case of extremity.

receiving the iforecasts on a timely bases.
If possible KMD can provide us with a mobile number which one can call and seek more clarification or more

specific information which may not be available in their weather forecast release

Undertake Rainfall-runoff modelling in various sub-catchments inorder to provide quantitive data & information

Having equipment that will make it easier for us to access the required information without having a proxy to get the required data.

Allowing free access to data.

adhere to

More or in-depth analysis especially for seasonal forecasts

Real time availability of climate data at a centralised location.

Targeted updates that would be useful for irrigation planning

Proposal to have Advanced-Data Integrations stems that seamlessly incorporate real-time weather and climate data into decision-making platforms used by the renewable energy department.
Establishing real-time monitoring systems that track weather conditions, enabling immediate responses to sudden changes in wind speed, solar radiation, or other relevant parameters.

It's already included in decision making

information and data sharing Portal

- Having a continuous up to date weather, climate and atmospheric composition information with clear interpretation which can be accessed through mobile phones.

integrating meteorological data with carbon cycle monitoring is crucial for understanding how rangelands and agropastoral systems function as carbon sources or sinks. Ensure comprehensive data collection of meteorological variables such as temperature, precipitation, humidity, wind speed, solar radiation, soil moisture and GHG gases. This data forms the foundation for understanding the environmental conditions influencing carbon fluxes. Maintain long-term meteorological data records to identify trends and seasonal variations that can impact carbon dynamics. Long-term data are essential for robust scientific analyses.

Summarized analysis

access to detailed, accurate, timely, agriculture specific data

We need to know the confidence level of the information at the time of forecasting, simplicity in scientific language of presentation, presentations to be self explanatory by use of friendly optically captivating graphs and maps, improvement in accuracy of predictions so that the information is reliable, quick responses in terms of alerts/updates in case there are changes observed on the ground. We need the information to be timely and to be tailor made to capture weather information regarding our areas of interest. Attention to be paid to our feedback so that issues raised are quickly addressed. We also need partnership when need arises on areas such as training of staff on weather observation.

If the information is shared timely and to relevant users

Regular training in data acquisition, processing and modern softwares

What other observations/products would you need for your mandate?

Number of responses: 55

Text answers:

soil temperatures

Standard precipitation index,Water requirement satisfactory Index

linking health data and climate to support in modelling for more predication of health conditions

Sea Surface Temperature, Sea level rise

Information on humidity and airborne salinity concentration.

None

Timely climate advisory systems.
Provision of granulated data that would be suitable for application to a specific project.

Forest fire prediction for early warning

Rainfall, temperature, humidity, wind & streamflow

heat monitoring, long term forecasts, simplfied and easy to understand data

Education on weather patterns based on climatic regions

N/A

Digital instruments for data collection

improvement of terminology, icons and clarity on words such as moderate, light showers and heavy rainfall.

Kenya Wind Map to EN 1991-1-4
Kenya Temperature Map to EN 1991-1-5.

MODELLED DATA FOR DIFFERENT SCENARIOS BASED ON HISTORICAL TREND

Riverine flood forecast maps

Sea level rise and sea surface temperature.

Atmospheric pollution levels for different pollutants

Granular ground data to validate satellite data

Gridded weather forecasts. Analysis ready observation datasets.

The kind of weather that is expected in the short term, medium term and long term .this will help to make decision on awareness creation and also policy decision

Extreme events information

Quality data
Free access to climate information dataset

Real time data on urban heat island effects and climate variations/ anomalies for incorporation in design of climate resilient infrastructures and selection of construction materials that are climate adaptative.

Long-term prediction of climate scenarios in order to assist in developing long term solutions for example in breeding for climate compatible plant varieties

Seasonal QPF for 90 day forecasting to inform the public on Water availability. We intend to put up a Water Availability Forecasting System (WAFS)

Provision of timely data for proper planning

None

Since, it has proved to be pretty difficult to get data on a regular basis, it would be nice to have a computer where all the information that is sent to the Meteorological department also received.

dissemination of information through diversified channels in the entire value chain

Marine weather reports in my area.

Unpoliticisation of KMD reports to lessen ground level consumption of their outputs.

The cloud cover data
The tides/ wave data for mangrove forest management purposes

rainfall
Humidity
temperature
wind (speed and direction)
air pollution

work on accuracy and use of modern technology

Rainfall and temperature data over a long period,to be used i models which would be used for Agro ecological and crop suitability
Data on atmospheric composition to calculate GHG emissions

Flooding information (Especially urban)
Heat and extreme temperatures warnings/advisories
Specific advisories on health in urban areas, especially informal settlements

accurate forecast

narrow down weather forecasts to county

Predicted flows for various rivers

Website where we can download the data if equipment is not working, receiver computer council. Evaporation pan

Historical data for 50 years back.

N/A

Granular data for financial institutions climate risks assessments, stress tests, scenario analysis and decision making.

An integrated system to aid in prediction of river flows

Solar Radiation and Insolation Data: to optimize the performance of solar panels and forecast energy generation more accurately.
Wind Profile and Turbulence Data are critical for wind energy generation. This data can help select optimal turbine locations and predict wind energy output.

None on top of the already agreed ones that are being provided as per Letters of agreement

- A model that will show the economic impact of weather, climate and atmospheric composition information to the community
- A tailor made forecast for the pastoralist community on the pasture and water availability

Develop integrated models and tools that combine meteorological data with carbon cycle data, including measurements of soil carbon, vegetation growth, and livestock emissions. These models can help quantify the carbon balance.

Planting seasons and crops for different regions

none

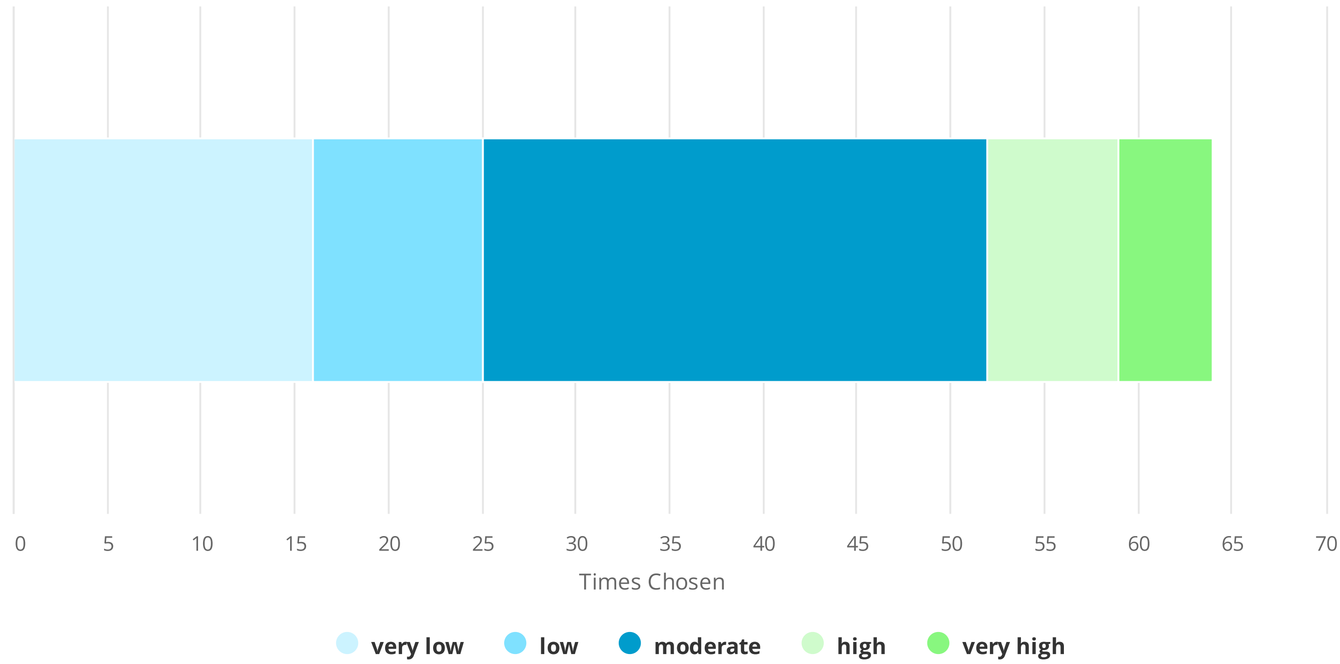
Pasture coverage, frost prediction, Moisture/humidity levels, Temperatures, Wind directions

