



Engineering

in KENYA

ISSUE 028

PUBLISHED BY THE INSTITUTION OF ENGINEERS OF KENYA

| AUG 2026



GEOSPATIAL ENGINEERING



ISSN : 2710-3951



Engineering in KENYA

PUBLISHER The Institution of Engineers of Kenya

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The Institution of Engineers of Kenya (IEK) publishes Engineering in Kenya magazine, whose target audience includes engineering professionals, practitioners, policymakers, researchers, educators and other stakeholders distributed to its target readers free of charge through hard and soft copies. IEK invites you to contribute articles for our next and future editions. Articles should reach the Editor not later than **20th October, 2026** for our next issue, whose theme is **Renewable Energy & Energy Storage Engineering** and related sub-themes, across all engineering disciplines. An article can range from engineering projects to processes, machinery, management, innovation, news and academic research.

The articles must be well researched and written to appeal to our high-end readers in Kenya and beyond.

The IEK Editorial Board reserves the right to edit and publish all articles submitted, in line with the standing editorial policy. All articles should be in Word document format, 500-700 words, font type Times New Roman and font size 12.

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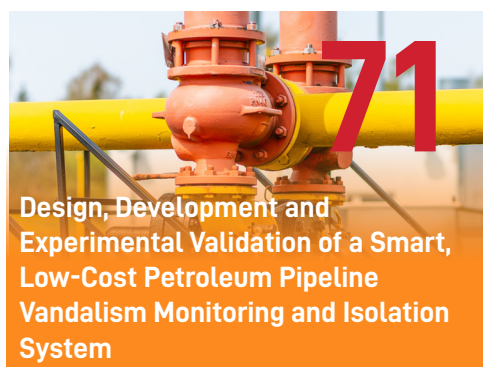
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Message From the Editor



**Eng. Prof. Alex
Muumbo, PE, FIEK**

There is a quiet but profound shift underway in how Kenya, and Africa more broadly, plans, builds and governs its physical space. Increasingly, the decisions that shape our roads, our power grids, our cities and our land records are being made not on instinct or precedent alone, but on data layered, mapped, and spatially referenced. This is the terrain of geospatial engineering, and it is the subject to which we devote this 28th issue of Engineering in Kenya Magazine.

Geospatial engineering sits at a deceptively quiet intersection of disciplines surveying, remote sensing, geographic information systems, spatial statistics and digital infrastructure yet its reach into national life is anything but quiet. It underpins how we register and administer land. It determines how a highway corridor or a power transmission line is routed. It shapes how cities anticipate flooding, how

farmers anticipate drought, and how statisticians count a nation. Few engineering disciplines touch as many sectors, or as many lives, with so little public fanfare.

This issue reflects that breadth. In the pages ahead, you will find conversations with leaders drawn from across government, industry, academia and professional practice: from the State Departments responsible for Lands and Physical Planning, Roads, Water and Sanitation, and Environment and Climate Change; from the chief executives of Kenya's national infrastructure authorities and utilities roads, rail, power, water and highways; from the Engineers Board of Kenya and the Institution of Surveyors of Kenya on standards, competencies and the future of professional practice; from the Kenya National Bureau of Statistics on spatial data and census mapping; and from the United Nations Office at Nairobi on the role of geospatial intelligence in sustainable development and disaster risk reduction. Academia and the next generation of practitioners are equally represented, a reminder that this field's future depends as much on the classrooms of today as on the boardrooms of tomorrow.

Taken together, these conversations illustrate a simple truth: geospatial engineering is no longer a specialist back-office function. It is becoming central to how national infrastructure is planned and maintained, how land tenure is secured, how climate and disaster risks are anticipated, and how our

cities will be built and rebuilt in the coming decades. The feature articles in this issue spanning GIS, remote sensing and satellite data for sustainable development, engineering solutions for cadastral systems and land governance, and the rise of smart cities and digital twins carry that same thread through to practical application.

As Editorial Board, we are conscious that an issue such as this does more than inform. It also signals to the wider engineering fraternity where the profession is heading, and invites those still on its margin's students, early-career engineers, allied professionals to see geospatial engineering not as a niche specialization but as a discipline with an expanding claim on Kenya's development future.

We are grateful to every interviewee and contributor who gave generously of their time and expertise to make this issue possible, and to the writers who conducted these conversations and shaped them into the features you are about to read. Their collective effort is what allows Engineering in Kenya Magazine to continue serving as a credible mirror of the profession reflecting not only where engineering in Kenya stands today, but where it is being deliberately taken.

We trust you will find this issue as informative and thought-provoking to read as it was rewarding to compile.

Happy reading.

Message From the President



Eng. Harrison Kiplimo Keter,
PE, MIEK

President, Institution of
Engineers of Kenya

I welcome you to EiK Issue 28, a publication that continues to provide an important platform for knowledge sharing, professional dialogue and reflection on the role of engineering in Kenya's development. This issue, dedicated to Geospatial Engineering, provides us with the ability to understand, interpret and apply spatial information that has become increasingly central to how we plan, develop and manage our built and natural environment.

Geospatial engineering has evolved significantly beyond the traditional understanding of mapping and surveying. Today, spatial data and technologies inform decisions across land administration, infrastructure development,

transportation, energy, water, agriculture, environmental management, urban planning and disaster risk reduction. As Kenya experiences rapid urbanization, infrastructure expansion, climate-related challenges and increasing demand for efficient public services, the ability to generate reliable spatial information and translate it into actionable intelligence has never been more important.

The breadth of contributions featured in this issue reflects this changing landscape. The publication explores the application of Geographic Information Systems (GIS), remote sensing and satellite data in sustainable development, while examining the role of geospatial technologies in land administration, cadastral systems and tenure security. It also considers how spatial intelligence can support road planning and asset management, transport corridors, electricity transmission and smart-grid development, water-resource planning, railway infrastructure and urban development. These perspectives demonstrate that geospatial engineering is not an isolated discipline; it is an essential component of multidisciplinary engineering practice and national development.

The emergence of smart cities and data-driven development further underscores the strategic importance of spatial intelligence.

As cities and infrastructure systems become increasingly interconnected, engineers must be able to work with accurate, timely and integrated spatial information. Concepts such as digital twins, real-time geospatial intelligence and spatial data integration are opening new possibilities for planning, design, monitoring and management. The future of engineering will increasingly depend on our ability to combine professional expertise with digital technologies and evidence-based decision-making.

Climate change and environmental pressures make this capability even more critical. Geospatial technologies provide powerful tools for monitoring environmental change, supporting climate action, mapping disaster risks and strengthening resilience. They can help policymakers, engineers and communities understand where risks are emerging, how infrastructure and ecosystems are changing, and where interventions can have the greatest impact. The integration of spatial intelligence into environmental and infrastructure planning therefore represents an important opportunity to strengthen the resilience and sustainability of our country.

As the newly constituted IEK Council assumes responsibility following a successful transition, we do so with a deep appreciation of the confidence

As the newly constituted IEK Council assumes responsibility following a successful transition, we do so with a **deep appreciation of the confidence that our members have placed in us.**



that our members have placed in us. Leadership within the Institution is a privilege and a responsibility. We recognize that the strength of IEK lies not only in its Council or Secretariat, but in the collective knowledge, commitment and professionalism of its membership.

Our IEK Council is therefore committed to strengthening the Institution as a platform through which engineers can contribute meaningfully to national development. We will continue to promote professional excellence, ethical practice, innovation, knowledge exchange and meaningful engagement between engineers, government, industry, academia and other professional stakeholders. We also recognize the importance of creating opportunities for engineers at different stages of their careers, particularly young and emerging professionals, to develop their capabilities, participate in professional discourse and take an active role in shaping the future of the profession.

Partnership will remain central to this agenda. The challenges facing Kenya are complex and cannot be addressed by any single profession, institution or sector. The contributions represented in this issue, from government institutions, regulatory bodies, professional organizations, academia, infrastructure agencies and industry demonstrate the value of collaboration. We sincerely appreciate the various industry and institutional partners who continue to support engineering knowledge development and provide platforms for professional exchange.

I equally commend the IEK Editorial Board for its commitment to producing a publication that is relevant, informative and professionally valuable. Developing

a quality magazine requires the collective efforts of editors, writers, reviewers, contributors, designers, industry partners and the wider engineering community. Their dedication has ensured that Engineering in Kenya continues to serve not merely as a record of professional activities, but as a forum for ideas, experiences and perspectives that can inform the practice of engineering.

I encourage you, our members, partners, students, policymakers and readers, to engage actively with the content of this issue. Read beyond your immediate area of specialization. Explore the perspectives offered by fellow professionals. Consider how geospatial intelligence can enhance your own work and how greater collaboration across disciplines can produce better solutions for our communities.

Most importantly, let us view geospatial engineering not simply as a technological field, but as a critical enabler of informed decision-making. The coordinates, maps, models and datasets generated by geospatial professionals acquire their greatest value when they help society make better decisions about land, infrastructure, resources, cities and the environment.

As we begin this new chapter of leadership at IEK, we remain committed to working with our members and partners to strengthen the engineering profession and enhance its contribution to Kenya's transformation. I invite you to engage with this issue, share its insights and continue the conversation beyond these pages.

I wish you an insightful and rewarding reading experience.

Message From the Honorary Secretary



**Eng. Grace Muthoni Kagundu,
PE, FIEK**

**Honorary Secretary, Institution
of Engineers of Kenya**

It is my great pleasure to welcome you to Issue No. 28 of Engineering in Kenya, themed "Geospatial Engineering."

As the new Council 2026-28 effectively begins its mandate, I am honored to serve the IEK as the Honorary Secretary. I take this opportunity to sincerely thank the membership for the confidence placed in us, recognizing that serving the institution is both a privilege and a responsibility. It is about strengthening a professional community whose expertise is needed for Kenya's economic take off and social development.

**Geospatial
engineering now
underpins almost
every aspect of
development
planning and
infrastructure
delivery.**

Spatial information has become the foundation for critical decisions - from land administration and cadastral systems to the planning of roads, transport corridors, energy, water resources and urban growth. This Issue No. 28 is uniquely compelling in its multidisciplinary character, as it shows how Geospatial Engineers, Quantity Surveyors, Architects and Infrastructure Planners are working together integrating spatial data with design and digital technology to shape smart cities.

The same principle applies to environmental sustainability and climate resilience, where remote sensing, GIS and satellite data are increasingly vital across agriculture, climate monitoring, environmental assessment and disaster management. This spatial intelligence lets professionals identify patterns, anticipate risks and intervene more wisely. As Kenya confronts urban growth, environmental change and rising infrastructure demand, Engineers must understand not only what is happening, but where and how systems interact across space.

This issue speaks to each category of the engineering community in different ways

To practising engineers, these pages offer insights you can apply directly in your work - a reminder that sustainable professional competence rests on continuous learning, ethical practice and collaboration across disciplines.

To young engineers and students, I hope the issue will stir your curiosity and encourage you to explore the opportunities emerging from geospatial technology and the wider digital transformation of engineering. This is a field your generation is expected to lead.

To colleagues in Academia and Research, this issue affirms the value of partnerships between IEK, our universities and industry to keep

our practice grounded in evidence and open to innovation.

And to policymakers, industry leaders and development partners, I hope these perspectives demonstrate the value of investing in professional expertise, reliable spatial data and technology-enabled decision-making.

The incoming Council remains committed to providing platforms where members learn from one another and engage with the wider profession. Engineering in Kenya is central to that effort - It is a space to exchange knowledge, showcase innovation and stimulate conversations that extend beyond any organisation or discipline. We look forward to deepening engagement with members, supporting professional development, nurturing the next generation of engineers and strengthening collaboration with government, industry, academia and fellow institutions.

I sincerely thank the IEK Editorial Board for the considerable effort behind this issue, and extend our appreciation to the contributors, interviewees, writers, reviewers and the industry and institutional partners whose expertise has enriched it. A publication of this quality takes real commitment and coordination, and it shows.

Finally, let's all look at Engineering in Kenya as more than a magazine. It is a professional conversation where your feedback, ideas and contributions are key to keep it relevant. Feel welcome to turn the pages, explore the ideas, challenge the perspectives, and join the conversation on the future of geospatial engineering. Thank You.

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Spatial Statistics and Census Mapping



By Dr. Macdonald G. Obudho EBS, MBS
The Director General
The Kenya National Bureau of Statistics (KNBS)

Transforming the collection, analysis and dissemination of official statistics

Geospatial engineering and specifically Geographic Information System (GIS) and remote sensing has significantly transformed how KNBS collects, analyses, and disseminates geospatial data through the adoption of modern digital mapping technologies.

These include but not limited to:

i. Data Collection

Initially, KNBS relied on manually drawn maps for Census and survey operations. In 1996, the Bureau began transitioning to digital mapping by producing computer-assisted cartographic maps for 26 of the then 62 districts using GIS technology. The next major advancement came during the 2009 Kenya Population and Housing Census, when aerial photographs were introduced to support cartographic mapping in major urban areas. For the 2019 Census Mapping, KNBS adopted high-resolution satellite imagery for mapping the entire country and replaced paper questionnaires with Computer Assisted Personal

Interviewing (CAPI) questionnaires embedded on tablets. These technologies greatly improved data quality by enabling precise identification of Enumeration Area (EA) boundaries and location of households.

Unlike in the past, where household locations were estimated and only a single GPS coordinate was collected, currently GPS coordinates are automatically recorded using tablets for each household visited during a Census or Survey. Digital maps integrated in the CAPI questionnaire also allows enumerators to capture GPS coordinates directly by tapping on the map, supplementing automatically recorded coordinates and improving positional accuracy.

ii. Data Analysis

Previously, spatial analysis was limited because maps were primarily used for navigation during fieldwork. With the adoption of GIS and remote sensing technologies, KNBS can now integrate statistical and spatial data to perform more detailed geographic analysis. The use of digital maps enables visualization of census and survey results, helping identify spatial

patterns, trends, and areas requiring targeted interventions. This has strengthened evidence-based planning and decision-making by government and other stakeholders.

iii. Data Dissemination

Traditionally, producing and printing census maps was a slow, manual process that required loading and printing of one map at a time. Geospatial engineering has automated much of this process, allowing KNBS to generate and print large volumes of maps efficiently using GIS commands.

KNBS now disseminates geospatial information through Census Atlases, thematic maps, and other GIS-based publications. In addition, the Bureau is in the process of developing a Geoportal, which will provide an online platform for users to access, visualize, and download geospatial and statistical data more efficiently. The adoption of geospatial engineering specifically GIS and remote sensing has transformed KNBS from a manual, paper-based mapping system to a modern digital geospatial framework. It has improved the accuracy, efficiency,



and timeliness of data collection, enhanced spatial analysis for informed decision-making, and modernized the dissemination of official statistics through digital mapping products and online platforms.

The role of census mapping in ensuring national coverage

Census Cartographic mapping is one of the preparatory activities for Census enumeration that is conducted for two years prior to the main Census enumeration. The main objective of census mapping is to divide the country into counting units known as Enumeration Areas (EAs). The EAs help to ensure the whole country is enumerated without duplication or omission during the census enumeration, they also help in planning and budgeting for the census enumeration, and ensuring equitable distribution of work to the census personnel. The EAs are created from villages and therefore are either part of a village, a whole village or combination of villages depending on the number of households which is between 50 to 149.



The Census mapping is divided into six activities which include: -

i. Planning and Preparation This phase involves planning and coordination of the mapping activities, including identification of mapping methodology, logistical preparation, and scheduling of operations. It also involves consultation with relevant stakeholders to ensure effective implementation of the mapping exercise.

ii. Development of tools and materials that are used for sensitization of National Government Administrative Officers (NGAOs). The tools and materials include mapping questionnaire, forms for various use, mapping templates and schemas, CAPI system and manuals.

iii. Sensitization of NGAOs which entails taking them through the processes of Census mapping and their role. This is done to ensure maximum support during the entire mapping process. The NGAOs serves as security and guide to both mapping and census personnel as they move from one household to another.

iv. Field mapping which involves visiting every village within the country with the help of NGAOs and determining the total number of households. All households are listed, administrative details collected and their geographical locations picked during this exercise. Location of points of interest such as learning institutions, places of worship are also captured and listed to guide in EA identification. Data collected is uploaded to servers for preparation and production of Enumeration Area maps.

v. Enumeration Area Map Production which entails mapping of data collected from the field on satellite imageries and aerial photographs, digitizing the village boundaries using data collected and guidance from field teams, delineating EAs by subdividing villages with households above 149 and merging those with households below 50 while those within Measure of Size (MOS) of 50-149 are left intact, creation of the census geo-file by adding administrative details to each EA and finally preparation and production of EA and sub-location maps.

vi. Field Map Verifications. All EA maps produced are taken back to the field where the NGAOs are convened at either locational or divisional level to verify the maps to ensure they accurately represent their areas as provided during field mapping and, that names of areas are correctly captured. Maps that require correction are forwarded to the map production team for rectification before the final maps to be used during census enumeration are produced.

Integrating AI, satellite imagery and remote sensing

As earlier stated, our relationship with geospatial technology has been building for over two decades. GIS-based census mapping was first attempted in 1999, refined for the 2009 census, and by 2019 had matured into a fully digital, paperless system where smartphone-based mapping was used to delineate enumeration areas nationwide, working alongside the NGAOs. High-resolution satellite imagery was also used to delineate our urban areas that year.

For the 2029 census, we're building on what was done in 2019. Our teams will still visit households and collect the actual census data. What's changing is the mapping and planning layer that comes before that. We're exploring how Artificial Intelligence, building footprint datasets and machine learning could support the delineation and updating of enumeration areas, which would feed into our census maps.

It's not census mapping alone where we lean on partnerships. We also work with partners like UN-Habitat, on gridded population datasets; data that supports small-area population estimates used across government and which we've used in calculating SDG indicators 11.7.1, 11.3.1, and 11.2.1.

Beyond the census working alongside partners on the methodology, we are also in the final stages of producing our first Natural Capital Accounts, covering forests, land and ecosystems under the SEEA framework. Remote sensing gives consistent, repeatable readings on forest cover loss and land degradation, which feeds into climate monitoring and resource planning.

Satellite imagery, building footprints, machine learning and remote sensing, are helping us build more accurate and current maps and population data, without losing the ground-level detail that only field enumeration can provide.

Mapping hard-to-reach and mobile populations

Our Cartographic mapping involves the use of smartphones and tablets that are GPS – enabled to capture precise geographical locations of each conventional household within the country which are then used to create Enumeration Areas. The combination of satellite imageries and GPS coordinates has been used to determine where these populations live and to ensure they are not skipped during census enumeration and when undertaking surveys.

In the informal settlements we ensure that during the mapping process we train and use the local residents and youth who understand the local terrain to help us gather information as they help reduce the challenges of insecurity, language barriers and community distrust which can be a major hinderance to accurate data collection.