Flood and drought early warning

Remote sensing weather products

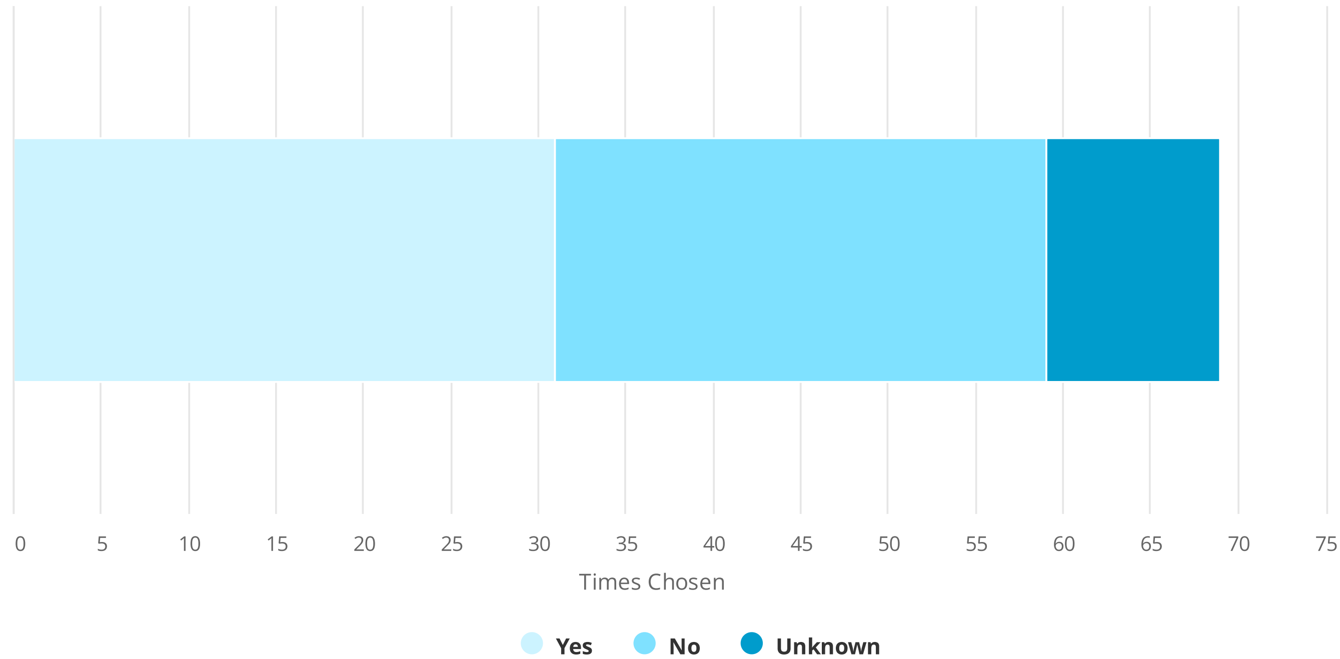
How would you rate your or your organization’s willingness to pay for some of the weather, climate and atmospheric composition information to help improve these services?

Number of responses: 64



Do you use information about atmospheric composition / air quality (greenhouse gases, aerosols, reactive gases)?

Number of responses: 69



For what purpose(s) do you use air quality information?

Number of responses: 29

Text answers:

Planning for resilience projects within livelihoods

Greenhouse gases connection with carbon storage by coastal and marine ecosystems as well as ocean acidification.

Level of reaction that leads to deterioration on highway structures

To ensure our operations do not excercebate the issue of air pollution especially during material extraction and road construction activities.

For research and monitoring purposes

WE ARE SUPPOSED TO GENERATE LANDCOVER CHANGE DATA (ACTIVITY DATA) THAT AID ESTIMATION OF GREENHOUSE GAS

Trying to understand localized air pollution phenomenon.

Research

we collect, analyze and share ground air quality data to inform policy and decision making

As part of the data to develop integrated hazard maps. Estimation of impacts of the intervention measures through of estimation of carbon sinks

1. Air polution control
2 monitoring of green house gases

Dispersion modelling in geothermal power plant designing and also getting to know whether our operations are affecting the local air quality

Information on air quality helps in rating of tea products for market purposes for example low carbon tea is expected to be produced in environment with minimal or near zero GHG emisions

For determining the quality of irrigation water

For monitoring air quality emissions so that we do not exceed the limits/ for compliance.

To determine the quality of water.

to enable us to scale adoption of green energy methods in our organization.

To evaluate the effect of trees and vegetation in influencing air quality eg urban areas and in mediating some of the negative effects of pollutants.

The type of tree species to be planted based on the region effectiveness on air cleansing

Research
Policy development and advice
Management planning (e.g. air quality plans)
Early warning
public awareness

To calculate the GHG emission levels,as is a requirement for the Nationally Determined Contribution (NDC) as per the Paris agreement for Kenya

nitrogen flash

Research

Personal- determine quality of air for different locations

Consulting for banks in Kenya

for the lolice maker support and

ICAO Annex 16 Volume Volume IV requirements on environmental protection particularly air pollution caused by civil aviation activities.

Climate change general understanding

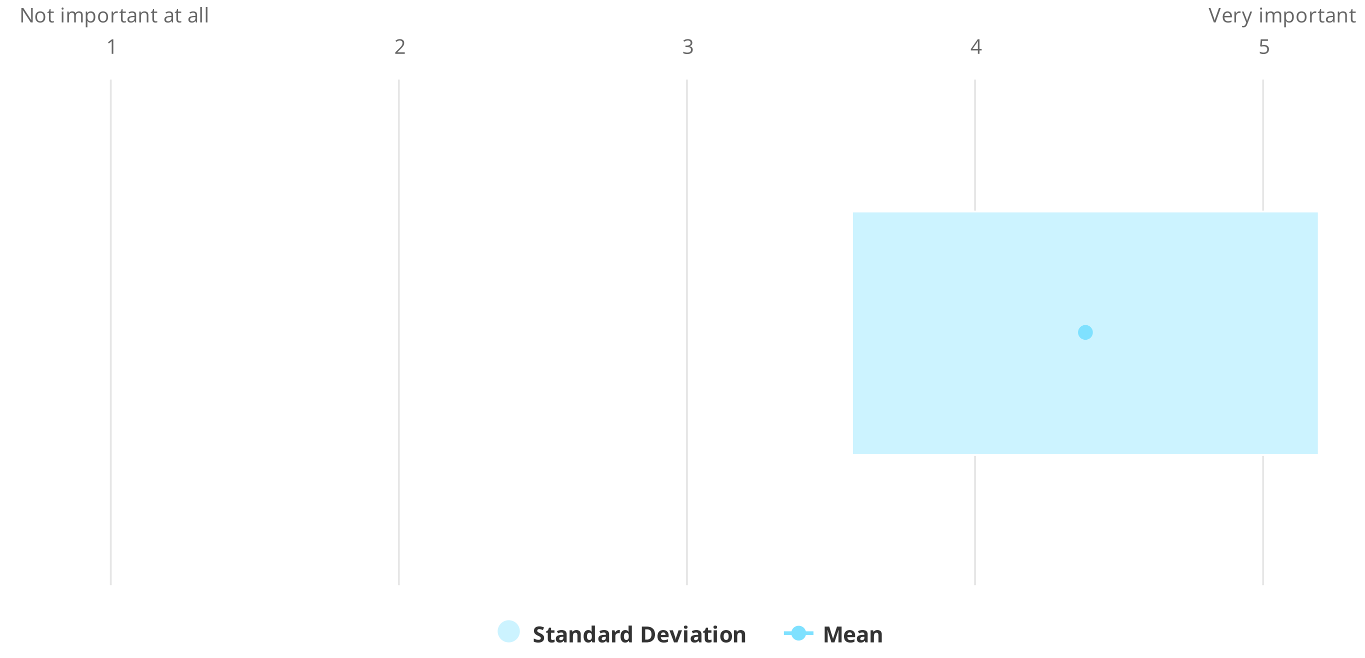
We monitor Greenhouse Gases such as Methane and carbon dioxide to determine whether ecosystems are a carbon source or sink. This helps us understand how to effectively manage grazing lands optimally to guide food production (livestock farming) while ensuring low emissions.

Due to activities of production/emissions to the air we need air quality information to determine if we legally comply to the set standards to avoid any pollution to the environment

Climate change research

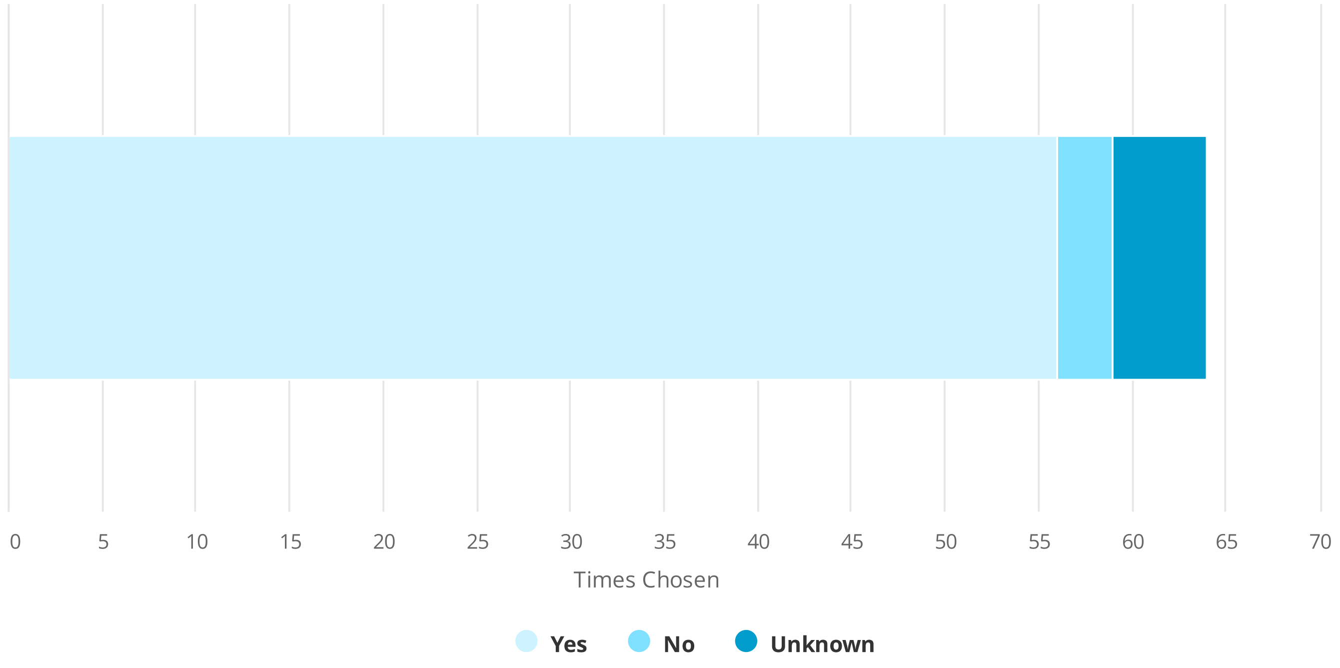
How important is timely information (measurement data) of air quality to you?

Number of responses: 29



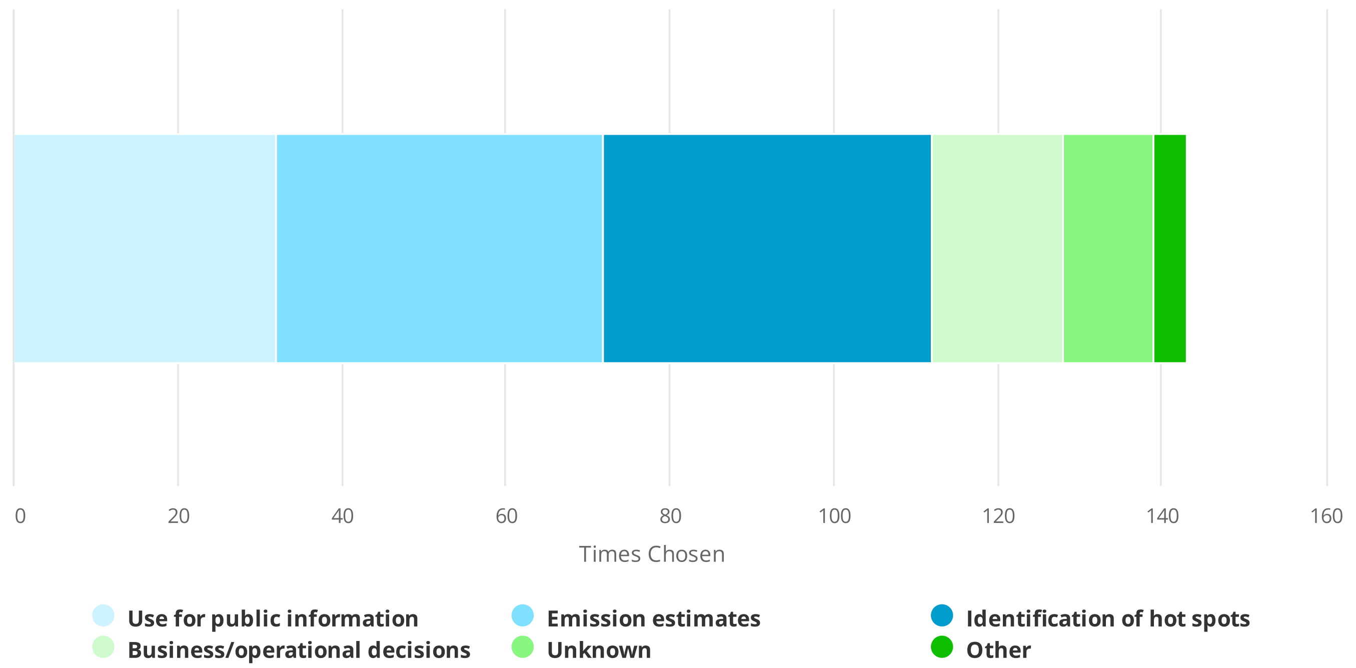
Do you see a need for (improved) information on atmospheric greenhouse gas concentrations?

Number of responses: 64



How could you benefit from timely greenhouse gas concentration data?

Number of responses: 64



"Other" text answers:

Enforcement of laws

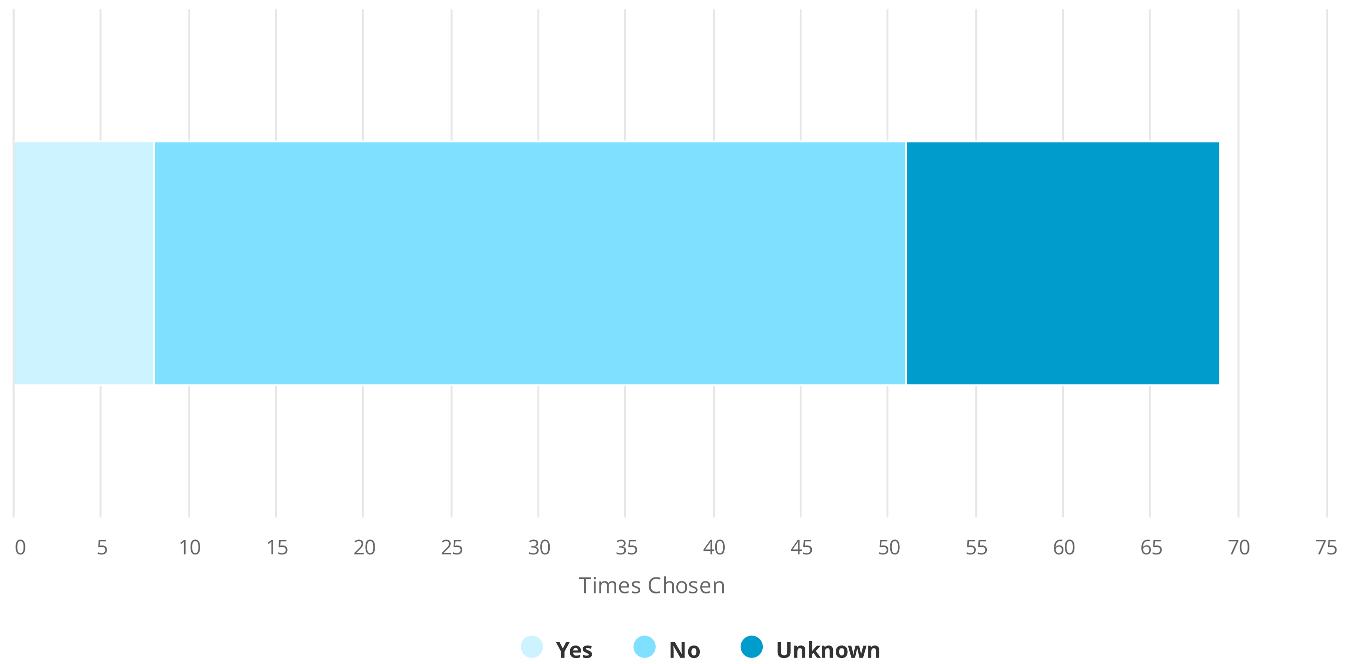
Other

farming

Residential area situation

Are you using data on atmosphere-biosphere exchange?

Number of responses: 69



For which purpose do you use atmosphere-biosphere exchange data?

Number of responses: 6

Text answers:

Climate change analysis and reporting

To help minimize pollution by designing efficient operation methodologies

Development of models for climate impacts on natural resources (water, agriculture etc)

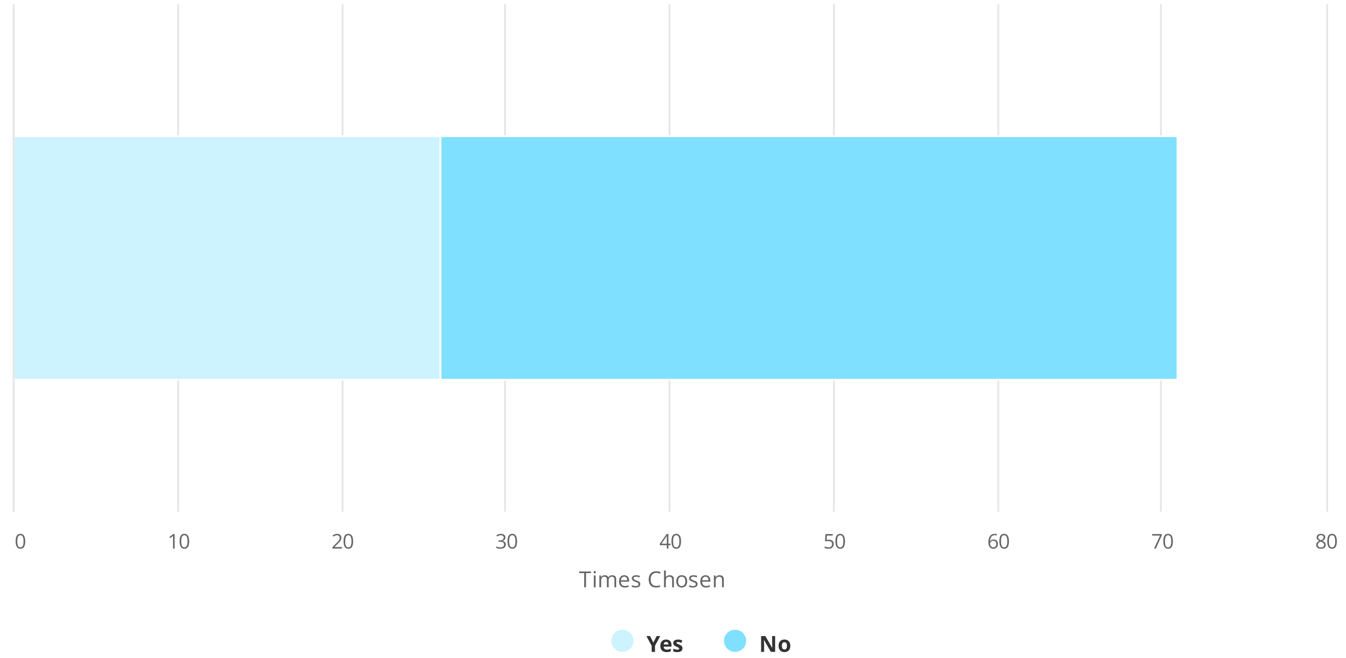
Research

The purpose for using atmosphere-biosphere exchange data is to understand how ecosystem functions and regulates uptake and release of GHG emissions. This way we can design sustainable management of the ecosystems for increased food productivity while ensuring low emissions.