For nomadic populations, KNBS through its offices across the 47 counties works closely with the NGAOs and the local community leaders to guide on where the nomadic pastoralists are residing and the possible areas, they will be residing during the Census enumeration period thus improving on the approach of locating these populations during such periods. These include identifying areas where nomadic households could congregate during the Census period i.e. grazing lands, watering points and migratory corridors thus ensuring the nomadic households are enumerated at the point where they are found on the reference night since Kenya conducts a defacto census.

Spatial statistics for National Planning and equitable resource allocation

Spatial statistics not only shows us where people actually live but also how many they are, which makes evidence-based planning possible. By combining our statistical data with geographic information, we give national

and county governments a much clearer picture of local realities, which supports the implementation of the constitution, Vision 2030, the Bottom-Up Transformation Agenda (BETA), County Integrated Development Plans (CIDPs) and other national development priorities. For infrastructure when we map population against existing roads, schools, health facilities and water systems, we can see exactly which communities are underserved, where people travel long distances to access essential services, informing where the next investment should be located.

Spatial Statistics are also central to how resources get shared. Kenya's devolved system depends on objective data to distribute revenue fairly across counties, and our population statistics feed directly into that i.e. revenue sharing, ward planning, budgets for health, education and water. Bringing in the spatial dimension means allocation reflects density, remoteness and urbanization, not just headcounts.

Spatial statistics is also used to target policy where it's needed, mapping poverty, unemployment, and access to services to find the real gaps, rather than spreading resources evenly. At its core, this is about planning based on where people live and what they actually need, not just population totals, which is what the Constitution's principle of leaving no region behind requires in practice.

Geospatial Data for climate resilience and disaster preparedness

Kenya has lived through both extremes in recent years, starting with severe prolonged drought followed by devastating floods. The 2024 rains displaced thousands of people and caused an estimated Ksh. 187 billion shillings in damage. That volatility is why geospatial data and spatial statistics have become central to how the country prepares for and responds to disasters.

Our role as KNBS is to provide the population and socio-economic



layer that turns hazard data into something actionable. Knowing where a flood or drought is happening is only half the picture, what matters is knowing who lives there and how many, how vulnerable they are and what infrastructure and services are in their path. That's where population statistics and spatial mapping come in, they let responders and planners understand exposure and vulnerability, not just the hazard itself.

This work also connects directly to our Natural Capital Accounting programme. By tracking forests, land and ecosystem resources through the SEEA framework, we help build a clearer picture of environmental degradation, land-use change, and resource depletion over time, which feeds into longer-term climate adaptation and land-use planning, not just emergency response.

For KNBS specifically, the direction is about making sure our population and spatial statistics are detailed and current enough to plug directly into that broader early-warning ecosystem, so that when a hazard is detected, the people and places most at risk are already mapped, not identified after the fact.

Modernizing census mapping: Milestones and Challenges

Initially Census mapping was done manually which involved working with the NGAOS to manually delineate EAs in sub locations within urban areas. With modern technologies including GIS technology census mapping and geospatial data management has heavily shifted from the previous manual field operations using Paper - and - Pen Personal Interviewing (PAPI) to real time data collection systems using CAPI in tablets and smartphones. Unlike the previous Census Mapping, the 2019 Census Mapping involved digitally capturing geographic coordinates of conventional households across the country by physically visiting these households, what followed was digitally delineating EAs, and Administrative/Statistical Units boundaries for the entire country using GIS technology thus ensuring we had a geodatabase for the entire country before we embarked on the Census enumeration. With this advancement in technology, we were also able to carry out Census Enumeration using CAPI as opposed to PAPI in the previous Censuses which enabled Census results to be released and published in a record

six months, previously the results were disseminated in over a year.

Among the challenges we encounter is having enough resources to ensure we keep up with ever changing technology in the GIS world, as you know resources are always rare and scarce. Another challenge we face include rapid urbanization and informal growth whereby unplanned settlements i.e. slums change faster than the updated satellite imageries thus creating situations where EAs which had originally been demarcated and mapped within the MoS could sometimes have low or high number of households depending on the situation that had occurred e.g. demolitions or new constructions.

Finally, as much as we try to map nomadic populations within the same period as the Census period, the seasonal nature of their migration and climate related migration sometimes make static EA boundaries invalidated, the areas mapped might be without the population during the Census Enumeration night.

First there is need to integrate socio-economic and demographic data with spatial location. This will ensure that every data that is collected has a spatial component and that this data is actually used to inform actionable policy and decision making.

Strengthening the National Statistical System through collaboration

First there is need to integrate socio-economic and demographic data with spatial location. This will ensure that every data that is collected has a spatial component and that this data is actually used to inform actionable policy and decision making.

Collaboration means there's improved knowledge sharing and capacity building. For instance, multi stakeholder engagement ensures there is alignment with emerging statistical priorities and harmonized data standards and priorities across MDAs and County Governments. For example, partnerships with UN-Habitat, KSA and DRSRS has enabled us to integrate non-traditional data sources such as satellite imagery and land use land cover maps to measure SDG indicators on the land consumption ratios, access to public transport etc.

Collaboration also ensures there is availability of other administrative data sources to compliment official statistics, in this regard, KNBS has established a TWC on Spatial data and statistics which will guide its next Census operations in terms of Census Mapping, this will ensure the Bureau gets authoritative GIS data from key stakeholders as it prepares for Census Mapping and ultimately the 2029 KPHC.

A Vision for the Future of Spatial Statistics in Kenya

First, I believe that spatial statistics should be at the core of decision making in this country, as such every major decision should rely on spatially disaggregated evidence.

My vision is to expand the usage of GIS and spatial statistics in dissemination of official statistics and specifically in interactive format where users and stakeholders are able to interact with statistics spatially, and also ensure that spatial statistics is fully integrated and embraced into national planning, guiding policy, service delivery and accountability.

For the professionals, I believe AI and other technologies like GIS are just accelerators and should be used for continuous professional development and betterment of our country, please embrace GIS and spatial technology boldly to expand your impact in society; by doing so I urge the professionals to partner closely with Statisticians in generating data that will help solve national challenges.

Highway Planning Using Geospatial Intelligence: Insights from Kenya National Highways Authority (KeNHA)



BY Eliud Munene,
Deputy Director – Survey and
Land Assets, KeNHA.

Bio Data: Eliud Munene is a seasoned professional Land Surveyor with over 30 years of experience in the land sector. He is currently the Deputy Director – Survey and Land Assets, at KeNHA.

His experience spans the entire road sector lifecycle management from: Highway Planning, Design, Construction and Maintenance. He has played a pivotal role and led successful delivery of key road infrastructure development projects/programs from conceptualization and design through to execution and management.

Mr. Munene holds a Master of Science Degree in Surveying and a Bachelor of Science Degree in Survey and Photogrammetry. He is a Licensed Land Surveyor with the Land Surveyors Board of Kenya. He is also a licensed drone pilot.

Q1. | From a highway planning perspective, how has geospatial engineering evolved from conventional surveying and mapping into a strategic decision-making tool? What types of geospatial information are most critical at the planning stage?

Geospatial data is very critical in the planning of highways. This involves getting the survey and mapping data which is quite critical for planning exercises. This is useful, for example, in the alignment identification,

even in the greenfield. The acquisition of geospatial data has been made more efficient and cost effective with the recent advancement in surveying tools and technology.

Q2. | When developing or upgrading a major highway, how is GIS and spatial analysis used to evaluate alternative alignments? In particular, how are factors such as terrain, land use, environmental constraints, settlements, drainage and existing infrastructure incorporated into the decision-making process?

When it comes to things like route and site selection, terrain and settlements among other datasets are mandatory. GIS is then employed as a critical tool for achieving the engineering objectives due to its advanced analysis tools. Of course, this can only be possible with adequate and accurate geospatial data. As KeNHA, we endeavour to use all these modern technologies for our projects.

Q3.

Modern highway planning can draw on satellite imagery, GNSS/GPS, LiDAR, UAV/drone surveys, Digital Elevation Models and other datasets. How are these different sources integrated, and what determines which technology is most appropriate for a particular project?

In effective highway planning, the use of different geospatial dataset is paramount. The determination of which datasets are required depends on the final ACCURACY objectives. For example, for things like pre-feasibility studies, technologies like google earth can be adopted. However, for more accurate data then we can think of using drones with LiDAR payload. In some cases, we also combine drone mapping with ground surveys.

Q4.

Beyond route selection, how does geospatial engineering contribute during detailed design, construction, quality control, and eventual operation and maintenance of a highway? Could you give an example of where spatial data has significantly improved project delivery or decision-making?

During the detailed design stage, geospatial data is very critical. This is where the use of drone and mobile LiDAR comes in combined with ground survey to ensure every required data is captured accurately. Of course, we also ensure that the survey works are tied to the national survey control network.

The collected data is used as an input into downstream engineering processes, for example, engineering design and even in maintenance projects. An example is the design for the proposed re-alignment of Nithi Bridge. Due to the nature of the terrain, it was determined that it would be quite difficult to undertake ground survey.

Drone LiDAR survey was, therefore, adopted which took only two (2) days to complete in comparison with the approximately three (3) weeks estimated for ground surveys. The accuracy of the geospatial data collected was also found to be quite high. This fast turn-around enabled the design to be completed in a timely manner and construction works are now ongoing.

Q5.

KeNHA has a Geoportal that brings together spatial information on the national road network. How far has the Authority gone in transforming the GeoPortal from a mapping and information platform into a genuinely operational decision-making tool? What types of planning, monitoring or operational decisions are currently supported by the platform?

KeNHA has a GIS database which acts as a repository of the geospatial data generated through the various projects undertaken. The system currently supports various functions, primarily in addressing various land related issues which is quite useful as most of our projects are implemented on land.

These functions range from planning of new corridors, expansion of existing corridors, engineering design, maintenance of the roads, legal cases etc. The system is still being improved to cater for all emerging need for geospatial data and also to integrate it with other corporate systems in order to enhance efficiency.





Q6.

To what extent is KeNHA applying geospatial technologies in highway asset management? How are GIS, spatial databases, remote sensing and related technologies being used for asset inventory, condition monitoring, maintenance planning and prioritisation of interventions?

Asset Management is an area that we are seriously working on in terms of enhancing efficiency. This is being tackled in various ways, and one of them is to adopt modern technologies. In terms of geospatial technology, we have endeavoured to improve the same through adoption of modern equipment and technologies.

Take for example, we recently hired a consultant to undertake mapping of some major road structures (bridges) with a view to enhancing the Authority Bridge Management System (BMS) and to obtain baseline data for planned bridge deformation monitoring. The consultant used mobile SLAM LiDAR for data collection and it was found to be quite useful.

Q7.

Major highway projects often interact with land ownership, utilities, settlements and environmentally sensitive areas. How does geospatial technology help engineers coordinate these competing requirements while reducing project risks, delays and potential conflicts?

One of the critical geospatial datasets that we have developed and keep on updating is the road corridor maps showing the abutting land parcels. This data has helped in very many areas for example planning, design, land acquisition for road expansion, legal cases.

Q8.

With advances in Artificial Intelligence, remote sensing, UAVs, LiDAR, cloud-based GIS and digital twins, which technologies do you believe will have the greatest impact on highway planning and asset management in Kenya over the next 5-10 years?

The technologies that will have most impact are UAVs/Drones. LiDAR sensors will also be quite widely used, whether installed on UAVs or terrestrial vehicles. These, when combined with artificial technology will be able to perform most of the tasks more easily and efficiently. Of course, the requisite software will also become better.

Q9.

As infrastructure becomes increasingly data-driven, what technical skills should young engineers and geospatial professionals develop to remain relevant in highway planning and infrastructure development? What is your vision for the integration of geospatial intelligence into Kenya's highway network?

The geospatial engineering field is quite interesting and engaging. Young professionals in the field should always be ready to learn new technologies and methodologies in order to remain relevant. AI is a must.

In the next couple of years, we hope that KeNHA will have a fully operational GIS system to enhance geospatial data storage, analysis and dissemination for various functional needs and thus enhance efficiency

Preparing Professionals for a Data-Driven Engineering Landscape



By Dr. Patricia Mwangi
Lecturer, Kenyatta University

A data-driven engineering landscape can be defined as the continuous collection, analysis, and presentation of data in an understandable format to support engineering decision-making. The shift towards collecting and utilizing data to make informed decisions is significant in addressing real-time challenges. In geospatial engineering practice, this translates into a greater emphasis on digital skills for collecting, processing and interpreting geospatial data through technologies such as Internet of Things (IoT), Robotics, Artificial Intelligence (AI), drones and satellite systems. Consequently, geospatial engineers must continuously enhance their digital competencies to catch up with the evolving technological landscape.

In my view, having only four universities in Kenya approved to offer Geospatial Engineering programs, is insufficient to meet the current and future workforce demand especially considering the growing demand for geospatial professionals across multiple sectors. However, more universities are in the process of developing

their curricula to introduce programs related to the geospatial field in response to this increasing demand. Unlike the 8-4-4 system where spatial data concepts were introduced in limited areas such as map reading and interpretation, the new Competency-Based Curriculum (CBC) has integrated more advanced geospatial concepts from the early stages of learning, recognizing that geospatial skills is a continuum. This approach will strengthen the learners' spatial awareness and skills from an early age, helping them to appreciate that a geospatial career is not an isolated career but a cross-cutting discipline that supports virtually every profession. It also reinforces the understanding that whatever we do has an impact on the space and environment around us.

Kenyan universities have made tremendous progress in adapting their curricula to equip graduates with the competencies required for an increasingly digital and data-driven engineering landscape. One notable approach has been strengthening collaboration with professional organizations and regulatory bodies such as the Institution of Surveys of Kenya (ISK) and the Land Surveyors Board. Universities have also

benchmarked with both local and international institutions to harmonize their curricula with emerging global trends. This enables them to learn from the successes, challenges and best-practices of other institutions, ensuring that graduates are equipped with relevant, industry-aligned skills.

It is worth noting that technologies are not policies; rather, policy serves as an enabler for technology adoption and education. For example, the Kenya National Spatial Plan (2015–2045) provides a framework for achieving the country's development goals through the effective utilization of spatial data. I believe effective policy implementation begins at every level of the government, including counties. Presently, several counties have developed a GIS lab to help in decision making. Public institutions and



Presently, several counties have developed a GIS lab to help in decision making. Public institutions and parastatals have also been using GIS for several years.



parastatals have also been using GIS for several years. Strong political goodwill can further accelerate the adoption of these technologies in infrastructure and development projects.

Leading economies, including the United Kingdom, Singapore, the United States, the Netherlands, and Australia have made significant progress in embedding AI, cloud GIS, digital twins, remote sensing, and spatial data science into both geospatial engineering education and national infrastructure programs. While Kenya may not yet be at the same level of technological advancement or possess the same economic capacity as these countries, I believe meaningful progress is being made. A good example is Konza Technopolis, one of Kenya's flagship development projects which demonstrates the growing integration of digital technologies into modern infrastructure planning and development. Another notable milestone is Kenya's first operational Earth observational satellite, Taifa-1, designed by Kenyan engineers in collaboration with international partners to collect critical data for agriculture, food security, environmental monitoring and disaster management. I also believe the increasing collaboration between Kenyan universities and leading international universities is helping to strengthen research, knowledge exchange and

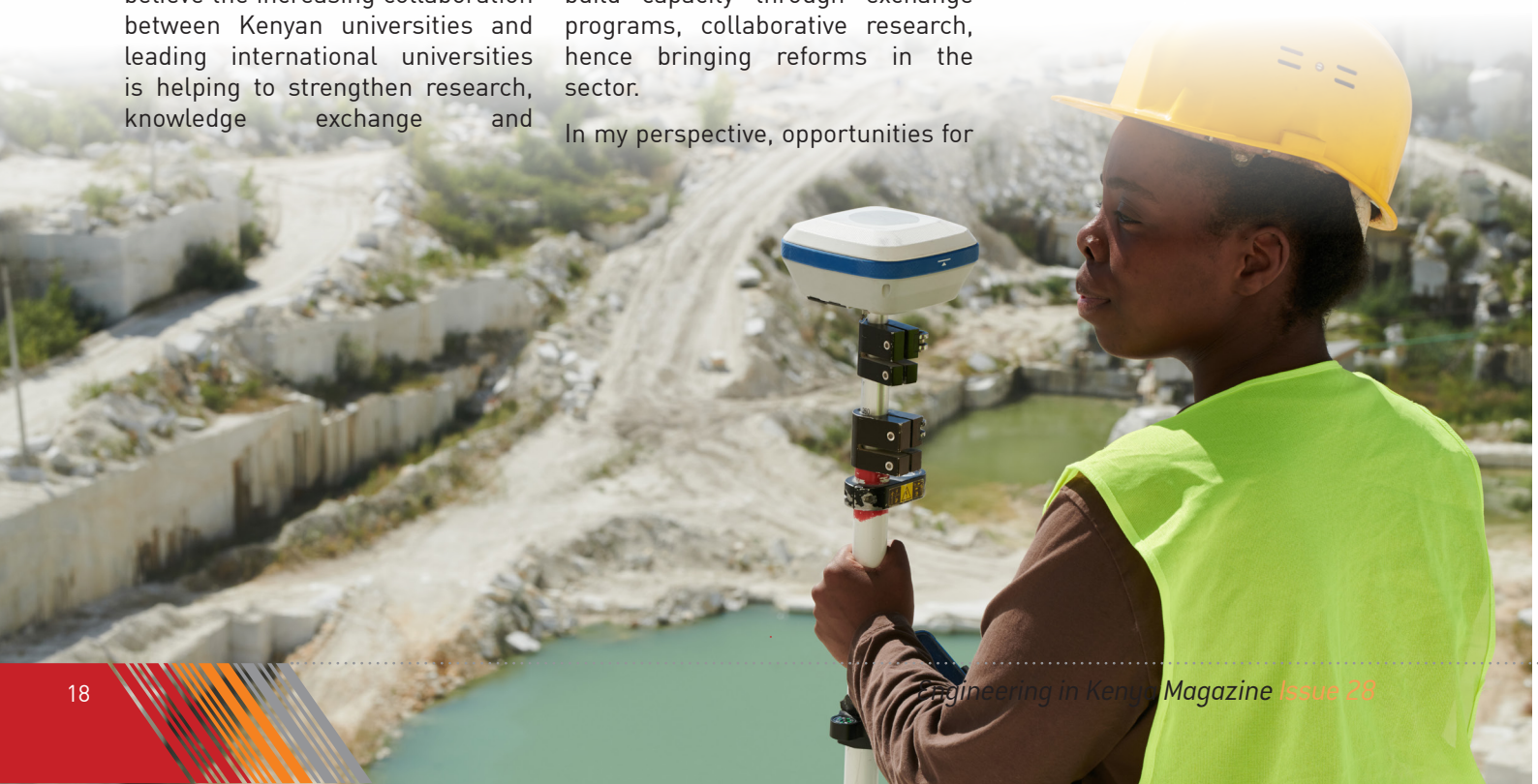
curriculum development. Such partnerships are essential in ensuring that Kenyan graduates remain globally competitive in an increasingly digital and data-driven engineering profession.

Financing remains one of the major challenges facing universities in Kenya. The high cost of developing modern laboratories, acquiring the latest technologies such as drones has been a challenge but has not hindered the growth of the discipline. More satellite companies are offering their high-resolution satellite datasets of up to 50 cm to individuals and organizations involved in research. This has greatly improved research and teaching as previously one needed to purchase high-resolution datasets. They also offer free training courses on various topics open to anyone willing to improve their competence in remote sensing or GIS. Organizations are also providing funds for research, innovation and travel grants that support higher education faculty and post-graduate students. International partnerships can play a significant role in strengthening geospatial education. Government-to-government (bilateral) and international multilateral partnerships in education have greatly supported institutions to build capacity through exchange programs, collaborative research, hence bringing reforms in the sector.

In my perspective, opportunities for

geospatial engineering graduates are virtually limitless, both in Kenya and internationally. This is because geospatial engineers possess versatile skills that are applicable across multiple industries. The discipline provides a strong foundation for supporting a data-driven engineering landscape, where spatial and non-spatial data are used to make informed decisions across sectors. I believe no profession is an island and therefore, achieving sustainable development requires collaboration and harmony among all disciplines. I also believe there is immense potential for innovation and entrepreneurship by leveraging emerging technologies to build start-ups that solve real-world challenges. Greater exposure through symposiums, innovation hubs, and access to technologies such as 3D printers can inspire students to develop practical solutions to societal challenges.

My advice to graduates and young professionals is to continually invest in themselves through lifelong learning. Stay up to date with emerging technologies and industry trends, pursue relevant professional development opportunities and build strong networks with peers and professionals both locally and internationally.



The Digital Aquifer: Protecting Kenya's Water Security Through Hydraulic Digital Twins



By Bertha Naliaka

Biodata: Bertha Naliaka is a Civil Engineer specialized in Water Engineering with over 15 years' experience in utility regulation, infrastructure development and WASH programming.

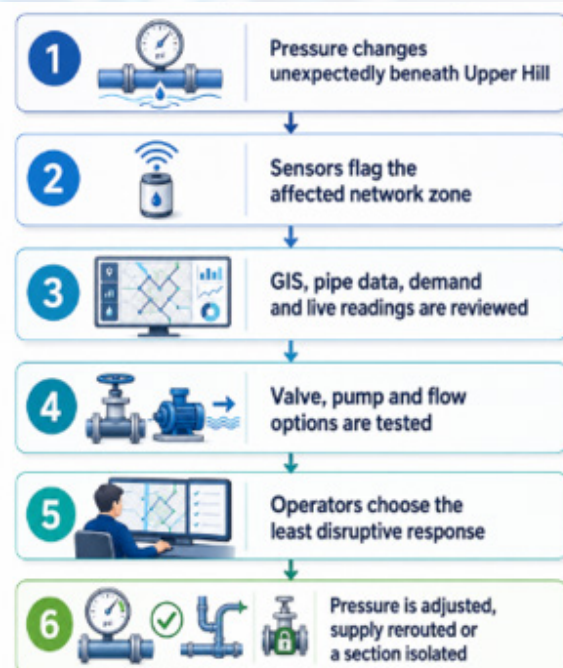
At 3:14 a.m., Upper Hill is quiet. Beneath one of its roads, the pressure inside a major water main begins to rise.

Nothing is visible above ground yet. The pipe has not burst, and no customer has called to complain. However, the pressure change is already moving through the network. In a conventional system, the problem may only become obvious when water reaches the road surface or when nearby buildings begin to lose supply. By then, treated water may already be escaping underground, and repair crews may be trying to locate the fault in heavy traffic.

A hydraulic digital twin offers an alternative approach to address this risk.

Inside the control room, operators can observe unusual behavior developing within a virtual representation of the network. The pressure and flow readings from the field are compared with the hydraulic model expectations. If something looks wrong, the affected area can be investigated, and different responses can be tested before changes are made to the actual system.

How the Digital Twin Responds in a Water Supply System.



What Makes It Work?

A useful digital twin depends on good information.

The GIS shows the locations of pipes, valves, pumps, tanks, customer connections, and District Metered Areas. Pipe material, diameter, age, and repair history add the details needed to understand the network properly.

Field instruments show what is happening at that time. Pressure sensors, flow meters, reservoir-level instruments, and acoustic leak detectors provide measurements that can be verified against the model.

The hydraulic model then helps engineers to test practical choices. What happens if the valve is closed? Can another route maintain the supply? Would lowering the pump output reduce the pressure without creating problems elsewhere?

That is the real value of the system: it supports engineering judgement before action is taken.

Acting Before a Burst Becomes an Emergency

Suppose the Upper Hill pressure reading appears abnormal. The first step is to confirm that the sensor itself is not faulty. Operators can compare it with nearby readings, reservoir levels, pump activity, and recent demand.

If the anomaly is real, the attention shifts to the part of the network under stress. Depending on the system layout, operators may reduce the pump output, adjust the pressure-control valve, or temporarily isolate a section while maintaining the supply through another route.

Where remote controls are connected to SCADA, some changes can be made from the control room. Where they are not, the same information can help field teams reach the correct location faster.

A digital twin cannot prevent all bursts. Pipes continue to age, and fittings continue to fail. It can provide utilities with an earlier warning and a better chance of limiting damage.

Beyond the Water-Main Network

The same idea applies to other areas.

In wastewater systems, operators can follow rising flows through sewers and pumping stations before overflow occurs. Drainage teams can combine rainfall forecasts, river levels, and drainage capacity to identify areas that are likely to flood.

At treatment plants, digital twins can help examine chemical dosing, filtration, energy use, and equipment performance. Irrigation managers can compare the available water with crop demand and soil moisture.

Similar approaches can be used to support groundwater systems, dams, industrial pipelines, and transport and energy networks.

The technology may differ, but the practical question is the same: What is happening now, what is likely to happen next, and what should we do about it?

Lessons from Other Cities

Valencia has combined hydraulic modelling, GIS, SCADA, smart meters and network sensors in its water operations. Idrica reports savings of more than one billion gallons of water each year and a 30% reduction in non-revenue water (Idrica, 2020).

Porto's H2Porto platform links water supply, wastewater, stormwater, maintenance and customer information. Reported benefits include a 25% improvement in operational efficiency and fewer water supply failures (Association for Project Management, 2021).

In Ayodhya, India, hydraulic modelling and digital twin technology supported the development of a continuously pressurized network targeting a 35% reduction in non-revenue water (Bentley Systems, 2023).

These cases are promising, although most reported results are from project and industry sources rather than independent evaluations.

What Would This Mean for Kenya

For Kenyan utilities, the starting point should be the network rather than the software.

Are the pipe routes correctly mapped? Are the bulk and zone meters working? Can the pressure readings be trusted? Are failures and repairs recorded properly?

Nairobi could begin with a few high-loss or high-pressure zones in the future. If better data and modelling help reduce losses, improve response time, or manage pressure more effectively, the approach can then be expanded.

For Kenyan water utilities, the strongest case for a digital twin is simple: it should help engineers understand the network better and make better decisions with the water that is already available.

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Education and Applications of GIS



By Dr. Jacinta Syokau Kimuyu, PhD, MISK, MIEEE-GRRS, FGSSK
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Evolution of Geographic Information Systems (GIS) and GIS education

GIS has evolved in distinct phases, and I consider myself fortunate to have witnessed and participated in that evolution.

I would describe the evolution of GIS in Kenya in four major phases:

The First Phase:

**The Pre-Digital Era
(1970s–1990s)**

The first phase spans roughly from the 1970s through the 1990s. During this period, mapping relied almost entirely on paper maps produced through traditional cartographic methods. Cartographers prepared maps manually using analogue drafting equipment. At the Technical University of Kenya, we still preserve the historical plotting machines, like the Wild A8 and B8 analog stereo plotting machines in our photogrammetry laboratory, which illustrate how mapping was carried out before digital technology became widespread. During this period, Survey of Kenya (SoK) was the custodian of analog maps and GIS was mainly in learning institutions like Kenya Polytechnic, University of Nairobi and Moi University, although data was scarce and expensive. As digitization gradually emerged in the 1990s, much of this work was supported by development partners such as the United Nations Environment Programme (UNEP), which required digital spatial data for environmental projects.

The Second Phase:

**Institutional Adoption
(2000–2010)**

Between 2000 and 2010, GIS began to gain wide acceptance within universities and research institutions. Interestingly, universities were producing graduates with GIS expertise long before many employers understood its value. During this period, access to open spatial data gradually improved, and the GIS community became more organized. In 2002, professionals established the Kenya GIS Forum, which brought together practitioners to promote the discipline. Around the same time, the Kenya GIS Users Group, supported by ESRI Eastern Africa, also played an important role in building awareness and encouraging collaboration.

Government institutions slowly embraced the new technology and established GIS units. Health GIS, in particular, gained considerable traction through disease mapping initiatives, including malaria prevalence mapping, which demonstrated the practical value of spatial analysis in public health. At this stage, our challenge was not simply finding jobs but convincing employers that GIS could transform the way they worked. A major milestone was the 2009 national census that used GPS and digital enumeration for the first time.

The Third Phase:

**Devolution Expansion
(2010–2016)**

The next major phase began after the promulgation of the Constitution of Kenya 2010, which introduced devolved government and created the country's 47 counties. This marked a turning point for GIS in Kenya. One of the first requirements for county governments was the preparation of County Spatial Plans, all of which needed to be GIS-enabled. From around 2014 onwards, demand for geospatial expertise increased dramatically. During the same period, Huduma Centers were established, mobile GIS applications became more widely adopted, satellite imagery became increasingly accessible, and digital data collection tools transformed field operations.

In 2016, I led a project for the Kenya Pipeline Company that used Mobile GIS applications to integrate engineering maintenance operations onto a single digital platform. Instead of relying solely on field reports, decision-makers could visualize operations in real time, demonstrating how GIS had evolved from a mapping tool into a strategic decision-support system. The 2019 census marked a turning point because it integrated GPS-enabled digital enumeration and GIS technologies into the data collection process.

Returning to the period between 2013 and 2016, this was also an era of remarkable research and innovation. OpenStreetMap data became increasingly available, mobile GIS applications gained widespread adoption, and satellite imagery became far more accessible.

One particularly significant development was the expansion of the constellation of Sentinel satellite imagery with optical and high-resolution multispectral missions like Sentinel-2 and radar/altimetry payloads like Sentinel-3 around 2015. The Sentinel programme provides freely available, high-quality satellite data used in GIS spatial-temporal analysis with excellent spatial and temporal resolution. The satellites high temporal resolution facilitates revisit frequency of approximately every ten days, making them ideal for continuous environmental monitoring.

The Fourth Phase:

**The Era of Big Data,
Artificial Intelligence
and Smart Geospatial
Solutions**

This is from approximately 2016 to the present. Nearly every sector now depends on GIS to integrate and analyze spatial information for better decision-making. Today's GIS education reflects these technological advances. Students are trained in cloud computing, real-time spatial monitoring, UAV operations, big data analytics, artificial intelligence, and decision-support systems. Kenya has also made significant progress through initiatives such as the National Spatial Data Infrastructure (NSDI), which promotes the sharing and standardization of geospatial information across institutions.

Another major advancement has been the adoption of Unmanned Aerial Vehicles (UAVs), commonly known as drones. While many people associate drones with photography or journalism, surveying drones are specialized instruments used for aerial photogrammetry and high-precision mapping. They have dramatically reduced the cost of aerial surveys, replacing many applications that previously required expensive aircraft operations.

Access to spatial data has also improved significantly. What was once scarce and costly is now readily available through both commercial and open-source platforms. In higher education, we increasingly encourage students to use open-source GIS software package like QGIS, which is a powerful free desktop GIS application. Although universities collaborate with software vendors such as Esri Eastern Africa through educational licensing programmes, open-source software provides greater flexibility and accessibility.

Some students embrace the technological advancement and develop their own innovative GIS applications and programming solutions, demonstrating how rapidly GIS education continues to evolve.

Preparing students to meet the demands of today's geospatial industry

At the Technical University of Kenya, innovation is at the heart of everything we do. We have intentionally shifted our focus from conducting research simply for academic purposes to developing research that leads to practical solutions, commercialization, and real societal impact. "I constantly encourage our students to think beyond the classroom. We ask ourselves: *How can we transform the knowledge we have into innovative solutions that address real-world challenges?*" Our students are now developing solutions that compete on international platforms. Last year, for example, several of our students participated in international hackathons, showcasing the innovative work being undertaken within the department.

When I was initially appointed as the Director of the School of Surveying and Geospatial Sciences in June 2024, one of the first things I asked my students was: "What do you want me to do differently to improve your learning experience?" The third-year Geospatial Engineering students gave me a very honest response. They told me, "We see students elsewhere doing highly practical and innovative applications, and we want the same opportunities." That conversation reinforced my commitment to making our programmes more industry-oriented. We brought in experienced professionals from the industry to teach specialized courses. For example, we invited a highly talented practitioner to teach Digital Image Processing, ensuring that students gained practical, industry-relevant skills in addition to theoretical knowledge. At the same time, we created opportunities for international exposure.

Through sponsorship from the IEEE Geoscience and Remote Sensing Society (IEEE-GRSS), members of our Student Chapter travelled to Rwanda in 2025 to participate in professional mentorship activities and interact with students and

researchers from across the region. Our IEEE-GRSS Student Chapter had been recognized as one of the best-performing chapters, and the experience in Rwanda was transformative. That is exactly the mindset we want to cultivate; students who are curious, innovative, and confident enough to develop solutions that address local challenges while competing on a global stage. The students later participated in an innovation hackathon and progressed to represent Kenya in Ghana, where they won second place. However, I challenged them to think differently. Imagine the impact if students from surveying, civil engineering, electrical engineering, mechanical engineering, computer science, and other disciplines combined their innovations into one integrated solution instead of working independently. One of the

The emergence of open-source GIS has been one of the biggest breakthroughs in geospatial engineering.

biggest challenges in engineering is that we often work in isolation. The future lies in multidisciplinary collaboration because the best engineering solutions emerge when different areas of expertise come together.

Furthermore, we work very closely with industry through Industry-Based Learning (IBL) programmes. Students are exposed to industry in two ways. First, we invite professionals from government agencies and private companies to the university, where they demonstrate modern equipment, emerging technologies, and current industry practices. They also expose students to advanced computing platforms. Again, our students undertake external industrial attachment, where they work directly within organizations

using state-of-the-art equipment and software on real projects. This practical exposure bridges the gap between classroom learning and professional practice.

Open-source GIS platforms and their influence on research, innovation and professional practice

The emergence of open-source GIS has been one of the biggest breakthroughs in geospatial engineering. It has fundamentally changed the way institutions conduct research and training.

Commercial GIS software has undoubtedly played an important role in advancing the profession, but it comes with recurring licensing costs. Every new version introduces additional plugins and features, which institutions must continually pay to access.

Open-source software such as QGIS has changed that landscape completely. With QGIS, users simply download the software, update it online when necessary, and continue working. For universities and research institutions that operate under tight financial constraints, this has been transformative. Since becoming Chairperson, I have never had to request funding from the university specifically to purchase GIS software licenses because we have been able to accomplish so much using open-source platforms. Today, there is an abundance of freely available spatial data, AI-powered analytical tools, and open-source applications. The challenge is no longer access, but understanding what is available and knowing how to use it effectively. The advantage is sustainability. Institutions are not interrupted by expired licenses or costly renewals. The software remains accessible, allowing staff and students to continue working without interruption. From an analytical perspective, QGIS is extremely capable. It integrates seamlessly with remote sensing data and GIS databases, making it a powerful platform for spatial analysis.

GIS and Climate Change Adaptation

During a recent collaborative mapping exercise with MapBiomass Brazil Network, the Kenya Team worked as regional teams and, within a single day, successfully produced a classified land-cover map of Kenya. The process demonstrated how rapidly modern geospatial technologies have evolved. These classification techniques form the basis for monitoring forest cover, estimating biomass, and conducting time-series trend analyses. For example, by comparing satellite imagery from 2010, 2015, 2020 and the present, we can determine whether forest cover has increased or declined over time. That information is particularly important for carbon trading/accounting and environmental management. This is why I often say we should move beyond simply talking about tree planting and instead focus on tree growing. Planting trees alone does not tell us whether forests are actually recovering. Using drones, GIS and remote sensing, we can monitor tree survival, quantify forest growth, and evaluate whether restoration initiatives are achieving measurable environmental outcomes. That is the evidence policymakers need.

Geospatial technologies are also playing a critical role in climate change adaptation. During COP26, I worked with a team from Glasgow Caledonian University on developing frameworks related to climate change research. One of the discussions centered on loss and damage. Countries in the Global South contribute relatively little to global greenhouse gas emissions, yet they bear a disproportionate share of climate impacts. Through geospatial visualization and spatial-temporal analysis, we can clearly demonstrate how climate change is affecting vulnerable communities. For example, regions that were historically free from malaria are now emerging as new hotspots because changing climatic conditions have created favorable environments for disease transmission. Such evidence strengthens policy discussions around climate finance, adaptation funding, and compensation for climate-related losses.

One concept we frequently study is the ecological shift. This refers to changes in environmental suitability over time. Some regions that were once highly productive have gradually become less suitable for certain

crops because of changing rainfall patterns, rising temperatures, and other climate-related factors. Conversely, areas that were previously considered unsuitable are becoming increasingly viable. Unless countries understand these shifts scientifically, agricultural planning becomes largely trial and error. For one student project, we mapped the potential growing zones for macadamia across Kenya. Using a multi-criteria analysis, we combined factors such as climate, soils, elevation and other environmental variables to identify areas best suited for production. The findings showed that Kenya has far more suitable land for macadamia cultivation than is currently being utilized. This illustrates how GIS can guide agricultural investment and land-use planning using evidence rather than assumptions.

More recently, I also led a project for Kajiado Municipality that focused on drought resilience and sustainable water supply. Using GIS-based spatial modelling, we assessed future water demand and developed a climate proofing model that identified groundwater as the most sustainable long-term option.