Monitoring dynamics of vegetation in relation to water and carbon fluxes in Permanent Sample Plots (PSPs)

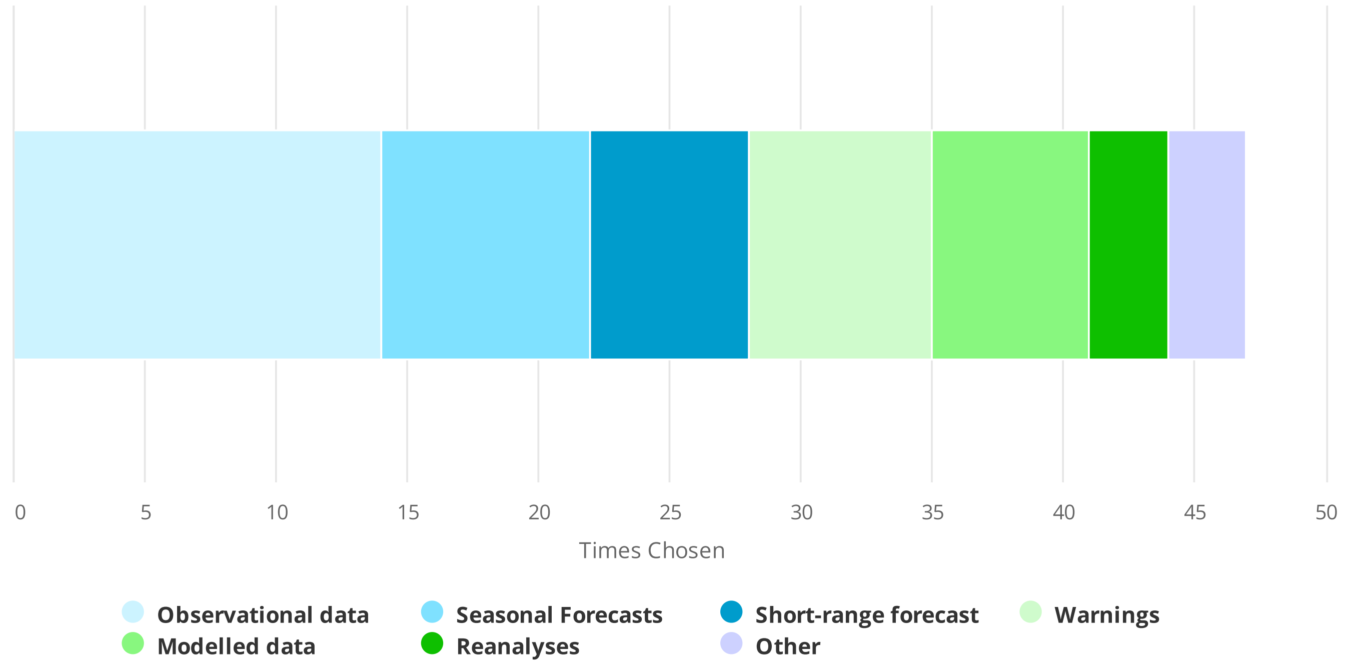
Do / did you provide weather, climate and/or atmospheric composition information?

Number of responses: 71



What kind of weather, climate and atmospheric composition information do you provide?

Number of responses: 23



"Other" text answers:

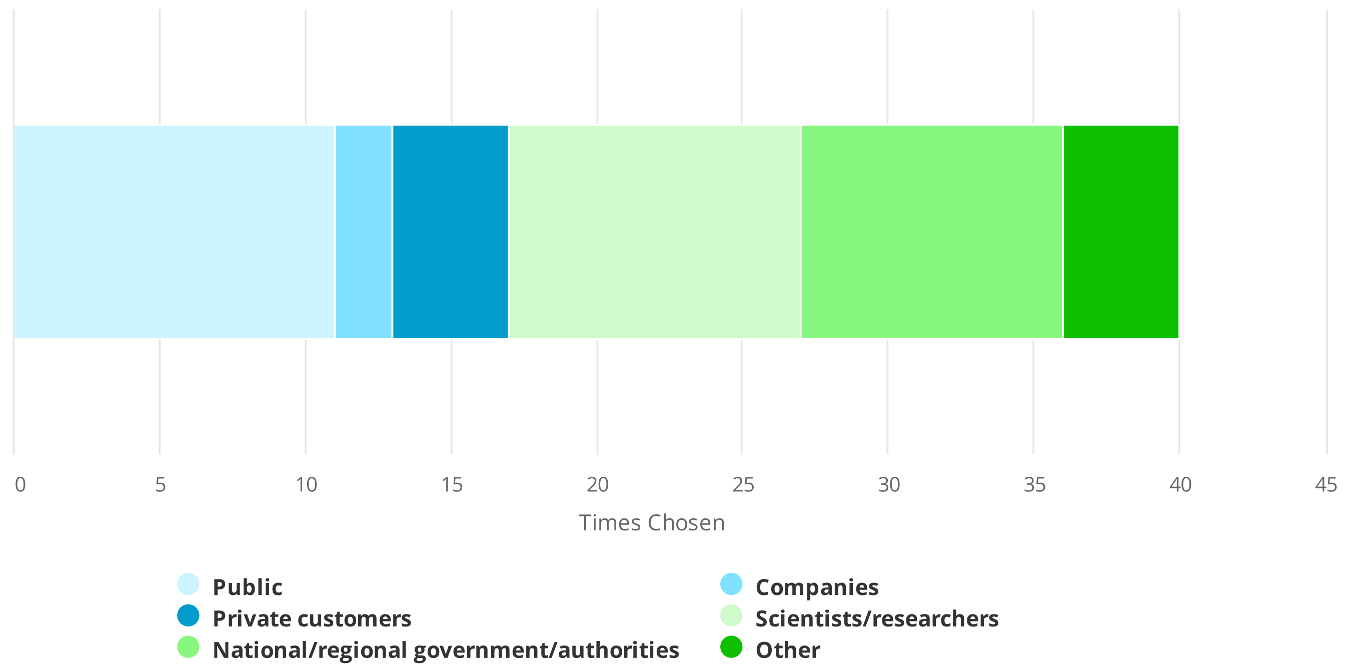
daily and weekly

Nairobi City weekly forecast

Rainfall data from some of our forest stations

Who do you provide this information to?

Number of responses: 23

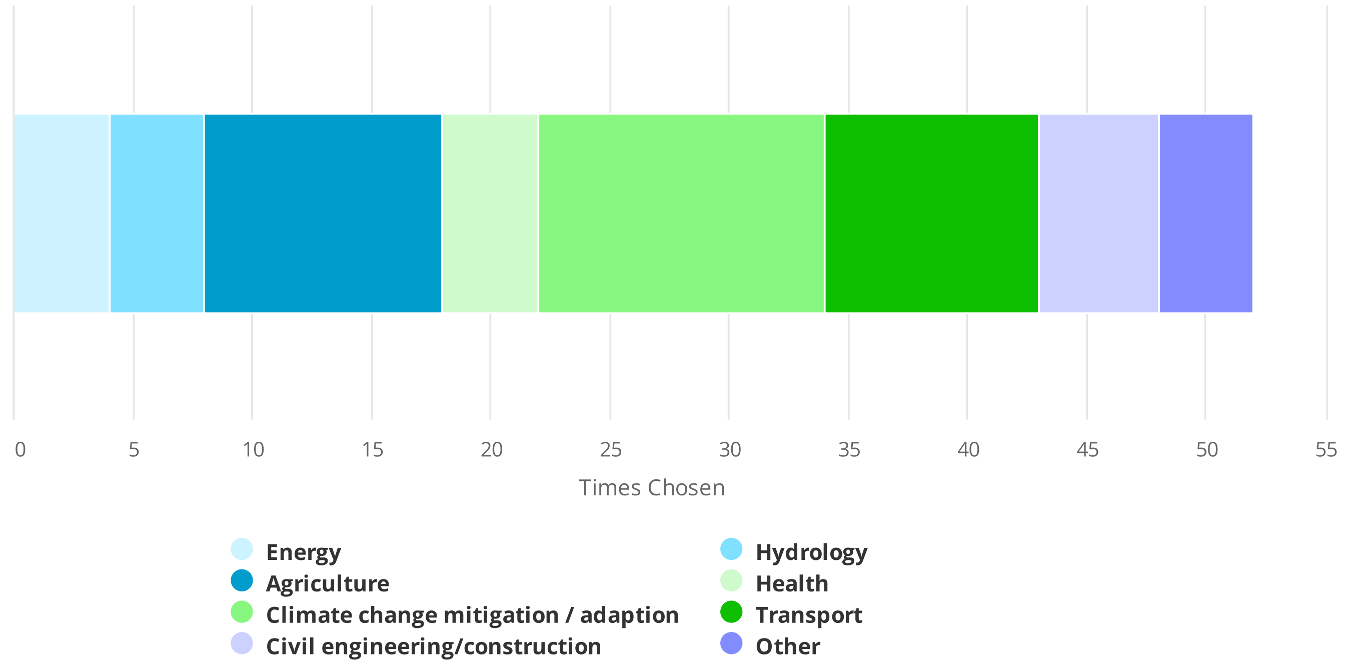


"Other" text answers:

Internal use
farmers
Aircraft
farmers

Is your weather, climate and atmospheric composition information intended for a specific sector / area? If yes, for which?

Number of responses: 23



"Other" text answers:

Mainly for research, which could include some of the above sectors

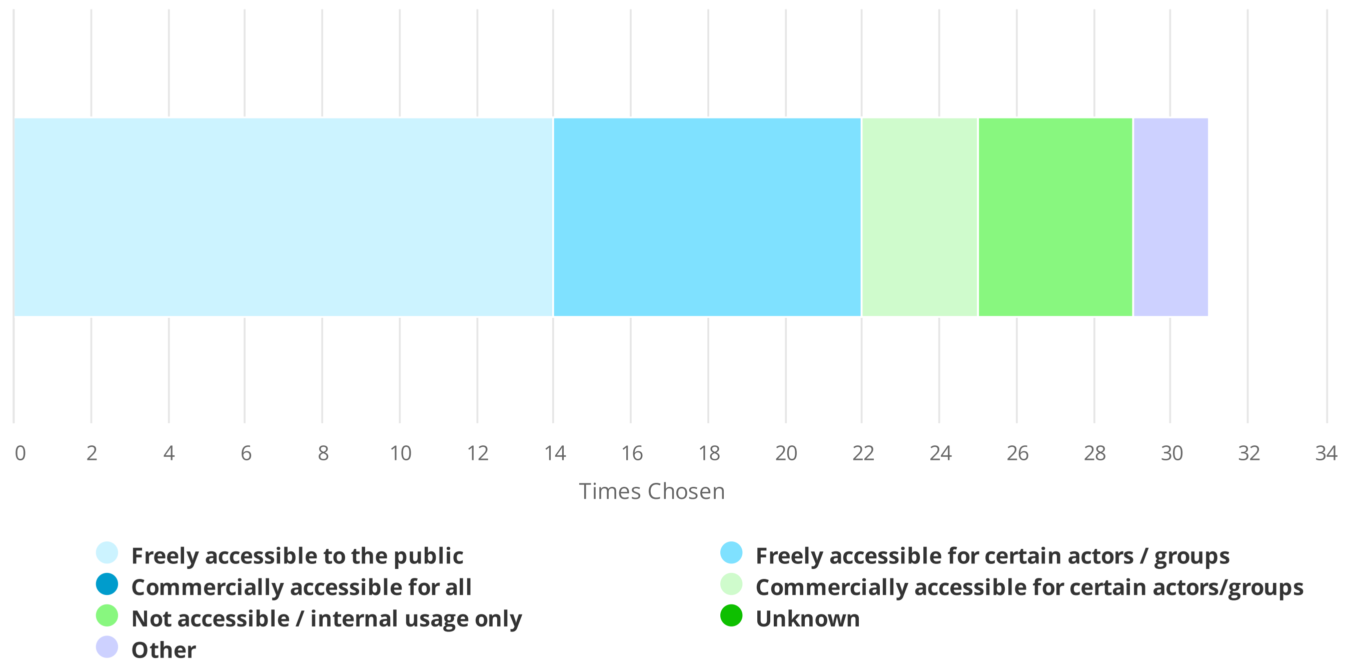
General public

We share rainfall data with KMD

Environmental conservation and education

How is the information you provide accessible?

Number of responses: 24



"Other" text answers:

Other

cell phone messages

How do you provide the information (e.g. Print media, Website, direct delivery to customers)?

Number of responses: 23

Text answers:

Direct deliver to customers

Daily print media, social media

Provided through online portals, website and social media

Ward of mouth and social media platforms.

Direct delivery to KMD

through SMS, WhatsApp group(s), Facebook, Instagram

1.weathermtaani Facebook page
2. Weather mtaani whattsapp group with 50 users who also send the translation to their networks.
3. Personal contacts
4. By word of mouth to 24 weather mtaani leaders.
5. In few cases I'm invited by local radio station I.e Pamoja radio.

Direct delivery

reports, websites, print media

Direct delivery for internal use

Radio and print

Direct delivery to client on request

Flood Advisories.

Data (Water-level. Discharge) via E-Citizen government platform.

NEMA website

Data shared directly to KMD

websites

Standards and journal articles.

facebook,google

publications

Civil Aviation channels such as VHF communication and Aeronautical Fixed Telecommunication Network (AFTN)

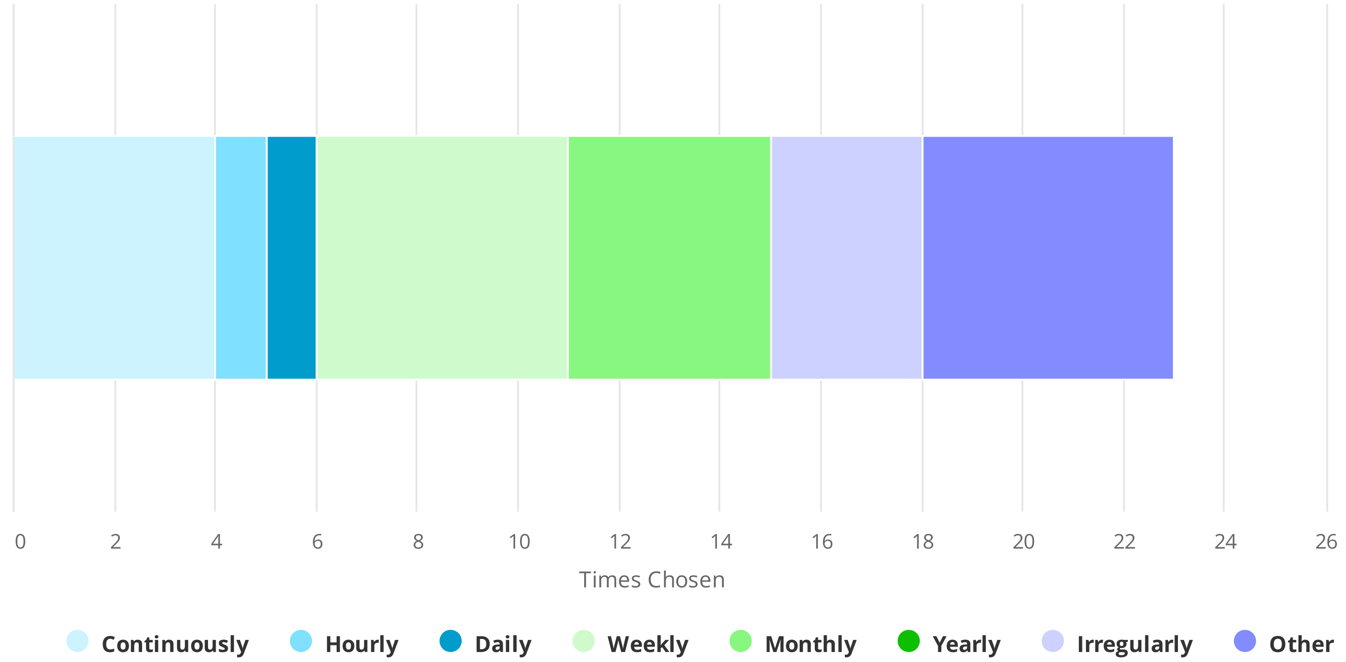
Direct delivery by email exchange and sharepoint.

eGranary

Not applicable

How often do you provide the information?

Number of responses: 23



"Other" text answers:

On Request

Seasonally

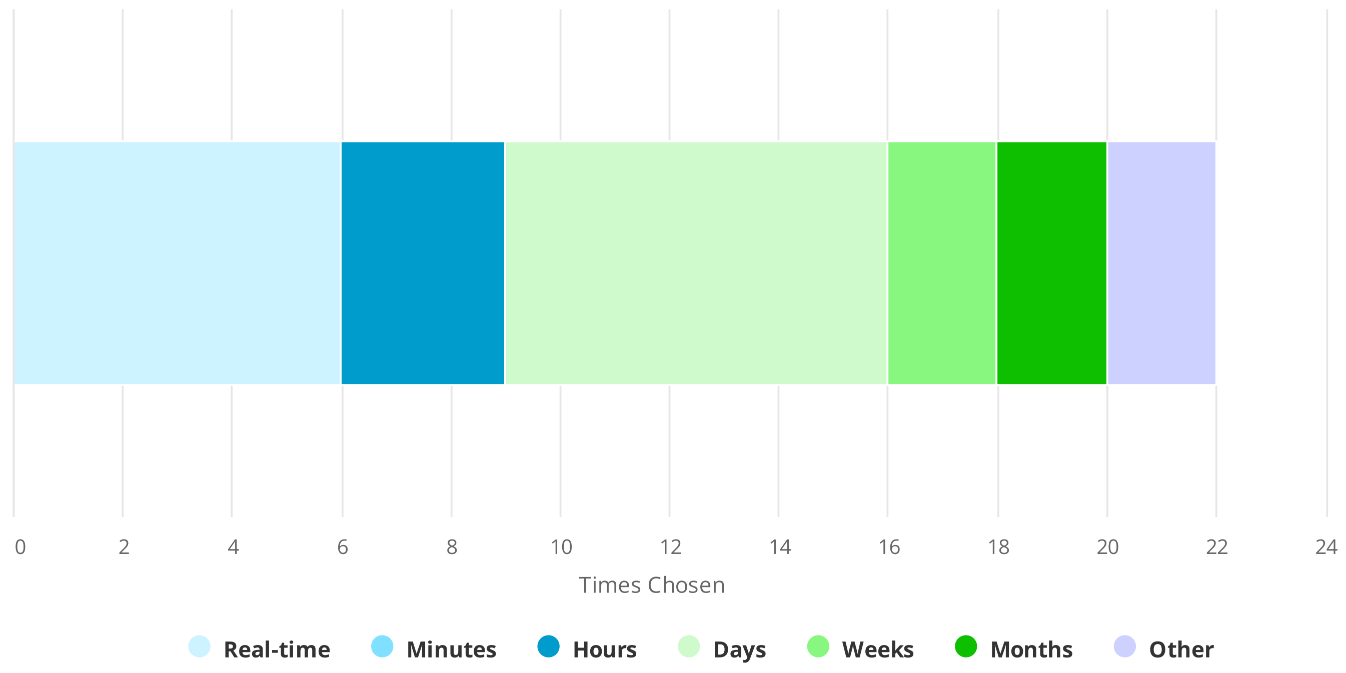
Quarterly

On request mostly. And monthly to some on-going research

on need basis

What is the current lead-time (delay) for providing the information?