A student hands over Second place to Dr. Kamuyu trophy after winning GAIathon 2025



Dr. Kamuyu and her students having a practical session on the use of RTK during the field practicals at Kibwezi

Collaboration between universities and industry

Industry-academia collaboration is absolutely essential. Engineering is about providing practical solutions. That practical orientation is reflected in the vision of the Technical University of Kenya: *Education for the Real World*. Industry brings practical challenges, while universities develop the knowledge, research and innovations needed to solve them. It is a symbiotic relationship because each side depends on the other. I first appreciated this model while pursuing my Master's degree at the University of Cape Town, South Africa in 2005. Academic staff were evaluated partly on the strength of their industry collaborations. They were expected to remain connected to the industry so that their teaching and research remained relevant. We have embraced the same philosophy at the TUK. We actively collaborate with both local and international partners through Memoranda of Understanding (MOUs). However, partnerships should never exist only on paper. Each collaboration must demonstrate measurable outcomes every year. That accountability ensures the partnerships remain meaningful and continue benefiting students, researchers and industry alike.

The future of careers in GIS and geospatial engineering?

Geospatial engineering continues to create opportunities across government, environmental management, infrastructure, agriculture, health, taxation, utilities and many other sectors. Our graduates are receiving international scholarships, participating in global competitions and contributing to major research initiatives around the world. Technology has also made

international collaboration much easier through virtual learning and research networks. Young people should therefore remain curious and willing to explore new ideas. Today, virtually every organization uses geospatial information. What matters most is developing strong technical skills, embracing innovation and remaining committed to solving real-world problems towards sustainable commercialization of Intellectual Property (IP).

Leading at the intersection of Academia, Industry and Professional Practice

I have always believed that geospatial engineering is a practical profession. That philosophy inspired me to establish GeoSAT Spatial Consultancy shortly after completing my PhD in 2015. Before that, I had worked with Didmap Limited as a technical expert. At some point, I began asking myself, "Why should I only execute projects for other organizations when I can create my own platform that delivers innovative solutions?" Rather than limiting ourselves to conventional surveying work, I wanted us to focus on developing intelligent, technology-driven solutions. Surveying is important, but I do not just see myself as simply engaged in taking measurements in the field all day. In the spirit of partnerships and mentorship, that technical work can integrate other competent field teams. My passion lies in asking how innovation and research commercialization can solve complex problems more efficiently. That same philosophy continues to guide GeoSAT Spatial Consultancy today. We develop sustainable, innovative and practical solutions that create real impact globally.



Part of the team that participated in GAIA 2025 Incubation Challenge (GAIAthon '25)- Digital Innovation Track

Engineering Approaches for Reducing Transmission and Distribution Losses to Strengthen Kenya's Energy Security and Resource Efficiency

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ABSTRACT

Kenya has made great strides towards becoming a world leader in integrating renewable energy into its electricity generation mix, with more than 80% of installed electricity generation capacity from renewables. Despite this, the country is still facing high transmission and distribution (T&D) losses beyond the regulatory limit. These losses not only have an impact on energy security, but also on energy grid resilience, utility profit and the potential of the clean energy transition. This paper presents an energy security, resource efficiency, and sustainable power system development perspective on T&D loss reduction. The study compares Kenya's governance, planning and technological frameworks to best practices in the U.S. and the EU countries, using a qualitative comparative policy analysis approach. The analysis is based on the reports of the Energy and Petroleum Regulatory Authority (EPRA), 3rd Council of European Energy Regulators (CEER) Report on Power Losses (2025), U.S. Department of Energy Resource Adequacy Report

(2025), and scholarly literature. The results show key governance, planning and grid modernization gaps. Kenya has a compliance-based regulatory framework which does not provide incentives for utilities to minimize losses, like European systems. The Least Cost Power Development Plan (LCPDP) 2024-2043 is based on gross generation capacity numbers which include an overestimate of the energy that will be available for delivery due to the losses associated with adequacy assessments. Furthermore, the limited digitisation of grids and smart metering limit the possibility to monitor loss effectively and invest in appropriate infrastructure. The paper suggests three measures for a policy shift: performance-based regulation, delivered-energy planning, and the faster deployment of smart grids. These measures are critical for unlocking the potential for more capacity, achieving greater financial sustainability, making gainful electricity access more climate resilient, and making electricity access more reliable and affordable in Kenya and across East Africa.

Key words: T&D Loss, Loss Reduction, Energy Security, Renewable Energy, Circular Economy

Introduction

Engineering innovations for a circular economy do not just involve the recycling of materials or the reduction of industrial waste. Circularity is also about finding the right balance between supply and demand of electricity in a system, so that energy is not lost before it can be used for productive purposes. Transmission and distribution (T&D) losses are energy that has already used capital, land, infrastructure, water, labour, and environmental resources, but that fails to provide any social or economic benefit. Loss reduction is thus an obvious resource-efficiency intervention and an integral part of energy security in Kenya, where the electricity generation mix consists largely of renewables.

Kenya has achieved significant progress in increasing renewable generation, primarily from geothermal, hydro, wind and solar sources. However, high T&D losses continue to weaken the benefits of this clean-energy transition. Losses decrease available generation capacity, lead to decreased utility revenues, limit reinvestment in maintenance and modernization, and increase the likelihood of supply interruptions. This shifts

loss reduction from an operational to an engineering, regulatory, and planning concern.

T&D losses are generally divided into technical losses and non-technical losses. Technical losses are caused by the physical attributes of the power system such as line resistance, transformer losses, voltage drop, network congestion, overloaded feeders and sub-optimal voltage levels. Non-technical or commercial losses are caused by illegal connections, meter tampering, billing errors, unmetered consumption, and revenue collection systems that are weak. Technical losses are caused by the design and operation of the infrastructure while commercial losses are caused by governance, data integrity, enforcement and customer-management systems.

In Kenya, the power sector T&D is coordinated by the Energy Act of 2019, which features the Ministry of Energy and Petroleum, the Energy and Petroleum Regulatory Authority (EPRA), Kenya Electricity Transmission Company (KETRACO) and Kenya Power and Lighting Company (KPLC). KETRACO is tasked with developing and operating the national High Voltage (HV) transmission network, and KPLC is

the main distribution utility, along with owning part of the transmission network (Energy and Petroleum Regulatory Authority, 2024). Despite the significant expansion of the national transmission network, losses remain high, highlighting that system efficiency has not matched increases in generation and electrification and renewable integration (KETRACO, 2025).

The issue is particularly crucial since the country's losses continue to exceed the regulatory benchmark. System losses were more than 23% for the 2024/25 year, whereas EPRA has set its benchmark at 17.5% (Energy and Petroleum Regulatory Authority, 2025). This translates to almost a quarter of the energy that goes into the network being lost due to non-conversion to billable and useful delivered electricity. This is akin to a hidden capacity deficiency: new generation is produced but a portion of the power is injected into the system in a manner that does not provide capacity for reliability, cost or productive capacity.

This paper articulates loss reduction as a circular-economy solution for the electricity sector of Kenya with the overarching research question being: What are the regulatory, grid digitisation and investment

planning strategies needed to minimise power losses and enhance energy security in Kenya? The paper calls for a performance-based regulation, accelerated deployment of smart grid and a new engineering and policy paradigm in Kenya to be created and implemented.

Literature Review

Analysis of the literature has revealed that an efficient electricity delivery system is a key prerequisite for energy security. Sadiq and Antar (2024) state that total energy available to consumers depends on the energy generated minus T&D losses. If losses are high, energy security can only be measured through installed capacity and renewable generation percentage if there are no other factors involved. It also needs to be measured in terms of the energy that can be reliably and cost-effectively delivered to end users.

Recent research on power system reliability and stability also indicates that renewable integration further emphasizes the need for flexible, well-monitored and resilient power system networks. Islam et al. (2024) emphasize the importance of energy storage and optimal system management for enhancing reliability and flexibility. Storage and new generation are not, however, adequate to make up for a distribution system, which is technically inefficient and suffers from a high commercial leakage. Loss reduction is thus to be dealt with simultaneously with generation expansion, development of storage and transmission.

Experience in Europe shows the benefits of incentive-based regulation in loss reduction. The 3rd CEER Report on Power Losses (2025) reveals that losses in many European countries are considered as a controllable performance variable (Council of European Energy Regulators, 2025). T&D operators are subjected to benchmarking, revenue-cap adjustments, reward-and-penalty mechanisms and mandatory reporting. The European

model is not consistent throughout the EU, but it shows how the design of the regulatory framework can achieve the goal of maximizing the efficiency of the system while maximizing the financial results of the utilities. Smart-metering penetration and grid digitalisation further aids the capacity to detect loss hot spots and to distinguish between technical and commercial losses.

The lesson that the United States resource adequacy framework brings is rather different but complementary. Three major reliability measures mentioned in the U.S. Department of Energy Resource Adequacy Report (2025) are delivered energy, Loss of Load Hours and Loss of Normalised Energy (U.S. Department of Energy, 2025). This means that the grid is not used as a simple connection between generation and demand, but rather as an active component that can be used to achieve the goals of the overall system. Losses, congestion, and transfer restrictions are relevant since during stress, the capacity available to serve customers is diminished.

The same conclusion is drawn from African and regional studies. In their study of South Africa, Powanga and Kwakwa (2023) reveal that governance and enforcement, corruption and political factors can have a significant impact on electricity losses. Their findings are relevant to Kenya as the commercial losses cannot be addressed only by engineering solutions. They need regulatory oversight, enforcement, proper measurement, and financial/institutional incentives for loss reduction.

There is also literature that links energy efficiency in the grid to long-term energy transition in the strategic framework of energy planning. Nwokolo et al. (2025) state that the energy pathways in Africa must simultaneously meet economic growth, access and decarbonisation needs, and that high renewable energy scenarios rely on the efficiency and modernization

of grids. The higher the losses, the less resource efficient expanded renewable energy will be, as more infrastructure will need to be erected to recover the lost energy. This affects the affordability and delays industrial development, rural electrification, climate goals.

Regional engineering evidence shows the importance of data-driven network planning. This study by Manirakiza and Ekwue (2019) on the Rwandan transmission network demonstrates that focused transmission reinforcement using simulation can successfully decrease technical losses. Their work shows that loss reduction is not just infrastructure everywhere, it needs diagnostic modelling, network data and investment prioritisation. It is important for the lesson to be learnt in Kenya as they have limited digitalisation which makes it difficult to determine whether losses are due to technical design, operational loading, theft, metering gaps or billing weaknesses.

The literature thus reveals that in Kenya, there is a gap in research because the country has acknowledged T&D losses as a major challenge in operation and finances of energy service providers, but loss reduction is yet to be fully institutionalized as an energy-security, resource-efficient and circular-economy intervention. Current targets and benchmarks must be embedded in a consistent implementation approach to incentives, planning models and smart-grid technologies.

Methods

This research is a qualitative comparative policy-analysis study. The design is appropriate because it is influenced by both engineering conditions and regulatory incentives, institutional requirements and planning assumptions and data systems, as well as T&D losses (Snyder, 2019; Creswell & Creswell, 2017). Through a comparative approach it is possible to assess the framework in Kenya and to



draw out practices that can be adapted to local technical and institutional conditions. The study is based on secondary documentary data of three types of sources. The national context includes EPRA statistics, LCPDP 2024-2043, sector information on system losses, reliability and network development and this is reflected in Kenyan policy and regulatory documents. Second, the 3rd CEER Report on Power Losses (2025) sets an international benchmark on incentive-based regulation, smart metering and loss governance in electricity systems across Europe. Third, U.S. Department of Energy Resource Adequacy Report (2025) sets a standard for delivered-energy planning and reliability assessment. These documents are supplemented by scholarly literature on power losses, reliability, energy planning and regional loss-reduction strategies.

Selection of documents was done purposefully. Sources were chosen due to their institutional authority, direct involvement with T&D losses and value for comparison of governance, planning and technology approaches. Primary utility data, customer-level metering data and feeder-level load-flow measurements were not used in

the analysis. This is a drawback as it would enable a more detailed technical modelling. The documents available, however, are sufficient for the purposes of identifying policy, regulatory and planning gaps which impact loss reduction.

Three dimensions were used in the analytical framework. The first dimension related to governance and incentive frameworks, such as regulatory accountability, reward-penalty regimes, tariff treatment and utility performance obligations. The second dimension was on strategic planning and integration of energy-security, such as whether losses are interpreted as a loss of deliverable capacity and whether planning models consider unserved energy and reliability stress conditions. The third dimension was technological and data foundations, namely smart metering, grid digitalisation, sensitisation, analytics and separating technical from commercial losses.

The documents were examined through an iterative process. Policy statements, performance data, planning assumptions and technology measures were identified, compared and coded across the three dimensions. These results were finally synthesized into engineering and policy

recommendations, following the theme of the conference, of circular economy and resource efficiency.

Results and Discussion

The contribution of this paper is a practical research and development (R&D) journey of converting loss reduction from an accounting goal to an engineering innovation agenda. The analysis reveals three interconnected gaps: Kenya's governance model is compliance-based and not performance-based, national planning is heavily focused on gross capacity, and grid digitalisation is insufficient to enable accurate measurement, enforcement, and investment prioritization.

The first observation is that Kenya's loss performance is not very strong relative to some of its East African counterparts (Energy and Petroleum Regulatory Authority, 2025). The regional comparison is shown in Figure 1, which shows that Kenya and Uganda performed above the 17.5% threshold, while Tanzania and Rwanda performed below or close to the 17.5% threshold.

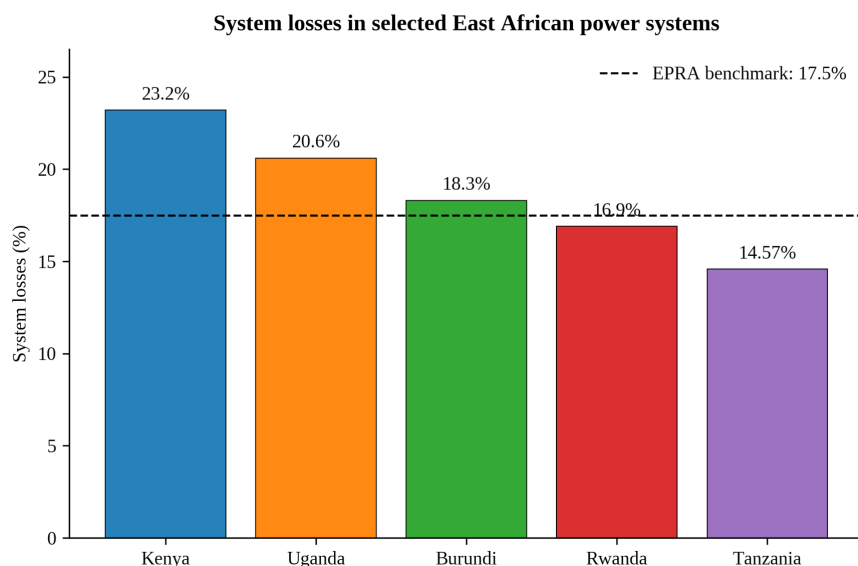


Figure 1. System-loss performance in selected East African countries compared with the EPRA benchmark.

T&D losses in the Kenyan system were approximately 23.2% whereas losses in Rwanda, Tanzania, Uganda and Burundi were lower. Restrictive connection checks, smart meters and investment in the high-voltage transmission system have been linked to relatively low numbers of losses in Tanzania.

Losses are relevant to circular economy and resource efficiency at the regional level as they account for wasted generated electricity and underutilized infrastructure. Every kilowatt-hour that is lost in a renewable-dominated power system is also lost geothermal wells, transmission corridors, wind turbines, hydropower infrastructure, solar installations, land, capital investment, and maintenance. that are not converted to the end-user value. Therefore, reducing losses generates additional capacity that can be used without a corresponding increase in generating plants.

With regards to governance, the second finding is noteworthy. There is a system loss benchmark in Kenya and systems which lose more than the approved amount are financially penalized in the national system. The framework is, however, largely retroactive and compliance-oriented. It doesn't offer enough incentive to reduce losses from one year to the next,

to improve performance at the feeder level or to prove losses are being recovered for output and production. By comparison, in Europe, performance-based regulation directly relates efficiency results and revenues. This puts constant pressure on the organization to cut losses, enhance data quality and invest in technology that yields tangible efficiencies. A Loss Reduction Incentive Mechanism in Kenya could be embedded in the tariff-setting process. The mechanism should contain a revenue-adjustment factor based on proven reduction in commercial losses year-on-year, a shared-savings model which provides for partial retention of revenue recovered from the reduction in commercial loss and a differentiated target for technical and non-technical losses. It should also incorporate more robust benchmarking with previous performance and peer utilities and feeder level baselines. This would make the rule more dynamic, than static, and be more of a performance-based regulation.

The third finding relates to planning. While losses must be more clearly subtracted from available energy in resource adequacy and security assessment, Kenya's LCPDP 2024-2043 is a long-term path of

development for both generation and transmission (Ministry of Energy & Petroleum, 2024). A gross capacity of a plant may be misleading if a significant amount of energy is lost before getting to the delivery point. A delivered-energy approach would measure the net available capacity, consider congestion and losses, and look at various new generation options as alternatives to loss-reduction investments to ensure adequacy. The delivered-energy approach under climate and demand stress is particularly relevant. Service reliability may be reduced due to combination of peak demand growth, Variable Renewable Energy (VRE), hydrological variability, transmission congestion and distribution faults. Loss reduction is no longer just an operational goal but a least-cost resource, if it is included in planning models as a source of unserved energy. This will help to make more rational capital allocation decisions as losses on high loss corridors may deliver more available electricity per shilling than some generation expansion alternatives.

The fourth finding relates to technology and data. To realize credible loss reduction, smart meters, feeder sensors, transformer monitoring, distribution-management systems and analytics serve as the building blocks. The granular data is hard to use without separating technical losses from theft, identifying overloaded transformers, quantifying transformer losses, and determining if any investment has reduced losses, or whether losses have been tampered with. The Rwanda transmission-network evidence shows that simulation and high-resolution data can highlight solutions that have vastly different loss reduction impacts. Kenya thus requires a more robust smart-grid R&D platform to connect measurement, analysis, pilot projects and scaling decisions.