Number of responses: 22



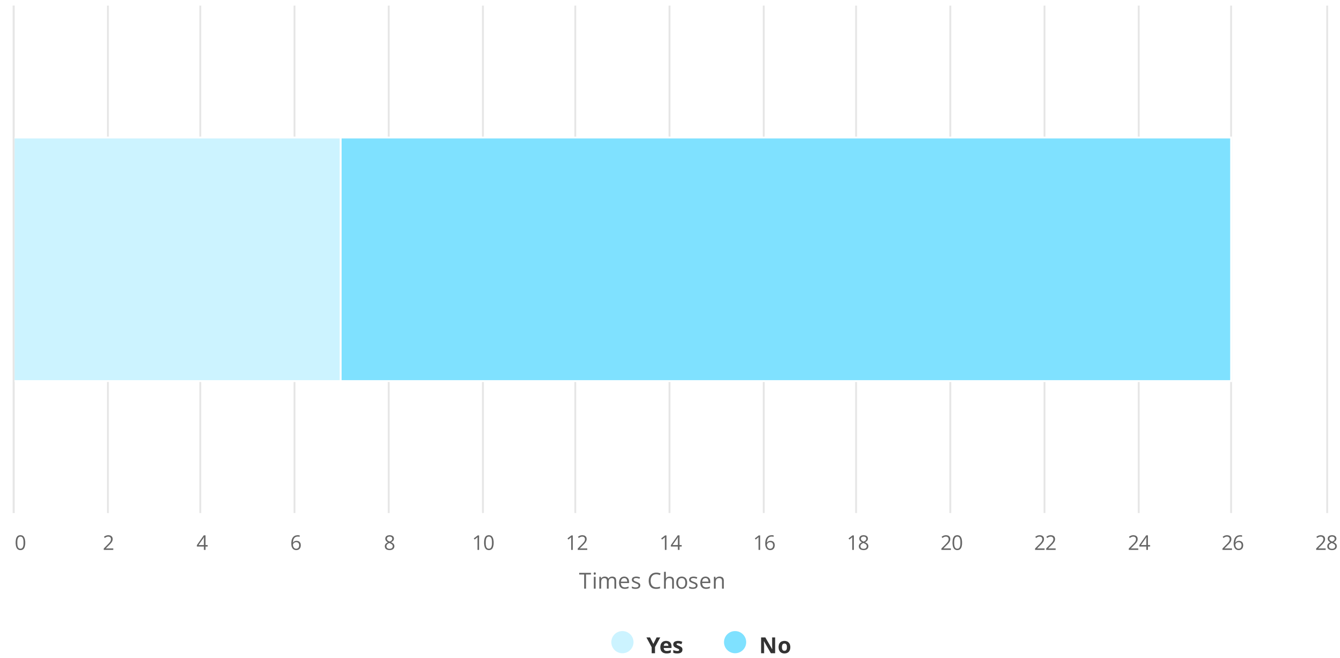
"Other" text answers:

On need basis

Other

Do or did you establish / operate a network for (intentionally) long-term weather, climate and atmospheric composition observation data?

Number of responses: 26



What is the name of the network?

Number of responses: 4

Text answers:

Weather Mtaani Community group

Consortium for better air quality in Africa

Waterlevel Monitoring Network

ILRI

When was the network established (year)?

Number of responses: 4

Text answers:

2017

2022

Precolonial

2021

Who (what partners) established the network?

Number of responses: 4

Text answers:

Kibera Community based group

UNEP and SEI

Precolonial

ILRI, University of Helsinki

Who initiated the process (came up with the idea, the need, the requirement)?

Number of responses: 4

Text answers:

Community leaders with KDI as their partners.

UNEP

Government Mandate

ILRI, University of Helsinki

Who provided the initial funding? How much?

Number of responses: 4

Text answers:

Kounkuey Design Initiative

UNEP

Precolonial

European Union Desire

Why was the network established (intended applications, legislation it is based on)?

Number of responses: 4

Text answers:

To create awareness on weather information and to disseminate it to the larger community to plan and use it on their daily activities.

Collect and share information on air quality in Major African Cities to inform policy and decision making

Government Mandate
Water Act 2016

This was through Earth Observation and Environmental Sensing project funding with University of Helsinki, ILRI and other partners.

How much time passed between the initial idea and the beginning of the operation of the network?

Number of responses: 3

Text answers:

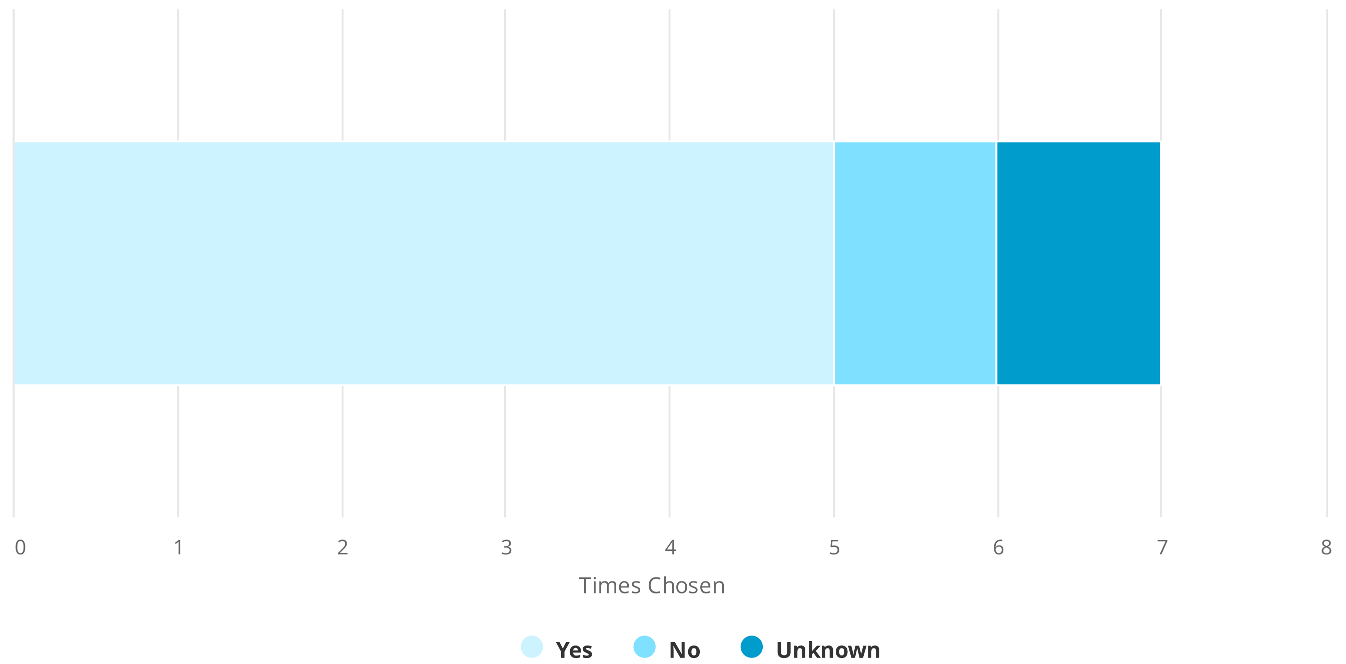
2 weeks

Precolonial

1 year

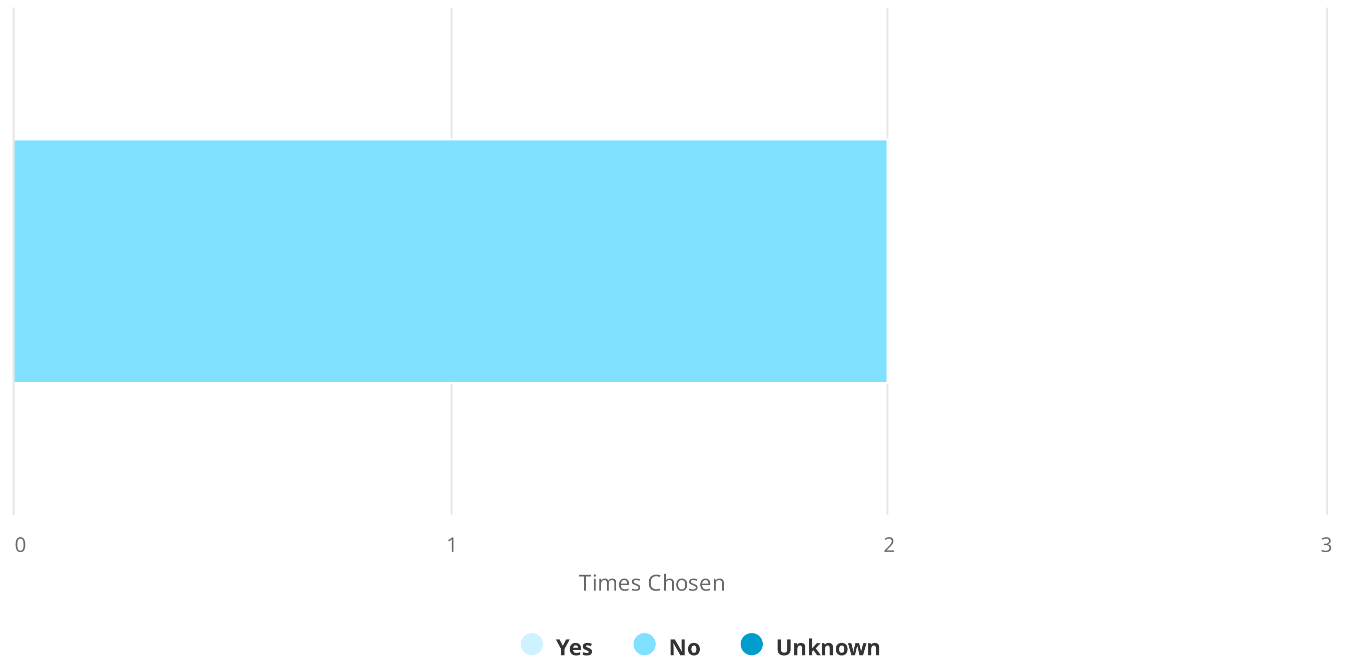
Was the network established with long-term monitoring in mind?

Number of responses: 7



Was the network intended for a campaign?

Number of responses: 2



Was the objective of the campaign achieved?

Number of responses: 0

No answers collected yet

Was the network dismantled after the campaign or did it just die?

Number of responses: 0

No answers collected yet

Who is operating the network?

Number of responses: 4

Text answers:

Weather Mtaani leaders

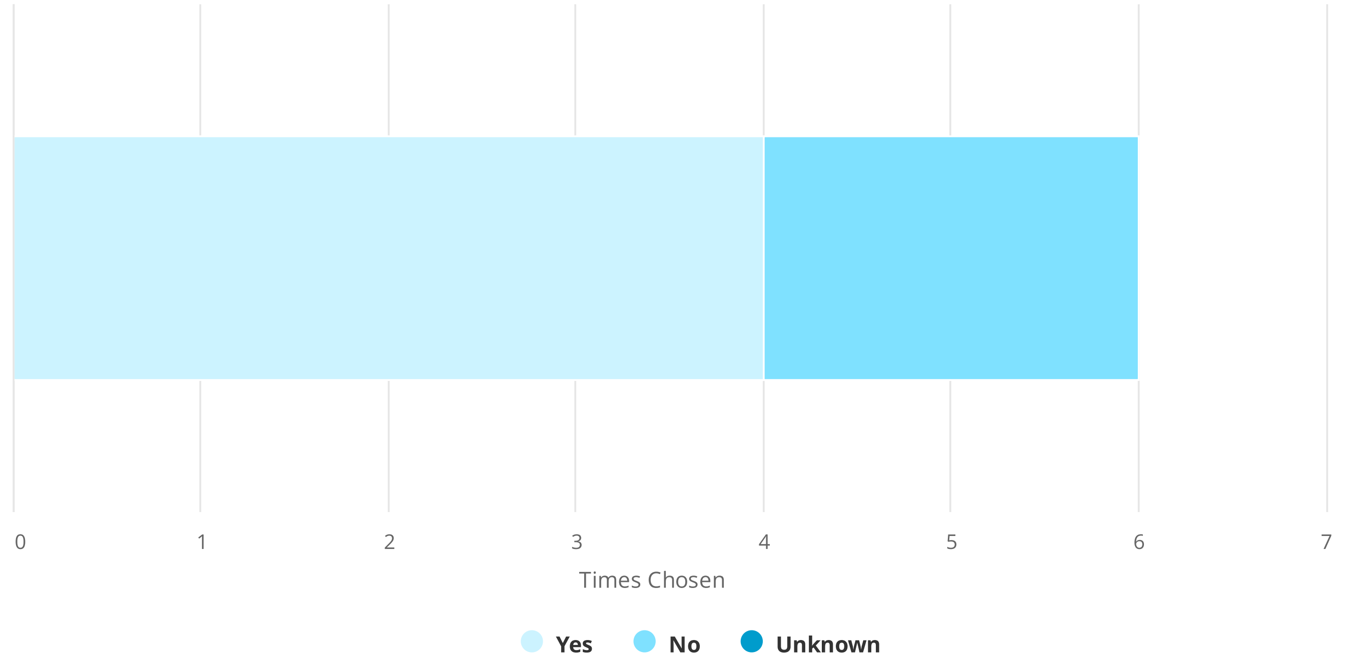
UNEP and SEI

WRA

ILRI/University of Helsinki

Was the current operator involved from the beginning?

Number of responses: 6



How much is the operational annual budget?

Number of responses: 3

Text answers:

360,000

To be discussed

N/A

How many person-years are invested in the operation on a yearly basis?

Number of responses: 3

Text answers:

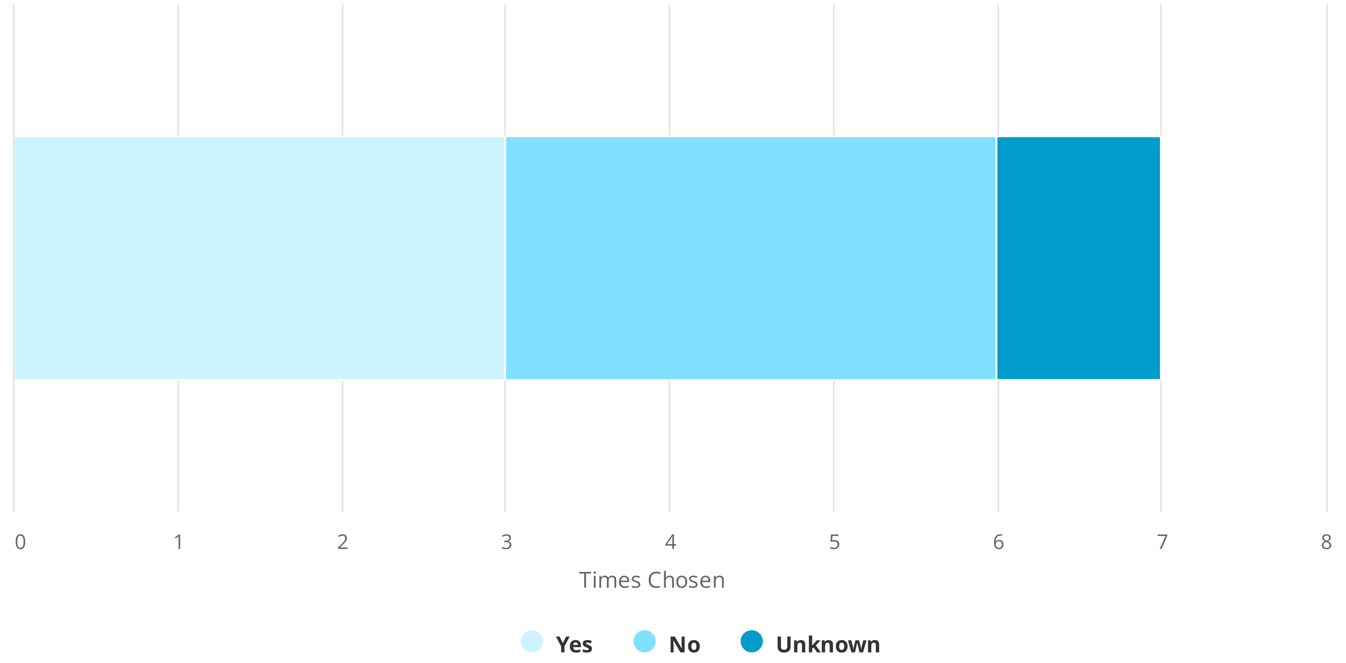
30 person

To be discussed

~20

Is the network fully operational?

Number of responses: 7



What parts are active/operational?

Number of responses: 2

Text answers:

Data management platform

Stations are operational but not 100%

What parts are closed / no longer operational?

Number of responses: 2

Text answers:

N/A

Some waterlevel stations

Why were they closed?

Number of responses: 2

Text answers:

N/A

It is common for some stations to breakdown
They are revived during routine maitenance

In case the network is no longer operational: How long was the network operated?

Number of responses: 2

Text answers:

N/A

This can be examined on a case by case basis

How many stations does the network contain?

Number of responses: 4

Text answers:

4

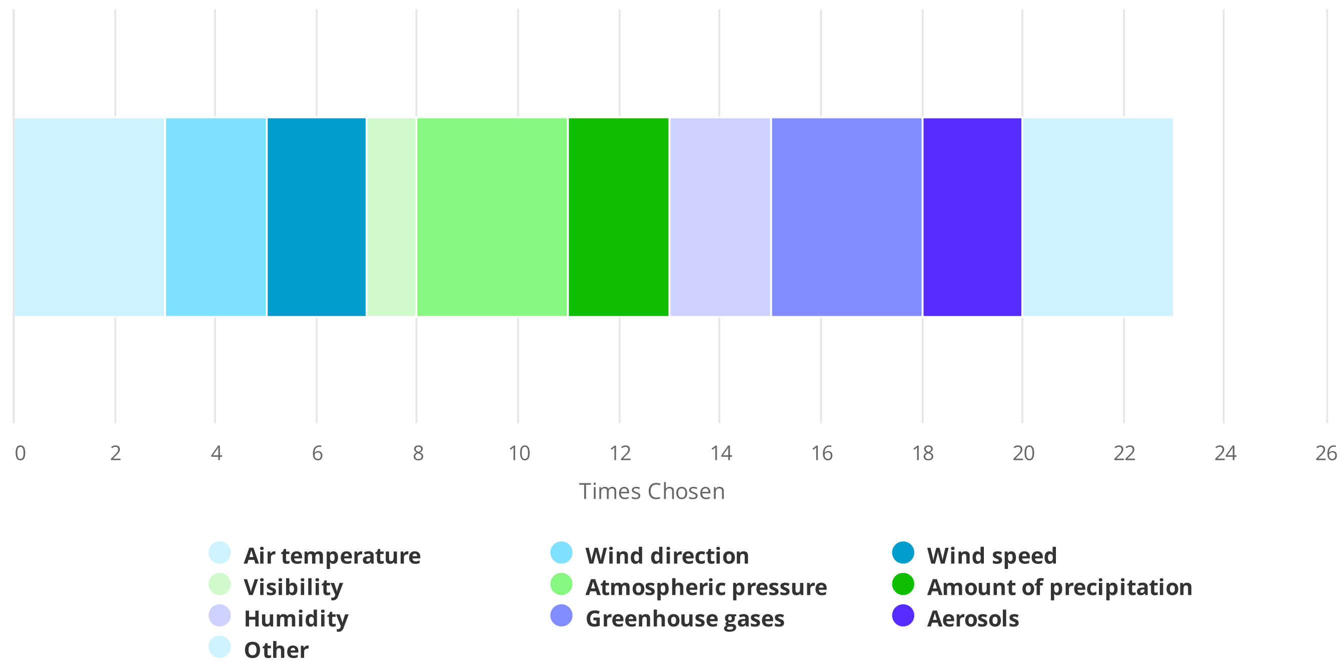
More than 100 air quality Sensors deployed across major cities in Africa

Over 1000 waterlevel monitoring stations

4

What are the observed variables?