There are five stages in the proposed R&D pathway. The first step is diagnosis, which involves

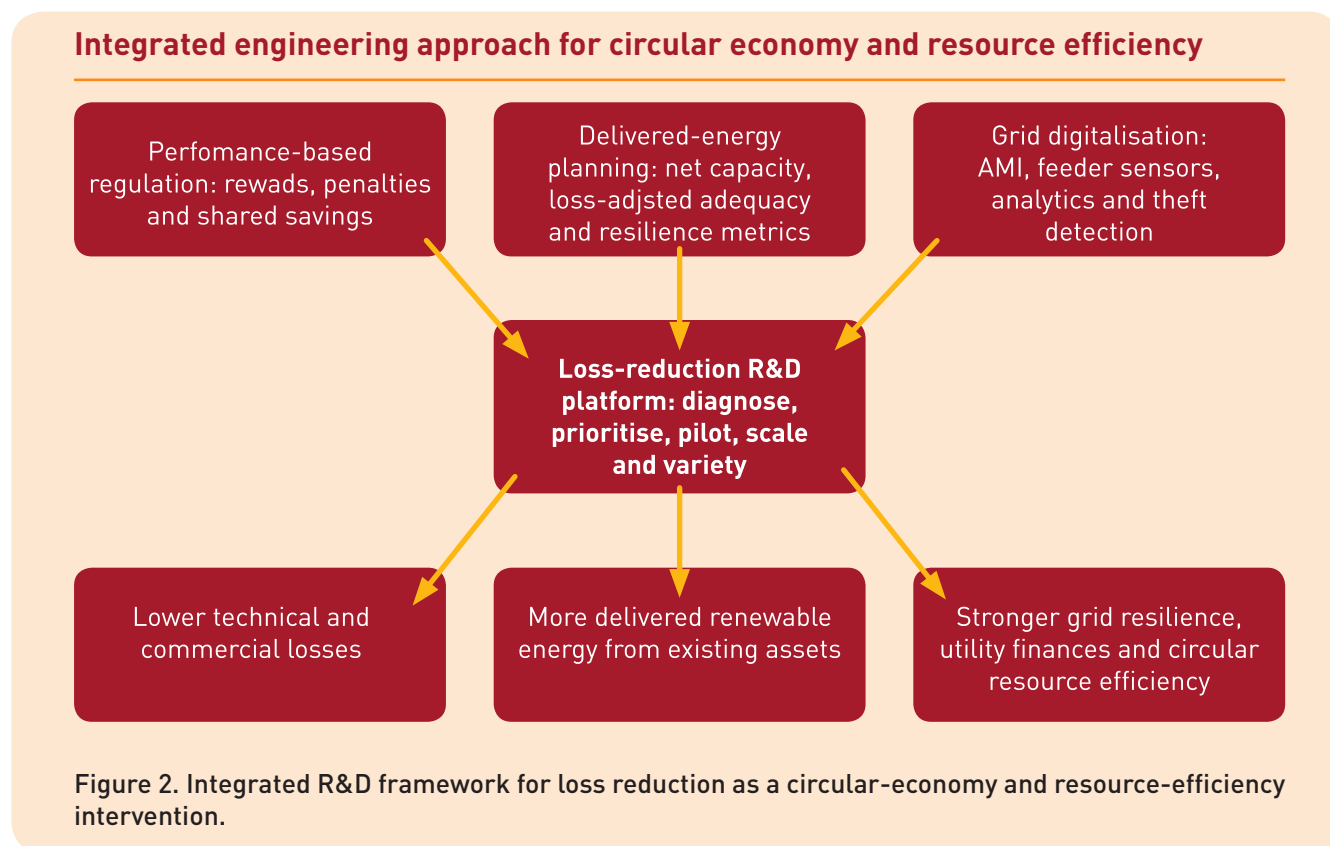


identifying the losses as a function of voltage level, feeder, customer class and time of day. The second stage is prioritization, ranking interventions by cost, loss-reduction potential, implementation risk and resilience benefit. The third stage involves piloting;

testing deployment of Advanced Metering Infrastructure (AMI), feeder automation, transformer upgrades, reconductoring, theft-detection analytics and community-based enforcement in specific areas. The fourth stage is scaling: bringing effective pilots into

regulated investment plans and procurement programmes. The fifth stage involves verification: creating audited, open, performance reports that indicate loss-reduction results.

A summary of this integrated engineering approach is shown in Figure 2.



The framework links regulatory incentives, delivered energy planning and grid digitalisation with a loss-reduction R&D platform. The anticipated results include reduction in technical and commercial losses, increased utilization of available renewable energy, better utility finances, enhanced resilience and resource efficiency. The framework is consistent with circular economy principles as it aims to maximise the use of the existing assets to provide energy services, rather than investing more resources to build new generation and network. The engineering interventions should be planned in a sequence based on their data needs and value added. The focus for smart metering

should be on large industrial and commercial customers, high loss feeders, peri-urban areas with commercial loss potential and distribution areas with overloaded transformers. Interventions to address technical losses should involve feeder reconfiguration, conductor upgrading, power factor correction, long low voltage runs, and transformer loading optimization and distribution automation. Commercial-loss interventions should involve tamper-proof metering, automated consumption analysis, expediting inspection processes, legal measures and customer education. The policy interventions should

reinforce the technical measures. It is necessary for utilities to provide EPRA with loss-reduction investment plans that have clearly defined baselines, milestones and methods of verification. Loss-reduction activities that improve the use of renewables and decrease the need for extra fossil fuel back-up should be funded with public funds or concessional climate finance. Digital platforms that are interoperable, cyber secure, and that can provide analytics at the feeder level should be preferred in procurement. Losses should be linked to indicators of reliability in utility performance reports, to ensure efficiency and resilience are addressed in tandem.

A progressive implementation plan is envisioned. In the short term, Kenya should harmonise loss definitions, establish loss level baselines at the feeder level, and implement pilot performance-based incentives, followed by the release of loss maps. On the medium term, the country needs to deploy AMI in priority areas, incorporate net delivered energy in LCPDP modelling and create a shared savings model for verified commercial loss reduction. The national planning framework should consider loss reduction as a formal resource adequacy option, similar to generation, storage, and transmission expansion, in the long term.

Conclusion

High T&D losses in Kenya is a structural problem of energy security and resource efficiency. They lower the total supply of renewable energy to customers; impact utility finances; limit the space for maintenance and modernization; and create reliability concerns. In a circular-economy point of view the losses are a waste of energy since energy has already been spent on those resources and infrastructure, but a portion of the output is not used for producing a useful service.

The comparative analysis reveals that Kenya can learn three lessons from the international community to improve its energy security. Kenya can implement performance-based regulation from Europe, where the utility's financial performance is tied to the actual reduction in losses. Delivered-energy planning can be imported from the U.S. to Kenya, where losses are considered a factor in the unserved energy and adequacy risk. Based on the lessons learnt from the regional engineering evidence, Kenya can implement data-driven grid modelling and specific infrastructure interventions to find the most cost-effective loss-reduction measures.

The paper proposes an integrated engineering solution, comprising performance-based regulation and accelerated smart-grid deployment, with delivered energy planning. They must be put into place via a structured R&D pathway with a diagnosis of loss, prioritisation of interventions, piloting of solutions, scaling up of successful interventions and verification of results. This can help tap into available capacity, enhance reliability, cut costs, improve utility finances, and contribute to Kenya's renewable energy and climate targets.

In Kenya and other countries in the East African Region, the key take-home message is that energy security is not just about increasing energy generation. It's when the energy produced is efficiently distributed to the end-user at a reliable and cost-effective price. Losses along the T&D chain should, therefore, be considered a fundamental engineering innovation for circular economy and resource efficiency.

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Mapping Kenya's Future: The New Frontiers of Geospatial Engineering

By Charlynn Jepkosgei



Charlynn Jepkosgei is a young, vibrant space ecosystem builder, thought leader and speaker. Recently featured on BBC News for her exemplary work in the space industry, she continues to leverage her skills to create meaningful impact. She thrives in translating Earth Observation data into practical solutions that address real societal challenges from climate resilience and food security to land degradation and sustainable development across Africa. Passionate about empowering others, she is the Founder of Women in Space Kenya - a professional organization dedicated to mentoring, inspiring and equipping young women & girls across Kenya and Africa to pursue careers in the space and geospatial sectors.

"I believe that space is a unifying domain with immense potential to solve real-world problems when guided by inclusive, ethical and cooperative principles. I am committed to advancing innovation, international cooperation and leadership in space science."

Mapping Kenya's Future: The New Frontiers of Geospatial Engineering

When I think about the future of geospatial engineering in Kenya, I do not think only about maps. I think about the intelligence behind those maps: what spatial data can tell us about our farms, our cities, our infrastructure, our environment and our changing climate and, more importantly, how we can use that knowledge to make better decisions before problems become crises.

My own journey into geospatial engineering was not exactly what I had planned. When I first joined Technical University of Kenya in 2012, I was admitted as a B. Com student but later wanted to transfer to study Civil Engineering because I was fascinated by roads, buildings and the process of turning designs into physical structures. Interestingly because of cluster points and all, I eventually found my way into Geospatial Engineering and that decision opened a completely different world for me.

As I progressed through the programme, I began to understand

that geospatial engineering sits at the intersection of engineering, technology and the broader Earth ecosystem. It brings together surveying, Geographic Information Systems (GIS), satellite remote sensing, spatial data analytics and now increasingly, artificial intelligence. I became particularly interested in remote sensing because it gave us the ability to observe places and things from a distant without getting in contact with them and processes at scales that would be impossible to capture through fieldwork alone.

That interest continued into my postgraduate studies in Spatial Engineering at the University of Twente's Faculty of Geo-Information Science and Earth Observation (ITC) in the Netherlands and later into my doctoral research in using remote sensing in understanding Agroforestry Ecosystem. Along the way, I have also had the opportunity to work and pilot drones to do research aside from satellite images. Also, working alongside students, researchers and field professionals has continually

reinforced one fundamental truth: geospatial engineering is vastly bigger than the static maps we historically associated with it.

The discipline is changing rapidly. We now have access to high-resolution satellite imagery, drones, artificial intelligence, cloud computing and increasingly sophisticated algorithms. But technology itself should never be the end goal. The question should always be: what problem are we trying to solve and how can geo-spatial intelligence help us solve it?

From Mapping Landscapes to Anticipating Change

One of the most important shifts in geospatial engineering is the move from simply mapping what exists to understanding how things are changing and increasingly, anticipating what may happen next. It is the transition from merely mapping what exists on the ground to dynamically monitoring change to support predictive decision-making. Instead of relying entirely on physical field teams every time information is needed, Earth observation allows

us to monitor massive landscapes and understand changes over time.

My doctoral research is a good example. I am exploring hyperspectral satellite remote sensing, drones and artificial intelligence to better understand complex agroforestry ecosystems. Agroforestry presents a unique remote sensing challenge. When trees, vegetation, and crop canopies coexist, a single satellite pixel contains a mixed spectral signature. The research challenge is developing advanced machine learning methods to unmix those pixels and accurately distinguish individual environmental components. When we unlock that level of detail, remote sensing yields precise insights for land management, biodiversity tracking, carbon monitoring, and climate resilience; we move from guesswork to evidence. In agricultural planning, spatial intelligence allows us to evaluate crop distribution across counties and project seasonal yield potentials. In civil infrastructure and urban planning, these same datasets allow us to monitor land degradation, track water catchments and guide sustainable development.

I have also seen how sophisticated spatial science can translate into very practical solutions. In one project, we developed a Smart Seed Recommender for maize farmers in Nandi by integrating satellite imagery, rainfall patterns, temperature information and soil pH. Instead of giving farmers generic recommendations, the platform provided location-specific guidance on seed selection and fertilizer application. An important lesson from that project was that innovation is only meaningful if people can actually use it. We therefore explored delivery through USSD, including a simple 254# interface, so that the solution could reach farmers who may not have smartphones or reliable internet access. We can have the most sophisticated satellite data and algorithms in the world, but if the person who needs the information cannot access it, we have not solved the problem.



Charlynne Jepkosgei conducts fieldwork in Busia, Kenya, alongside her colleague in the Geospatial Engineering profession

That is why I often describe **“geospatial engineering as more than a technical discipline. It is part of the decision-making infrastructure of a nation.”**

Whether we are looking at agricultural productivity, access to healthcare in remote areas such as Turkana, infrastructure planning or environmental management, location provides an essential layer of intelligence.

Bridging the Gap Between Science and Policy

One of the challenges I see in our sector is the gap between technical research, professional practice and policy. As engineers and researchers, we frequently write technical reports filled with complex jargon that remain on academic shelves rather than translating into policy directives. If research is to drive real-world impact, we must master science communication. For instance, Geospatial technology provides a visual medium to bridge

this gap. Instead of explaining complex remote sensing algorithms in abstract technical terms to a municipal leader, we can present clear, comparative spatial maps. By showing how a landscape or urban center has evolved, comparing visual layers from 2010, 2012, 2020, and 2026, the spatial evidence tells an undeniable story. Visual evidence makes science accessible, empowering decision-makers to act on time.

This proactive approach is essential for managing for example how Kenya faces climate-related risks, rapid urbanization, flooding and environmental degradation. We should not wait to map the damage after a disaster. Spatial risk modelling can help us identify vulnerable areas, plan interventions and develop early warning systems before a crisis occurs. In many cases, the greatest value of space technology is not simply telling us what has happened ~ it is helping us avoid what could happen.

“Space technology can tell us so much. It can help us avoid so much.”

Space technology is also much closer to our everyday lives than many people realize. It is not only about astronauts and rockets. Downstream space applications power our daily lives, from GPS navigation applications like Uber to weather forecasting, telecommunications, agriculture, environmental monitoring and many other services we use every day. Kenya has taken important steps in building its space ecosystem, including through the Kenya Space Agency, but institutions are only the beginning. We also need sustained investment in human capital, research, innovation and pathways that allow young engineers to turn ideas into solutions that can actually be deployed.

Building Inclusive Pathways and Empowering Innovators

For me, investing in people is inseparable from building the future in any sector. That conviction is what led me to start and lead **Women in Space Kenya**. Throughout my academic journey and early career, I often found myself in spaces where there were very few women. Upon graduation, I experienced firsthand how difficult it can be to navigate the early stages of a career without

structured mentorship, professional networks or someone to help you understand which opportunities are available or just guide your thoughts and ideas.

Women in Space Kenya grew out of that experience and gap. Initially, the idea we had with the co-founder was simply to mentor a small group of perhaps 5 to 10 young women. But when we opened our first call for mentees in the first program, we received more than 100 applications within two weeks and that response told us something important: the interest and talent were already there. What was missing was access to mentorship and we decided to build on that. Since then, Women in Space Kenya has grown into a structured community focused on mentorship, capacity building, school outreach and creating connections between emerging professionals and the wider space and geospatial ecosystem. We have worked to connect women and girls with mentors, researchers, industry professionals and opportunities that can help them build sustainable careers and also placing our mentees directly into industry pipelines where they gain hands-on experience while adding real value to host companies.

One of the things I am particularly proud of is seeing mentorship become a cycle rather than a one-way relationship. Someone who enters a programme as a mentee can eventually become a professional, a researcher, an entrepreneur or a mentor to someone else. That is how we create lasting change not simply by opening a door for one person, but by helping that person hold the door open for others.

For young engineers entering the field today, whether in civil engineering, GIS, surveying, computer science or other disciplines, I would encourage them not to limit themselves to the traditional idea that graduating means simply looking for a job. The geospatial and space sectors are expanding rapidly. There are opportunities to become an entrepreneur, consultant, software developer, researcher, policy advisor or innovator. Focus on becoming a problem solver. Above all, put fear aside and **dare yourself**. Dare to attend that conference, ask that difficult question, present your research/idea, reach out to someone whose work inspires you, build new networks and collaborate across disciplines. Some of the most groundbreaking engineering solutions emerge when diverse minds join forces to solve shared challenges.

Looking Ahead

I am profoundly optimistic about the future of geospatial engineering in Kenya. We already have talented engineers, researchers, universities, government institutions and a growing private sector. The opportunity now is to connect these pieces more deliberately and build an ecosystem in which local knowledge and local talent can generate solutions for local challenges and eventually for the rest of Africa.

For me, success is not simply about professional titles or individual achievements. It is about impact. I want my research to contribute to better understanding of agriculture,



Women in Space Kenya; Mentoring women in space



agroforestry, climate resilience and sustainable land management. As an educator, I want to continue helping students see themselves as engineers who can create solutions rather than simply wait for opportunities. And through Women in Space Kenya, I want to see many more women confidently occupying spaces in research, engineering, entrepreneurship and leadership.

Kenya also needs to move from being primarily a consumer of geospatial and space technologies to becoming a stronger creator of knowledge, products and services. That means investing consistently in research and development, strengthening links between universities and industry, supporting startups, improving access to data, and creating policies that encourage local innovation. International partnerships remain important, but sustainability requires us to build capacity that can thrive beyond individual projects or grants.

If there is one message, I would want a young girl reading this to carry with her, it is this: never allow someone else's perception of your limits to define the size of your dreams. You do not need to have everything figured out before you begin. Start with curiosity, keep learning, find people who believe in your potential, and do not be afraid of rejection. Sometimes the opportunity you think is too big for you is exactly the opportunity you should apply for.

Finally, Geospatial engineering is no longer simply about producing maps after decisions have been made. It is about generating the spatial intelligence that can help us make better decisions in the first place. If we can translate that intelligence into information that a smallholder farmer can use, a policymaker can understand and an engineer can implement, then geospatial engineering will not simply support Kenya's development - it will help shape it.

Mapping The Future Beyond Coordinates; The Strategic Role of Land Surveyors in Safeguarding Kenya's Green Spaces Amid Urban Growth



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Preserving Kenya's green spaces is a key necessity for sustainable development, climate resilience and ecological justice. As urbanization accelerates across the country, these vital natural areas ranging from national parks and forests to wetlands and urban green belts face unprecedented threats from encroachment, infrastructure expansion and land degradation. These green spaces are not obstacles to progress, they are foundational assets whose ecological, cultural, economic and planning value must be integrated into the country's vision for sustainable growth.

Kenya is home to an array of unique ecosystems that provide refuge to countless plant and animal species some of which are found nowhere else in the world. These ecosystems are not just habitats they serve essential functions regulating local climates, purifying air and water, sequestering carbon and mitigating floods. They also support critical groundwater recharge systems, agricultural productivity and buffer communities against the impacts of

climate change. Whether located in the heart of Nairobi, the forests of Mount Kenya, the wetlands of Yala or the savannahs of Tsavo among many other zones, these spaces form the ecological infrastructure that underpins national wellbeing.

The rapid spread of concrete and asphalt across Kenya's urban and peri urban areas is shrinking these green zones, compounding urban heat island effects, increasing air pollution and destabilizing natural hydrological cycles. The loss of green cover disproportionately affects vulnerable populations who depend on ecosystem services for daily survival such as access to clean water, protection from flooding and food security through subsistence farming.

Green spaces also hold immense economic value. They are a cornerstone of Kenya's tourism industry attracting local and international visitors and generating revenue that supports jobs in hospitality, transportation, conservation and the creative economy. Beyond tourism, these landscapes support livelihoods in agriculture, beekeeping, fisheries and traditional herbal medicine. They also play a growing role in carbon markets and climate finance mechanisms offering Kenya a pathway toward low carbon climate resilient development.

Habitat fragmentation forces wildlife into human settlements increasing the frequency of human wildlife conflict. Species already facing pressures from poaching, pollution and land use change are pushed closer to extinction. Global estimates show extinction rates among birds and mammals are now 100 times higher than natural background levels largely due to human activity. Restoration is

costly, time-consuming and often incomplete. Once lost, ecosystems rarely return to their original state.

This crisis is not unique to Kenya. The United Nations and the International Union for Conservation of Nature (IUCN) have called for global action to halt biodiversity loss and restore degraded ecosystems. The UN Decade on Ecosystem Restoration (2021–2030) underscores the urgency of investing in nature as a means of securing long term human welfare. Kenya as a signatory to international environmental agreements and the custodian of globally significant biodiversity has a duty to uphold these principles through strong domestic policies and on the ground action. To do so, the value of green spaces must be fully recognized in national and county level planning. These areas must not be treated as idle or underutilized land awaiting development. They are living systems that support social stability, economic vitality and environmental security. Development must be pursued in ways that preserve a natural city rather than displacing it.

Instead of expanding into ecologically fragile areas, Kenya's urban centers can grow through smarter land use strategies. This includes vertical development, revitalizing underutilized land and upgrading informal settlements with sustainable infrastructure. Regeneration of aging industrial and commercial zones especially in cities like Nairobi, Mombasa, Kisumu, Nakuru and Eldoret offers an opportunity to accommodate growth without sacrificing natural areas. Equally important is the decentralization of economic activity with investment in well planned satellite towns and secondary cities

connected by efficient transport networks and essential services.

Green spaces also serve as powerful cultural, educational and spiritual resources. From school trips to nature reserves to community led forest conservation initiatives, these environments foster ecological literacy and a sense of stewardship in future generations. They provide open air classrooms for scientific research, conservation training and civic engagement. Across the country, environmental defenders, researchers and community-based organizations are working tirelessly to protect these spaces often in the face of considerable risk.

Kenya's legal framework especially the **Wildlife Conservation and Management Act, Environmental Management and Coordination Act** and related land use regulations provide mechanisms for protecting ecologically sensitive areas. However, enforcement remains inconsistent and political or commercial interests too often override environmental considerations. Weakening these protections would not only endanger ecosystems but also set dangerous precedents for land use governance across the country.

Professionals in the geospatial sciences, built environment, environmental law, planning and civil

society all have a critical role to play. Sustainable development means planning for growth that complements rather than compromises the natural systems that sustain human life. It means recognizing that not all land holds equal value, some must remain untouched to protect the collective good. Short term infrastructure gains must not come at the cost of long-term resilience, public health and social equity.

Kenya must also reject the false dichotomy between development and conservation. Globally, cities are redefining themselves by integrating green infrastructure, prioritizing ecological health and creating equitable access to nature. Kenya has the opportunity to lead the region by demonstrating that green spaces are not relics of the past but essential assets for the future. The preservation of forests, wetlands, parks and wildlife corridors is not a nostalgic gesture, it is a forward-thinking decision grounded in science, equity and intergenerational responsibility.

Ultimately, green spaces in Kenya are more than scenic landscapes or tourist attractions, they are lifelines. They sustain biodiversity, anchor cultural heritage, inspire scientific innovation and build resilience against climate change. Protecting these areas is about securing the health, identity and prosperity of Kenya's people today and for generations to come.



A drone mapping a cityscape (puchong 2025)

Mapping, Measuring & Designing Smart Cities: How Smart Infrastructure Is Driving Sustainable Roads, Energy, Water and Urban Development in Kenya



By; Ivy Chelangat

An Electrical and Electronics Engineering graduate with a background in Telecommunications and an interest in geospatial technology, digital infrastructure, engineering innovation and sustainable development. She is also a technical writer and contributes to engineering publications, with a focus on translating technical concepts and emerging technologies into practical and engaging insights.

What makes a city smart?

Is it the sensors along its roads, the fibre beneath its streets, intelligent traffic systems or buildings that respond to their occupants? Perhaps. But before a city can become smart, engineers must first understand something much more fundamental: **the city itself**. Where are its roads, buildings, utilities, waterways and property boundaries? How does the terrain influence development? Where is traffic concentrated? Which infrastructure already exists, and how will new infrastructure interact with it? The intelligence of a city therefore begins long before construction. It begins with **mapping, measuring, designing and connecting information**.

Before We Build, Can We See the City?

Modern geospatial engineering has moved far beyond producing conventional maps. Through Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), remote sensing, photogrammetry, LiDAR and spatial databases, engineers can build

increasingly detailed digital representations of the physical environment. Consider a proposed road corridor. It is not simply a line between two points. Within that corridor may be existing carriageways, drainage structures, buildings, water pipelines, fibre-optic cables, electricity infrastructure, land parcels and environmentally sensitive areas. A technically sound road design therefore depends on understanding these spatial relationships before construction begins.

This is already reflected in Kenya's road sector. Current Kenya National Highways Authority (KeNHA) requirements call for GIS datasets covering road assets and existing services such as water, fibre and sewer, together with inventory dates, geotagged photographs, metadata and validation information. GIS data is required in editable formats so that it can continue to support infrastructure management rather than becoming a static project document. The question is no longer simply, "Can we map the road?" It is: **Can we maintain a reliable digital record of the road throughout its entire life?**

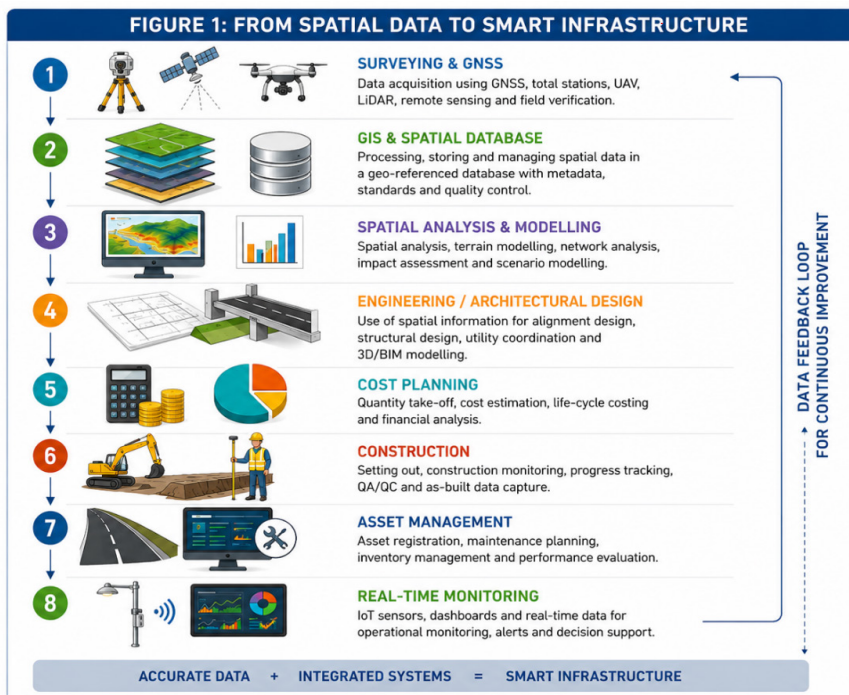


Figure 1: From Spatial Data to Smart Infrastructure — Surveying & GNSS — GIS & Spatial Database — Spatial Analysis & Modelling — Engineering/Architectural Design — Cost Planning — Construction — Asset Management — Real-Time Monitoring.

You Cannot Design What You Have Not Measured

Mapping establishes location; measurement establishes the physical reality on which engineering decisions depend. A modern infrastructure survey may combine RTK-GNSS, total stations, digital levels, UAV photogrammetry, remote sensing and field verification. These techniques can produce topographic surveys, digital terrain models, road inventories and spatial databases that feed directly into engineering design. But technology alone does not guarantee good engineering. Survey control must be properly established, coordinate reference systems must be appropriate, observations must be checked and datasets must be validated. An error introduced during data acquisition can propagate into design, quantities, construction and ultimately asset management.

This makes the geospatial engineer increasingly important in multidisciplinary infrastructure projects. Their role is not simply to tell other professionals **where something is**, but to provide the spatial framework within which engineering decisions can be made.

As cities become more complex, this spatial framework becomes the common language connecting surveying, civil engineering, architecture, planning, construction and infrastructure management.

A Road Is Never Just a Road

A major highway interacts with almost every component of the environment through which it passes. It affects movement, land, drainage, utilities, settlements, businesses, ecosystems and regional economies. The proposed **Mau Summit-Eldoret-Malaba corridor** illustrates this complexity. Current project preparation involves feasibility work for a major capacity upgrade, with Intelligent Transport Systems and climate-resilient infrastructure forming part of the proposed development.

For such a corridor, spatial intelligence is fundamental. Engineers need to understand the existing alignment, terrain, traffic environment, land requirements, utilities, environmental constraints and surrounding settlements before decisions about upgrading or redesigning the corridor can be finalised. The same principle

applies at the construction stage. A road is not simply designed and handed to a contractor. Survey control, setting-out, construction monitoring, quantities, drainage and asset information all depend on accurate spatial information. This is why the role of geospatial engineering extends across the project lifecycle from **feasibility and design to construction and maintenance**.

The transformation is also occurring on Kenya's rural road network. The Kenya Rural Roads Authority (KeRRA) has sought an enterprise-wide GIS system designed to support data visualisation, spatial analysis and decision-making for road infrastructure. Its technical requirements include integrating CAD and survey information with GIS, supporting road inventories, project monitoring and other spatial workflows. The significance is greater than acquiring new software. It represents a move towards **institutionalizing spatial intelligence in infrastructure management**.

Who Pays for a Smart City?

There is another question that smart-city discussions sometimes overlook: **How much will the smart solution cost not only to build, but to operate and maintain?** A city can have sophisticated technology and still be economically inefficient.

This is where quantity surveyors, cost engineers and other built-environment professionals become essential. A smart lighting system, for example, may have a higher initial cost but lower energy consumption and maintenance requirements. The appropriate engineering decision therefore requires life-cycle thinking rather than focusing only on the initial construction price. The same principle applies to roads, buildings, water systems and energy infrastructure.

BIM and GIS can strengthen this relationship. GIS provides the **geographical context** where the project exists within the wider environment while BIM provides detailed information about the

asset being designed. Quantity surveying then adds another dimension: **what will it cost to build, operate, maintain and eventually replace?** The Institute of Quantity Surveyors of Kenya has highlighted BIM, geospatial data systems, project-management information systems, life-cycle planning and cost engineering as part of the technology-driven transformation of the built environment. A smart city therefore requires more than technological innovation. It requires **technical and economic intelligence working together.**

When Water, Energy and Data Share the Same City

Roads are only one part of an urban system. Beneath and above them are networks supplying water, electricity, wastewater services and communications. This is where the idea of an integrated smart city becomes particularly interesting.

Konza Technopolis provides a Kenyan example of this approach. Its smart-city ecosystem includes an Intelligent Transportation System, smart poles, surveillance cameras, environmental monitoring sensors and high-capacity fiber, centrally managed through an Intelligent Operations Centre. Its strategic planning also identifies GIS-integrated asset management, smart parking, public Wi-Fi and IoT services alongside roads, water networks, sewer systems and energy infrastructure.

The significance is not any single technology. A smart pole is useful. A water sensor is useful. A traffic system is useful. A GIS database is useful. But when these systems can exchange information, engineers and city managers gain something much more valuable: **a connected view of how the city is performing.** This principle is also evident in major mixed-use developments such as **Two Rivers**, where power, water, wastewater and ICT infrastructure are integrated with the built environment.

The lesson is simple: **infrastructure should not be designed as isolated systems when the city itself operates as one system.**

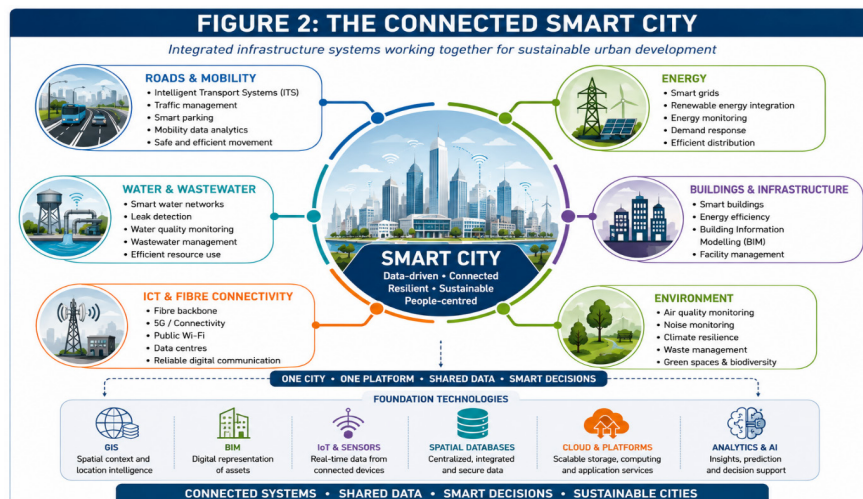


Figure 2: The Connected Smart City Roads & Mobility, Energy, Water & Wastewater, Buildings, ICT & Fibre and Environment connected through GIS, BIM, IoT, sensors and spatial databases.

From Project to Living System

Traditionally, an infrastructure project could be viewed as complete once construction ended. Smart infrastructure changes that concept. The digital information created during surveying and design can continue into construction, commissioning, operation and maintenance.

A road's digital record can contain its geometry, drainage structures, signs, bridges, pavement condition and maintenance history. A building's BIM model can connect to information about equipment and energy performance. Utility networks can be spatially referenced and updated as assets change. This creates a continuous information chain: **Survey — GIS — Design — Construction — Asset Management — Monitoring.**

The value of geospatial engineering therefore increases after construction, because the same spatial framework can support decisions throughout the asset's operational life. Instead of treating data as something produced for a single project and then forgotten, infrastructure owners can maintain a living information environment that evolves with the asset.

What Happens When the City Can Think?

The next step is the **digital twin**: a

dynamic digital representation of a physical asset or environment that can combine models, spatial databases, sensor information and operational data. Imagine a road system whose digital model contains its geometry, pavement condition, drainage assets and maintenance history while real-time information provides traffic or environmental conditions. Or imagine an urban water network where spatial data and sensor information help identify abnormal pressure or potential failures before they become major disruptions.

This is where GIS, BIM, IoT, remote sensing, artificial intelligence and real-time data begin to converge. But there is an important engineering warning: **a sophisticated digital system cannot compensate for poor foundational data.** A digital twin built on inaccurate surveys, incomplete asset records or poorly coordinated datasets will simply produce a sophisticated representation of inaccurate information.

That brings us back to the beginning: **Map accurately. Measure carefully. Design intelligently. Build responsibly. Manage continuously.**

The city of the future will be built on data

Kenya's transformation towards smarter infrastructure is already visible not only in flagship developments such as Konza,

but in the everyday requirements of road agencies and infrastructure projects. The important shift is that geospatial information is becoming part of the infrastructure itself. Roads are being represented through spatial databases. Projects increasingly depend on digital information. Utilities must be coordinated. Costs must be considered across the asset life cycle. Sensors and intelligent systems are beginning to connect physical infrastructure with real-time information.

The smart city, therefore, is not simply a city filled with technology. It is a city in which **engineering decisions are informed by accurate spatial information, multidisciplinary collaboration, life-cycle thinking and continuously updated data.**

And perhaps the question for the engineers shaping Kenya's urban future is no longer, "How do we make a city smart?" but rather, "How do we make every decision about where we build, what we build, how it performs and how it is maintained more intelligent than the decision before it?"

The smart city does not begin with a sensor. It begins with knowing where everything is.

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Table 1: Smart Infrastructure in Practice Selected Kenyan Examples

Current example	What is happening	Geospatial/engineering relevance
Mau Summit–Eldoret–Malaba Corridor	Feasibility and preparation for capacity enhancement, ITS and climate-resilient infrastructure	Corridor mapping, engineering surveys, traffic analysis, environmental assessment and spatial planning
Rironi–Nakuru–Mau Summit	Highway construction underway	Survey control, setting-out, terrain and corridor data, construction monitoring and asset information
KeNHA road programmes	GIS datasets incorporated into road-asset and maintenance requirements	Spatial databases, road inventories, geotagged assets and GIS professionals
KeRRA Enterprise GIS	Development of an enterprise spatial information environment	Road inventory, survey integration, project monitoring, land acquisition and spatial decision support
Konza Technopolis	Smart poles, ITS, fibre, sensors and intelligent operations infrastructure	GIS-integrated asset management, spatial infrastructure and IoT
Two Rivers	Integrated power, water, wastewater and ICT infrastructure	Multidisciplinary infrastructure coordination and digital urban systems

Financing the Engineers Who Build Kenya's Future

How SACCOs are Empowering Engineers, Growing Enterprises and Driving National Development



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Introduction

Ask an engineer how they financed their first site vehicle, their consultancy's working capital, or the plot of land they're now building on, and there's a good chance a SACCO is somewhere in that story. Savings and Credit Co-operative Organizations have quietly become one of the most important financial tools available to engineers in Kenya arguably more important, for many practitioners, than the commercial banks that dominate financial headlines.

1. A movement too big to ignore

Kenya's co-operative sector is enormous by African standards. The SACCO Societies Regulatory Authority (SASRA), which supervises deposit-taking SACCOs, reported that the regulated sector closed 2025 with about 7.8 million members, total assets north of Kshs 1.2 trillion, and member deposits above Kshs 830 billion, spread across 357 SACCOs and 669 branches. Government policy has leaned into this growth, treating co-operatives as a core channel for deepening financial access and mobilizing savings for housing,

agriculture, and small enterprise. Engineers have not sat on the sidelines of this movement they built their own corner of it.

2. Engineers built their own

The clearest example is Mhandisi Sacco Society, established under the Institution of Engineers of Kenya (IEK) and marketed as the only Sacco in the country built by engineers, for engineers. Its membership spans IEK members, engineers board of Kenya, staff of construction and consultancy firms, public-sector engineers, academics, and technical practitioners generally. Entry is kept deliberately low friction application fees paid upon registration and the value proposition is simple: save with the SACCO, and become eligible for loans priced well below what commercial banks typically charge, alongside, investment products built around an engineer's career stage.

Sitting alongside are other saccos, which widens the net to architects, quantity surveyors, town planners, environmental consultants, landscape architects, and construction project managers plus their families and firm staff. Many engineers also belong to employer-

based or general-membership SACCOs, giving them a second, often larger, pool of savings and credit to draw on.

3. Mhandisi Sacco society and the engineer

Engineering being one of the key drivers of economic and social development. From roads, bridges and buildings to energy systems, manufacturing, water infrastructure and digital technologies, engineers provide the expertise required to transform ideas into solutions that improve people's lives.

However, technical expertise alone is not enough to enable engineers to reach their full potential. Access to affordable finance, investment opportunities, financial security and business capital is equally important. This is where Mhandisi Savings and Credit Cooperative Societies play an increasingly important role.