Number of responses: 6



"Other" text answers:

weather forecast
Particulate Matter
Waterlevel and Discharge

What instruments are used?

Number of responses: 5

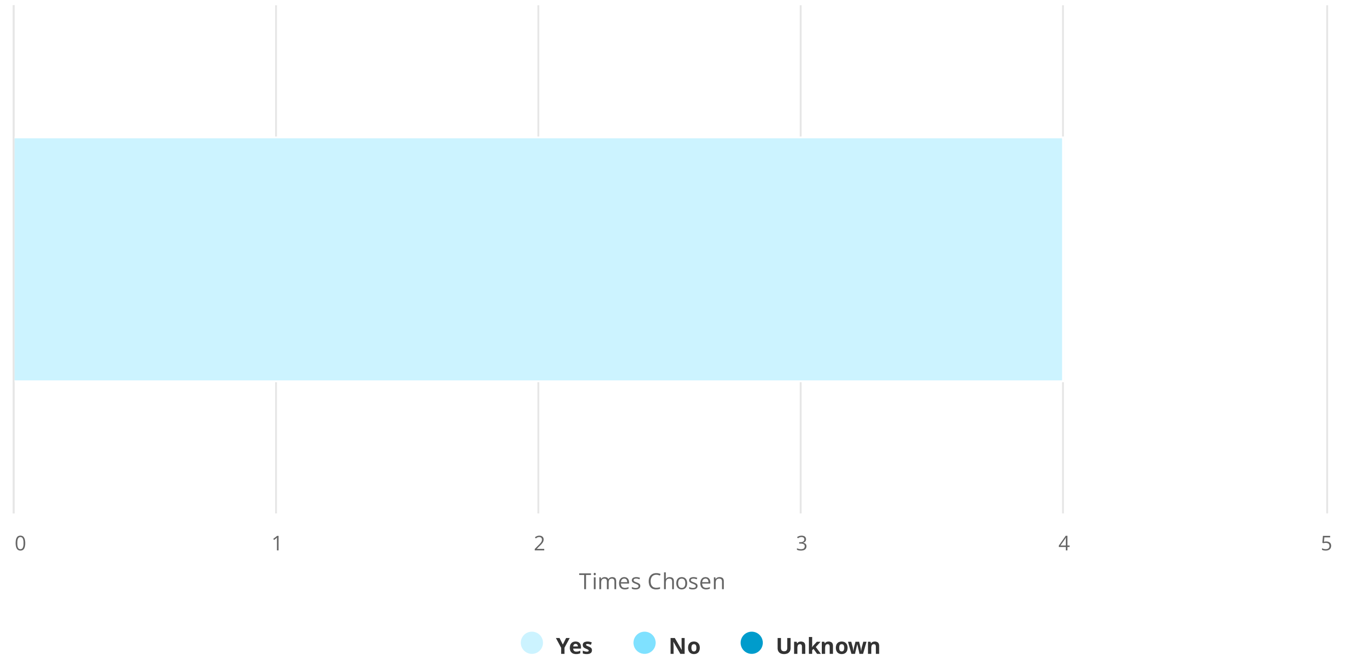
Text answers:

sms whatsapp, facebook, door to door awaness, word of mouth
air quality sensors
Water gauges(Manual and Telemetric), Discharge Measuring Equipment
AEROSOL CHEMICAL COMPOSITION , SCANING MOBILITY PARTICLE SIZER, BLACK CARBONE ANALYSER AND LOW COST INSTRUMENT

Eddy Covariance complete station

Are all stations equipped with the same instruments and are measuring the same variables?

Number of responses: 4



Where are the stations located (distributed over whole country, specific region, etc.? / focusing on rural or urban areas?)

Number of responses: 5

Text answers:

Laini Saba, Makina, Lindi, Gatwekera and entire community of kibera

major cities in Africa

Whole country across all basins

COUNTRY SIDE AND IN CITY CENTER

Kenya (Kapiti and Taita-South Eastern Kenya)

Who is the data owner?

Number of responses: 5

Text answers:

Weather Mtaani group

UNEP

WRA

RSA

ILRI and University of Helsinki

What is the data policy?

Number of responses: 5

Where can the data be obtained?

Number of responses: 4

Text answers:

weather mtaani websites

UNEP and SEI

WRA

ILRI and University of Helsinki

In case data is not freely available, why not?

Number of responses: 2

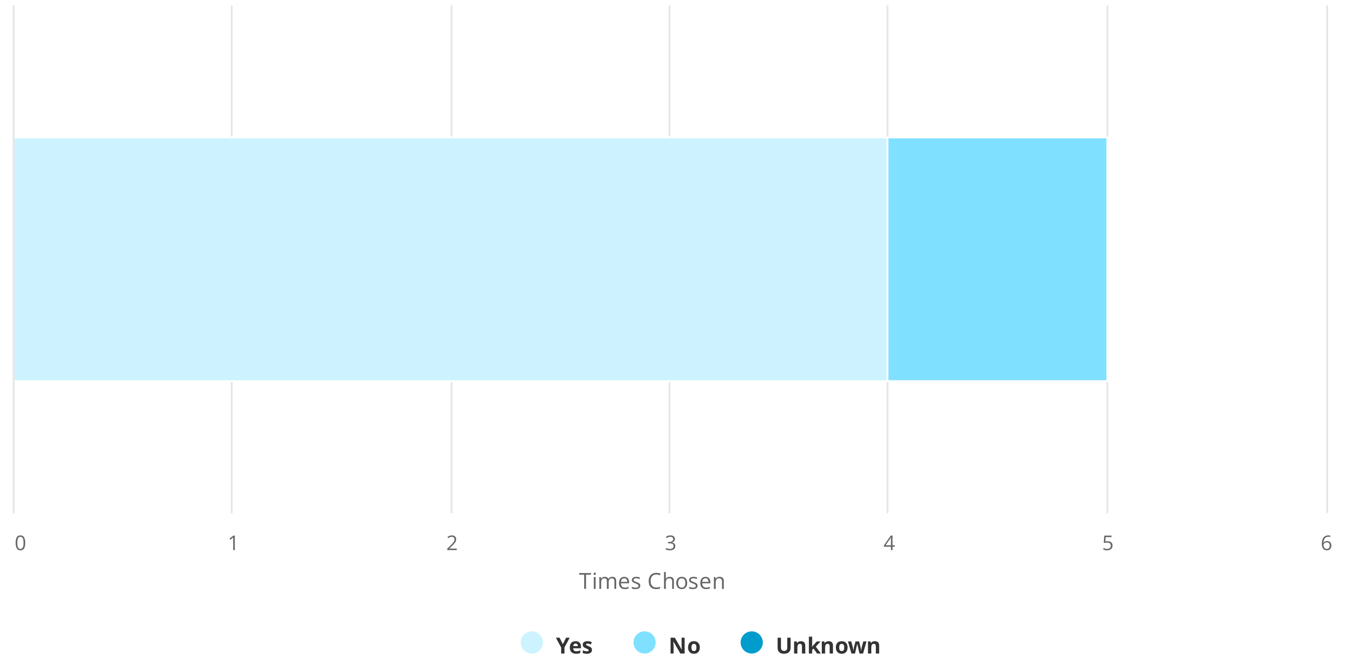
Text answers:

Government policy (Water Act 2016(

The data is available on a collaborative basis

Were the original objectives for making the observations achieved?

Number of responses: 5



If not, why not?

Number of responses: 1

Text answers:

The project is on-going.

What are the gaps in the network (either in terms of spatial distribution, temporal coverage, or even missing observed quantities)?

Number of responses: 4

Text answers:

Spatial distribution sensors have not yet been installed in all the major cities in Africa

spatial distribution, temporal coverage, and observed quantities

Stations in northern Kenya are not well distributed.

We experienced theft of equipment leading to data gaps of few months (~3months gap).

What other observations would you need for your mandate?

Number of responses: 5

Text answers:

heat warnings

N/A

QPF

Free data.

Biomass and soil

Are there any reports documenting the use of the observations? If yes: can you provide a link?

Number of responses: 3

Text answers:

Yes

https://wra.go.ke/water-situation-reports/

This is in progress. We are currently writing the draft papers.

Are there existing (climate) services / applications that rely on the network? If yes, please name them.

Number of responses: 1

Text answers:

N/A

Do you have a 'lessons learnt' report from the project(s) leading up to the network? If yes: can you provide a link to the document or send it to us: kadi-survey@mail.icos-cp.eu?

Number of responses: 1

Text answers:

https://capacity4dev.europa.eu/projects/desira/info/essa-east-africa_en