For engineers, particularly young professionals and those operating engineering consultancy and contracting businesses, Mhandisi Sacco can provide an alternative and complementary source of financial support.

i. Improving access to affordable finance

One of the most significant contributions of the SACCO is providing members with access to credit. Engineers often require substantial capital for personal development, acquisition of professional equipment, property investment, education, business establishment and other financial needs.

Unlike conventional borrowing, the SACCO lending is built around member savings and cooperative relationships. Members can build their savings over time and use them to access credit for productive and personal investments.

Historically, Mhandisi SACCO has provided engineers with different credit facilities, including loans for personal development and emergency needs. Its model of using fellow members as guarantors has also helped reduce some of the barriers associated with conventional lending. This access to affordable credit can be particularly important for young engineers who may have professional qualifications and technical capabilities but limited collateral or accumulated wealth.

ii. Supporting Engineers to Build Wealth

A strong engineering career should not only generate professional income; it should also provide opportunities to build long-term financial security. Mhandisi SACCOs encourage a culture of regular saving. Through monthly contributions, members gradually accumulate capital that can be used for investment, property acquisition, education and retirement planning.

This is particularly relevant to engineers because many professionals earn relatively stable incomes but may not have adequate structures for converting that income into long-term wealth. The establishment of engineering-focused Mhandisi SACCO was partly driven by the need for engineers to save and invest and establish a stronger financial foundation.

iii. Financing Engineering Businesses and Consultancies

Mhandisi SACCOs can also contribute directly to the growth of the engineering sector by financing engineers who want to establish or expand businesses. Engineering consultancies, contractors and technical enterprises require working capital to acquire equipment, pay employees, undertake feasibility studies, prepare bids and execute projects before receiving payment from clients.

Access to appropriate credit can therefore help an engineer move from being an employee to becoming an entrepreneur and employer. This has a multiplier effect. When an engineer establishes a successful consultancy or contracting firm, the business can create employment for other engineers, technicians, graduates and support staff. Mhandisi SACCO financing therefore has the potential to support not only individual engineers but also the broader engineering business ecosystem.

iv. Supporting Professional Development

The engineering profession is continuously evolving. New technologies, regulations, construction methods, environmental requirements, digital tools and project-management approaches require engineers to continually update their knowledge.

The Engineers Board of Kenya requires practicing engineers to attain at least 50 professional development units annually for renewal of their practicing license.

Mhandisi SACCOs can complement this requirement by supporting members to finance professional development activities such as postgraduate education, certification programmes, conferences, technical training and specialized equipment.

The benefit extends beyond the individual. An engineer who

continuously improves his or her knowledge contributes to higher standards of engineering practice and better project outcomes.

v. Enabling Home and Property Ownership

Housing and property investment are major components of long-term financial planning. Mhandisi SACCOs have traditionally played an important role in enabling members to acquire land, construct homes and invest in property.

This is significant for engineers because home ownership can provide financial stability while property investment can become an important source of long-term wealth.

At the national level, SACCOs have a substantial role in housing finance. Research by FSD Kenya indicates that about 25% of regulated SACCO loan books in 2025 were directed towards land and housing.

Engineering-focused mhandisi SACCO therefore provide members with structured pathways to property ownership while simultaneously mobilizing capital within the professional community.

vi. Promoting Financial Discipline

Another important impact of Mhandisi SACCO is the development of financial discipline.



Regular savings encourage engineers to plan their finances rather than relying entirely on their monthly salaries. Members learn to distinguish between consumption and investment, build emergency reserves and plan for major financial commitments.

This discipline can be especially valuable for young engineers entering the profession. Starting to save early allows an engineer to benefit from the cumulative effect of regular contributions over many years. The Mhandisi SACCO therefore becomes more than a place to obtain a loan. It becomes a financial planning partner in an engineer's lives.

vii. Strengthening Professional Solidarity

Mhandisi SACCOs also have a social and professional dimension.

Because members save together and support one another through cooperative structures, mhandisi SACCOs can strengthen relationships within a profession. Engineers from different sectors, organizations and generations can interact through a common financial institution.

This can create opportunities for mentorship, networking, partnerships and exchange of professional knowledge.

For a profession such as engineering, where collaboration is essential, stronger professional networks can translate into business opportunities, knowledge transfer and improved industry participation.

viii. Supporting the Engineering Sector Through MSME Development

The economic impact of Mhandisi SACCO lending extends beyond individual members.

When engineers use Mhandisi SACCO loans to establish businesses, purchase equipment or expand consultancies, they contribute to the growth of micro, small and medium enterprises within the engineering value chain.

Kenya's experience with SACCO-based financing demonstrates the wider potential of cooperative finance. Under the SAFER project, participating SACCOs had disbursed significant financing to MSMEs across numerous sectors and counties, demonstrating how SACCOs can serve as effective channels for expanding access to finance. For the engineering sector, this model can support enterprises involved in construction, manufacturing, energy, environmental services, water, transport and other technical fields.

4. From Individual Financial Empowerment to National Development

The ultimate impact of SACCOs on engineers is therefore much broader than individual financial welfare. An engineer who obtains financing to pursue postgraduate studies becomes more skilled. An engineer who acquires equipment becomes more productive. An

engineer who establishes a consultancy creates employment. An engineer who invests in property builds financial stability. A group of engineers who pool their resources creates a stronger financial institution capable of supporting even larger investments.

Engineering itself is a capital-intensive profession. The availability of appropriate financial mechanisms can therefore influence how quickly engineers can transform technical knowledge into businesses, projects and innovations.

5. The Future: Mhandisi SACCO as Strategic Partners to Engineers

The future relationship between Mhandisi SACCOs and the engineering profession should go beyond traditional savings and lending. Engineering SACCOs can develop specialized products for different stages of an engineer's career:

- i. Graduate engineers: savings, education loans and professional development financing.
- ii. Early-career engineers: asset financing, housing loans and biashara loans.
- iii. Established professionals: investment financing, property development and business expansion.
- iv. Engineering firms: working-capital facilities, equipment financing and project-based financing.

Mhandisi Sacco also has embraced digital banking, financial literacy, investment in properties on the housing sector and partnerships with professional institutions to provide more comprehensive support to their members.

6. Conclusion

SACCOs have the potential to become powerful financial partners in the development of engineers and the engineering sector. Their impact can be seen in improved access to affordable credit, increased savings, property ownership, professional development, entrepreneurship and financial security. More importantly, these benefits can extend beyond individual engineers to engineering firms, employees, communities and the wider economy. For the engineering profession, the message is clear: technical excellence and financial empowerment should go hand in hand.

A financially empowered engineering workforce is better positioned to innovate, establish businesses, invest in productive assets and participate meaningfully in national development.

As Kenya seeks to expand infrastructure, industrialization, technology and sustainable development, strong financial institutions serving engineers can play an important role in ensuring that the professionals responsible for designing and building the country's future are themselves financially equipped to do so.

From Village Dreams to Engineering Aspirations: How IEK Shaped My Journey



Emmanuel Mwachofi
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The steep slopes and valleys of the Taita Hills have a way of imprinting cultural values and childhood memories deeply into a person. I had the privilege of growing up in such a place, and for many years, it was the only world I knew. The childhood mistakes that taught me difficult lessons, the deep-rooted Catholic faith that gave me a moral compass, and my early education all shaped the foundation of my life. Yet, it was my encounter with the Institution of Engineers of Kenya (IEK) that would fundamentally alter the trajectory of my future.

Growing up in ushagoo, I watched a neighbor who worked as a civil engineer and developed a strong ambition to build my future through science and engineering. My family, particularly my mother, nurtured that dream. She exposed me to construction documentaries on National Geographic and constantly encouraged me to keep my eyes fixed on that vision.

After my father's untimely demise, however, my academic ambitions encountered a painful financial barrier. I had earned a place in high school through sheer determination,

but as one scholarship application after another fell through—including applications to KCB, Starehe Boys, the M-PESA Foundation and Family Bank, hope began to fade.

Then came an unexpected turning point.

A television interview recounting my journey reached the right ears. One night, I received a phone call from the journalist who had interviewed me, informing me that an engineer from the IEK Coast Branch had expressed interest in supporting my education. That single phone call marked the moment when ambition met opportunity.

Shortly afterwards, I travelled to Nairobi; a young boy stepping out of the Taita highlands and into the capital, to meet the IEK leadership, including the then IEK President, Eng. Erick Ohaga. Sitting in that boardroom, we had a serious conversation about the next few years of my life. For the first time since losing my father, I felt that I had a strong, paternal presence standing behind me.

IEK did not simply step in as a corporate sponsor to pay my school fees; it embraced me as family. The Institution gave me something more valuable than financial support: belief, guidance and an unwavering network of people who were invested in my future. In many ways, that support helped fill the void left by my father.

Throughout my high school years, IEK's commitment went far beyond financial assistance. I was assigned dedicated mentors: **Eng. Clifford Nyambedha, Eng. Annette Ingaiza and Eng. Lilian Kilatya**, all whom were members of the Future Leaders Committee whose guidance became a cornerstone of my growth. Whether I was dealing with academic pressure, seeking personal direction or simply looking

for sound advice, I knew I could reach out to them.

That level of trust and accessibility created a deep sense of responsibility within me. I made a quiet promise never to disappoint the people who had invested so much in my future. That promise drove me through countless late nights of study and ultimately to the successful completion of my KCSE examinations at Maranda High School.

Looking Towards Mechatronic Engineering

As I prepare to transition to university, my vision for the future has become increasingly focused on one discipline: **Mechatronic Engineering**.

My interest in mechatronics stems from a desire to position myself at the heart of industrialization. By integrating mechanical, electrical, electronics and computer engineering, mechatronics creates enormous possibilities for innovation and industrial transformation.

We are living through a significant transition from Industry 3.0 to Industry 4.0, characterized by the integration of artificial intelligence, advanced robotics, automation and data-driven technologies into increasingly complex mechanical and industrial systems. I believe mechatronics will play a central role in this evolution, providing the multidisciplinary expertise needed to design and operate the intelligent systems of the future.

My decision is also rooted in a personal fascination with mechanical and electrical systems, a passion that took shape in the libraries and science laboratories of Maranda High School. Participating in science fairs and regional competitions gave me opportunities to experiment with integrated

systems, while reading scientific research papers expanded my understanding of what engineering can achieve.

To me, mechatronics is not simply an academic degree. It is a bridge between scientific ideas and real-world industrial transformation.

From Beneficiary to Apprentice

As I prepare to embark on my university journey, my relationship with IEK has evolved into something even more transformative. I was privileged to have the opportunity to work within the IEK offices as an apprentice, an experience that is helping usher me into adulthood and professional life.

Beyond the technical foundation of engineering, IEK is exposing me to the practical realities of the workplace: financial discipline, self-reliance, professional communication, networking, teamwork and engagement with corporate leadership.

This experience has given me an appreciation of an important truth: becoming an engineer is not only about acquiring technical knowledge. It is also about developing character, professionalism, responsibility and the ability to use one's knowledge to serve society.

A Promise to Pay It Forward

Receiving this level of grace and investment comes with a solemn responsibility. IEK did not simply open a door

for me; it showed me what can happen when people choose to believe in a young person's potential.

As a result, my ambition extends far beyond personal success or professional titles. I carry a lifelong commitment to give back to society what has been poured into me. I want to become a bridge for the next ambitious boy or girl sitting in a remote village, wondering whether their dreams are too big for their circumstances.

Whether through mentorship, creating opportunities in engineering or helping young people overcome financial barriers, I intend to pay this gift forward in full measure.

Looking back at the boy who once played football on the village pitch before running home to do his chores, the ambition remains unchanged. What has changed is the scale of the vision and the strength of the support behind it.

The Institution of Engineers of Kenya did more than fund my education. It stepped into the void left by my father, anchored my present and gave me the professional foundation from which I can build my future.

My journey into engineering is only beginning. But I know that wherever it takes me, I carry with me a responsibility to ensure that someone else, somewhere in another village, gets the opportunity to dream and the support to turn that dream into reality.



IEK did not simply step in as a corporate sponsor to pay my school fees; **it embraced me as family.** The Institution gave me something more valuable than financial support: **belief, guidance and an unwavering network of people who were invested in my future.**



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GIS, Remote Sensing and Satellite Data for Sustainable Development

On the morning of 14 April 2023, a SpaceX Falcon 9 lifted off from Vandenberg Space Force Base in California carrying, among other things, a satellite about the size of a loaf of bread.

That satellite was Taifa-1, Kenya's first operational Earth observation satellite. Since then, it has been passing over Kenya several times a day, collecting images of farmland, the coastline, lakes and growing cities.

By space-industry standards, Taifa-1 is a small and relatively modest satellite. It cost roughly KES 50 million to build and captures black-and-white images at 16-metre resolution, alongside colour data across six bands at 32 metres. It is nowhere near the kind of detail associated with high-end spy satellites, but it can still tell an important story. It can show signs of drought, changes in vegetation or the spread of weeds across a lake.

And perhaps that is the most important point about Taifa-1. Its value is not just in the images it takes. It represents Kenya moving from simply using satellite information produced elsewhere to having a greater role in producing that information itself.

Kenya's space story did not begin with Taifa-1.

It goes back to 1964, when Kenya and Italy reached an agreement that led to the establishment of the San Marco Platform near Malindi, now known as the Luigi Broglio-Malindi Space Centre. Over the years, the facility was used for more than twenty sounding rockets and nine satellites, including NASA's SAS-1, better known as "Uhuru", which carried out the first thorough X-ray survey of the sky in 1970.

Since then, Kenya has slowly built up the institutions needed to support a wider space programme.

The Regional Centre for Mapping of Resources for Development (RCMRD), established in Nairobi in 1975, now serves twenty member states and trains about 3,000 technical officers every year. It also hosts a regional hub for NASA and USAID's SERVIR programme.

Then came the Kenya Space Agency in 2017. Its role was to bring together Kenya's different interests in space, including satellite technology, manufacturing and the use of space data.

Universities have also been part of that journey. The University of Nairobi built Kenya's first satellite, a small CubeSat that was launched from the International Space Station in 2018 and de-orbited two years later. Today, three more universities are working with the Kenya Space Agency on a 3U satellite of their own design.

Taifa-1 itself was developed through a partnership between Kenyan company SayariLabs and Bulgaria's EnduroSat. SayariLabs served as the prime contractor, which was significant because it showed that a Kenyan company could take a leading role in a national space mission rather than simply provide support.

A ground station at Kasarani situated within RCMRD and completed around the time Taifa-1 was launched, provides another important piece of the system. It monitors the satellite and receives the data it sends back to Earth.

Of course, the real test of a satellite is not what happens in orbit. It is what happens with the information once it gets back down to Earth.

Of course, the real test of a satellite is not what happens in orbit. **It is what happens with the information once it gets back down to Earth.**

For Kenya, agriculture is an obvious place to start. A large part of the country's farming still depends on rainfall, so satellite data can help track crop health, soil conditions, livestock and changes in vegetation. It can also contribute to decisions about when rains are arriving and whether conditions are suitable for planting.

The same type of information can be useful during floods and droughts. It can help monitor wildfires and track locust movements before they become a much bigger problem for farmers.

Lake Victoria provides another good example. Through the European Space Agency's TIGER initiative, RCMRD and Digital Earth Africa have been using Sentinel-2 imagery to monitor invasive water weeds along the Kenyan shoreline.

This is the kind of problem that is difficult to follow from the ground. A boat can cover only so much shoreline at a time. From space, the changes can be observed across a much wider area and over a longer period.

Satellite imagery is also being used in less obvious ways.

Researchers have trained neural networks using freely available Landsat and Sentinel imagery to estimate whether different areas have access to infrastructure such as electricity, sewerage, piped water and paved roads. The results are not perfect, but they are encouraging. The models correctly identified electricity infrastructure 88 percent of the time, sewerage 86 percent, roads 79 percent and piped water 74 percent.

For countries where collecting this information on the ground can take a lot of time and money, even an imperfect first map can be useful.

The same technology is finding its way into urban planning. Satellite imagery can support cadastral mapping, land-tenure surveys and monitoring of informal settlements as they expand.

In other words, the satellite is only one part of the story. The real value comes from what people can do with the information once it is available.

Climate Camera, or ClimCam, began operations on 11 April 2026 as a joint project involving the space agencies of Egypt, Kenya and Uganda. With support from the UN's space office and Airbus, the project uses a 3.5-kilogram AI-equipped instrument mounted on the International Space Station's Bartolomeo platform.

ClimCam passes over East Africa four times a day and is designed to monitor things such as floods, drought and crop stress. At 10-metre resolution, it can provide more detailed imagery than Taifa-1, with some of the data being routed through a ground station in Uganda.

The hardware is interesting, but the collaboration may be more important.

Instead of Egypt, Kenya and Uganda each trying to build their own system, they worked on one together. That kind of cooperation is still relatively uncommon in Africa's space sector. If it becomes more common, the long-term benefits could go well beyond this particular mission.

There is a tendency to focus on the exciting part of space programmes: the launch, the satellite and the photographs from orbit.

The less exciting parts are often where the real problems are.

One of them is skills. University programmes have struggled to keep up with the skills the industry needs. There are still too few qualified instructors, while computing resources can be limited. Kenyatta University researcher Simon Onywere has raised some of these concerns publicly.

Then there is the issue of access to data.

It might seem strange that researchers in countries with their own satellites would struggle to access satellite data, but this does

happen. Researchers across Africa have described bureaucratic difficulties when trying to obtain data collected by their own national satellites. As a result, many continue to rely on freely available Sentinel and Landsat imagery.

There is also a wider problem with cooperation between African space agencies. Data-sharing across countries is still not common enough. That makes the Egypt-Kenya-Uganda ClimCam project stand out more than it probably should.

The private sector has its own challenge. A survey found that 22 percent of African geospatial companies did not even know that their own countries operated active satellites.

That is not a technology problem. It is an awareness problem.

And awareness is probably one of the easier things to fix.

The harder issue is political commitment. Earth observation can easily become something that attracts attention when a satellite is launched, only to receive less attention once the cameras are no longer around. For the technology to be genuinely useful, it needs consistent funding, accessible data and institutions that use it as part of their everyday work.

There is an interesting tension at the centre of Kenya's space ambitions.

On one hand, Kenya now has its own satellite. On the other hand, Kenyan researchers can access Landsat and Sentinel imagery for free. Those international datasets are often easier to access than data from domestic satellites.

That raises an obvious question: if the free data is already good enough for many applications, why spend money building satellites?

The answer is partly about control.

A country that depends entirely on satellites operated by others does not decide what those satellites measure, when they collect the data or how national priorities are reflected in those systems.

That does not mean every country needs to build every

satellite itself. It does mean that having some domestic capability gives a country more choices.

But owning a satellite on its own is not enough.

The real measure of Taifa-1's success will be what happens to the data after it is collected. Does it reach researchers? Does it reach government agencies? Can farmers, planners and disaster-response teams actually use it?

Those questions will matter more in the long run than the launch itself.

In less than a decade, Kenya has moved from experimenting with a small CubeSat to operating its own Earth observation satellite and participating in a joint climate-monitoring mission attached to the International Space Station.

The next step is already taking shape. Kenyan universities are working with the Kenya Space Agency on a 3U satellite, suggesting that the country's space programme is beginning to develop a pipeline of local engineers and researchers rather than relying entirely on external expertise.

But the biggest opportunity may not be in building satellites at all.

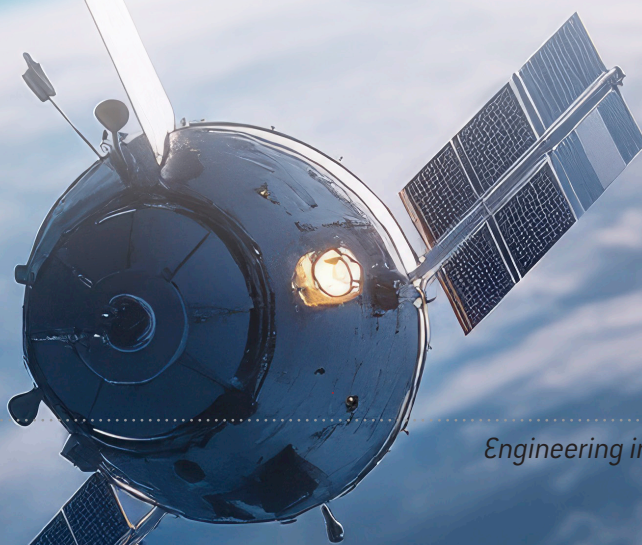
It may be in everything that happens after the satellite sends its data home.

Someone still has to build the ground systems. Someone has to manage the data. Someone has to develop the software and models that turn satellite images into useful information. Someone has to connect that information to an actual decision, whether that means telling a farmer that conditions are changing, helping a county prepare for flooding or helping a planner understand how a city is expanding.

That is where embedded systems, IoT, data engineering and infrastructure all start to meet the space sector.

Kenya has already shown that it can put a satellite into orbit.

The next challenge is making sure that what comes back down from orbit is useful enough to change something on the ground.



Numerical Simulation of Dam-Break Floods and Sediment Transport: A Case Study of the 2024 Mai Mahiu Disaster, Kenya

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ABSTRACT

Extreme rainfall events increasingly trigger floods, landslides, and debris flows that cause severe socio-economic and environmental impacts. In mountainous catchments, landslide debris can obstruct river channels and culverts, forming temporary dams whose sudden failure may generate destructive dam-break floods. Despite the increasing occurrence of such hazards in Kenya, limited studies have examined the associated flood hydrodynamics and sediment transport processes.

This study simulates the 29 April 2024 Mai Mahiu disaster to evaluate flood propagation, sediment transport, and implications for infrastructure and disaster-risk management. Numerical simulations were conducted using the TELEMAC-2D hydrodynamic model coupled with the SISYPHE sediment transport module, incorporating site-specific topography, rainfall data, and sediment characteristics. Analysis of Landsat imagery acquired on 12 May 2024 showed that antecedent rainfall prior to the dam-break event triggered slope failures covering approximately 128,000 m² (32 acres) within the Tongi River catchment,

generating an estimated 96,000 tonnes of soil and debris. Scenario analysis results indicate that landslide debris blocked culverts approximately four days before embankment failure, leading to temporary water impoundment and subsequent dam-break flooding. Simulation results further suggest that progressive erosion by overtopping was the most likely failure mechanism. Peak flow depths of approximately 23 m were simulated near the breach zone, accompanied by severe channel erosion and significant downstream sediment deposition. Deposition was concentrated in low-velocity areas such as channel bends, bridges, and culverts, identifying these locations as highly vulnerable to blockage and infrastructure failure.

The simulated flood depths and sediment deposition patterns provide critical information for the design of hydraulic structures, including bridges and culverts, as well as for flood-hazard mapping and land-use planning. The findings also provide useful insights for improving early-warning systems and disaster preparedness in landslide-prone catchments.

Key words: Dam-break flood; Flood modelling; Sediment transport; TELEMAC-2D; SISYPHE; Risk assessment

Introduction

Extreme rainfall events are increasingly associated with the failure of both engineered and natural dam systems, often resulting in catastrophic flooding, infrastructure damage, and significant loss of life. Intense and prolonged precipitation can rapidly elevate reservoir levels, induce slope instability, and weaken embankments through saturation and internal erosion, ultimately triggering sudden breaching. With the growing influence of climate variability and change, the

frequency and magnitude of such hydrometeorological extremes are expected to increase, thereby amplifying the risk of dam-related disasters (Hervouet, 2007).

Recent global events highlight the devastating consequences of rainfall-induced dam failures. In September 2023, two dams near Derna, Libya, collapsed following Storm Daniel, resulting in more than 11,000 fatalities and widespread destruction (Daily Nation, 2023). Similarly, the failure of Arbaat Dam near Port Sudan on

24 August 2024, following intense rainfall, caused at least 148 deaths and displaced approximately 50,000 people (Al Jazeera, 2024). Historical cases further underscore this risk; for example, the Belci Dam failure in Romania in 1991 was triggered by severe flooding and resulted in multiple fatalities (LA Times, 1991). These events demonstrate the vulnerability of both engineered and natural impoundments to extreme rainfall conditions.

In Kenya, dam-related disasters have also had significant impacts.

The Solai Dam failure in 2018, attributed to prolonged heavy rainfall, resulted in 48 fatalities and extensive downstream damage (NTV, 2018). More recently, on 29 April 2024, a catastrophic flood event occurred in Mai Mahiu, Nakuru County, leading to at least 71 deaths and over 110 injuries (CNN, 2024; Citizen TV, 2024). Unlike conventional dam failures, this event was driven by a complex interaction of processes, including intense rainfall, landslides, and blockage of the Tongi River at an old railway embankment. The blockage resulted in the formation of a temporary upstream impoundment, which subsequently breached, releasing a highly concentrated flow of water, sediment, and debris (NTV, 2024). The resulting flood caused widespread destruction, including damaged infrastructure, loss of livestock, and displacement of communities.

Numerical modelling has been widely used to simulate dam-break processes and associated flood dynamics. Hydrodynamic models such as TELEMAC-2D, HEC-RAS 2D, and MIKE 21 are commonly applied to simulate flood wave propagation and inundation extents following dam failure (Brunner, 2016; Hervouet, 2007). Additionally, coupled hydro-sediment models, including SISYPHE and GAIA within the TELEMAC framework, enable simulation of sediment transport and morphological evolution during extreme flood events (Villaret et al., 2013). These tools have been successfully applied in various case studies to support hazard assessment and flood risk management.

However, most existing dam-break studies have focused on engineered dams with well-defined geometries and relatively predictable failure mechanisms. Comparatively little attention has been given to the complex, cascading hazards associated with landslide-induced river blockages, where dam formation, reservoir impoundment, dam failure, flooding, and sediment transport occur as interconnected processes. Furthermore, in many developing countries, including Kenya, high-resolution event-based modelling studies that couple hydrodynamic and morphodynamic processes to reconstruct and assess the impacts of such disasters remain scarce.

The Mai Mahiu event represents a unique and complex case of rainfall-triggered damming and breaching, involving the interaction of hydrological, geomorphological, and infrastructural factors. Despite its severity, there is limited quantitative analysis of flood extent, flow characteristics, and sediment dynamics associated with this event.

This study aims to address these gaps by simulating the Mai Mahiu dam-breach event using a coupled hydrodynamic and sediment transport modelling approach. Specifically, the objectives are to: (i) reconstruct the breach and flood propagation dynamics, (ii) map the spatial extent of inundation and associated hazards, and (iii) identify sediment erosion and deposition patterns resulting from the event. The findings are expected to contribute to improved

understanding of complex dam-break processes and support the development of more effective flood risk assessment and disaster preparedness strategies in flood-prone regions.

Materials and Methods

Study Area

Mai Mahiu is located in Nakuru County within the Rift Valley region of Kenya, approximately 75 km northwest of Nairobi. The town lies along the Nairobi–Nakuru highway and serves as a major transport corridor. The area is characterized by rugged terrain, steep slopes, and volcanic formations typical of the Great Rift Valley.

The region is highly susceptible to natural hazards, including landslides and flooding, due to its topography, degraded vegetation cover, and increasing rainfall intensity. The Tongi River, which drains the catchment, plays a critical role in shaping the local hydrology but is prone to rapid discharge increases during intense rainfall events.

The surrounding environment of Mai Mahiu is also heavily influenced by agricultural activities. The fertile volcanic soil supports a variety of crops, including maize, beans, and horticultural produce, which are important to the local economy. Livestock farming is also common in the region, and the area has seen significant rural development over the years.

The April 2024 disaster was exacerbated by blockage of river flow at a railway embankment, leading to temporary impoundment and subsequent catastrophic failure.

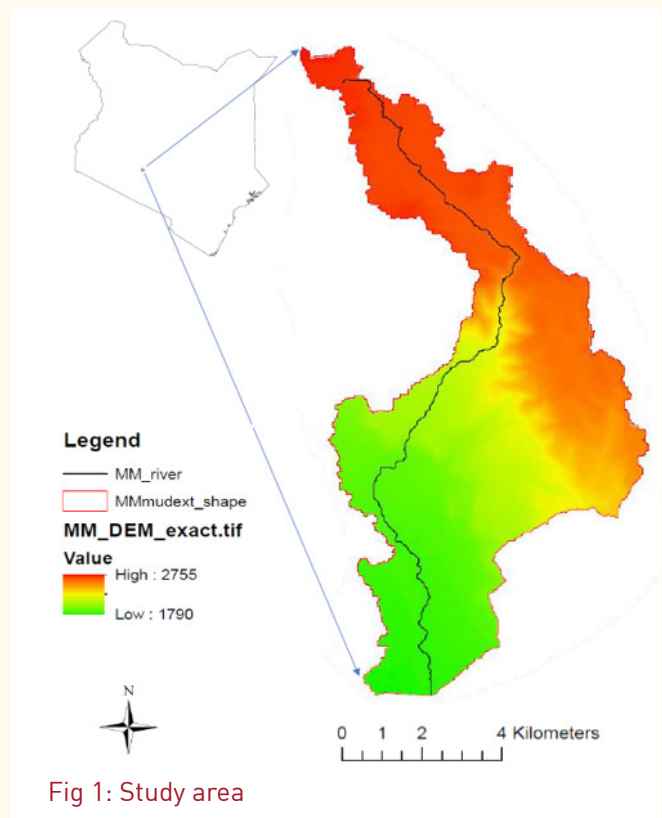


Fig 1: Study area

Data and Materials

The following datasets were used:

- Rainfall data: University of Guelph W3S platform (source: <https://www.uoguelph.ca/watershed/w3s/>).
- Digital Elevation Model (DEM): SRTM (30 m resolution) (source: NASA Shuttle Radar Topography Mission (SRTM)(2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by OpenTopography. <https://doi.org/10.5069/G9445JDF>. Accessed 2026-05-04)
- Soil data: ISRIC Soil Database (source: <https://data.isric.org/geonetwork/srv/api/records/4648929a-8031-49cc-9d56-9f3aeff2f8d9>).
- Land use: ESA WorldCover (2021) (source: <https://worldcover2021.esa.int/downloader>).
- Satellite imagery: Pre- and post-event imagery (source: <https://eos.org/thelandslideblog/mai-mahiu-3>)

The software tools used:

- TELEMAC-MASCARET (v7p3r1)
- ArcMap 10.1
- BlueKenue
- Google Earth Pro
- Microsoft Excel

TELEMAC-MASCARET modelling system(v7p3r1)

The TELEMAC-MASCARET system is an open-source, integrated numerical modelling framework developed under the coordination of Electricité de France (EDF) for the simulation of free-surface flows, sediment transport, and morphodynamic processes in natural and engineered hydraulic environments. The suite has been widely applied in river hydraulics, flood modelling, coastal processes, and dam-break analysis due to its robustness, flexibility, and capability to handle complex geometries through unstructured meshes (Hervouet, 2007; Villaret et al., 2013).

In this study, version v7p3r1 of the TELEMAC-MASCARET suite is employed with a dynamic coupling between TELEMAC-2D and SISYPHE. In the coupled framework, TELEMAC-2D provides the hydrodynamic forcing variables—namely flow velocity, water depth, and bed shear stress—at each computational time step. These variables are transferred to SISYPHE, which computes sediment transport rates and updates bed elevations based on the governing sediment continuity equations. The updated bed morphology is then fed back into TELEMAC-2D, thereby influencing subsequent flow computations. This two-way coupling allows for the simulation of feedback mechanisms between

flow dynamics and morphological changes, which are critical in dam-break scenarios involving high sediment loads and rapidly evolving channels.

TELEMAC-2D model

TELEMAC-2D is a depth-averaged hydrodynamic model that solves the shallow water equations using finite element or finite volume methods on unstructured grids. Its ability to represent complex topography, wetting and drying processes, and transient flow conditions makes it particularly suitable for simulating dam-break floods and rapidly varying flows. The model computes key flow variables, including water depth, depth-averaged velocity components, and bed shear stress, which are essential for analyzing flood propagation and hydraulic impacts.

TELEMAC-2D solves the depth-averaged shallow water equations derived from the Navier–Stokes equations for incompressible flow (Hervouet, 2007). The model computes water depth and velocity fields over an unstructured mesh using finite element or finite volume methods.

$$\frac{\partial h}{\partial t} + \bar{u} \bar{\nabla} (h) + h \bar{\text{div}} \bar{u} = S_b \quad \text{continuity equation (2.1)}$$

$$\frac{\partial \bar{u}}{\partial t} + \bar{u} \bar{\nabla} (\bar{u}) = -g \frac{\partial Z}{\partial x} + S_x + \frac{1}{h} \bar{\text{div}} (h \bar{v} \bar{\nabla} u) \quad \text{momentum equation along x (2.2)}$$

$$\frac{\partial \bar{v}}{\partial t} + \bar{u} \bar{\nabla} (\bar{v}) = -g \frac{\partial Z}{\partial y} + S_y + \frac{1}{h} \bar{\text{div}} (h \bar{u} \bar{\nabla} v) \quad \text{momentum equation along y (2.3)}$$

$$\frac{\partial T}{\partial t} + \bar{u} \bar{\nabla} (T) = S_T + \frac{1}{h} \bar{\text{div}} (h \bar{v} \bar{\nabla} T) \quad \text{tracer conservation equation (2.4)}$$

The governing equations include:

Sisyphe Model

Sisyphe is designed to simulate both bedload and suspended sediment transport under the action of currents and waves, and it solves the Exner equation to predict bed evolution (Villaret et al., 2013). The module supports multiple sediment classes and a wide range of sediment transport formulations while accounting for key morphodynamical processes, including erosion, deposition, and multilayer bed evolution. These capabilities make it well suited for simulating the complex sediment dynamics associated with extreme flood events.

The Sisyphe model solves a bed-evolution equation (2.5) and, in case of cohesive sediment, an advection diffusion equation for suspended load concentration (2.6). The model adopts a finite element or a finite volume method for the equation's solution.

$$(1-n) \frac{\partial z_f}{\partial t} + D \bar{\text{div}} (\bar{Q}_{sc}) + (E-D)_{z=s} = 0 \quad (2.5)$$

$$\frac{\partial C}{\partial t} + \bar{U} \frac{\partial C}{\partial x} + \bar{V} \frac{\partial C}{\partial y} = \frac{1}{h} \left[\frac{\partial}{\partial x} \left(h \varepsilon_s \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left(h \varepsilon_s \frac{\partial C}{\partial y} \right) \right] + \frac{(E-D)_{z=s}}{h} \quad (2.6)$$

Friction Closure Model

Sediment's detachment, transport and deposition in land or channelized flow mostly takes place in the region near bed. Accurate representation of near-bed flow is critical for modelling sediment transport. A modified friction formulation incorporating sediment-induced turbulence damping was applied at Western Scheldt estuary in Belgium to simulate coastal erosion (Toorman & Bi, 2015). This approach accounts for additional energy dissipation due to suspended particles, improving simulation accuracy in shallow and debris-laden flows.

The bed shear stress can be computed as follows:

$$\frac{\tau_b}{\rho} = f_d \left(\frac{\kappa U}{\ln \left(\frac{h}{z_o} \right) - 1 + \frac{z_o}{h}} \right)^2 + \left(\sqrt{\left(\frac{3}{2} (z_o + \beta \phi h) \frac{U}{h} \right)^2 + 3 \frac{U}{h} \nu(\phi)} + \frac{3}{2} (z_o + \beta \phi h) \frac{U}{h} \right)^2 \quad (2.7)$$

where τ_b = the bed shear stress (kg m⁻¹ s⁻²); ρ = the density of water (kg/m³); U = the shear velocity (m/s); κ = the von Karman coefficient (which decreases from the clear water value 0.41 to lower values depending on the sediment load); U = the local depth-averaged flow velocity (m/s); h = the local water depth (m); f_d = the suspension friction (or apparent roughness) coefficient, and has been found to be 0.045; ν = the water viscosity (m²/s); ϕ = the volumetric suspended particle concentration; β = the equivalent Nikuradse roughness length scale and z_o = the effective roughness length scale (m) and is computed from the following relation:

$$\frac{z_o U_*}{\nu} = \exp(-\kappa B_o) + f_\beta(k_{z+}) k_{z+} \exp(-\kappa B_w) \quad (2.8)$$

Where;

$$z_{o+} = \frac{z_o U_*}{\nu}; k_{z+} = \frac{k_{z+} U_*}{\nu}; B_o = 5.5; B_w = 8.5 \text{ and } f_\beta(k_{z+}) = 1 - \exp[-k_{z+} \exp(-\kappa B_w)]$$

$$\text{The turbulence damping factor, } f_d = \left(1 - \exp\left(\frac{-h_L}{A_*}\right) \right)^2$$

$$\text{Where; } h_L = \sqrt{\frac{2U_* h}{\nu}} \text{ and } A_* = 17$$

Modelling Approach

Assumptions

- The average depth of the landslide failure was assumed to be 0.5 m for estimating the volume of mobilized material.
- It was assumed that 80% of the mobilized landslide material was transported downstream and deposited within the temporary reservoir formed upstream of the blocked railway embankment culverts.
- The deposited landslide material was assumed

to have a porosity of 60%, representing the loose nature of the debris and influencing the storage capacity of the temporary dam.

- The volume of water impounded upstream of the railway embankment was estimated using the TELEMAC-2D rainfall-runoff model, driven by the rainfall recorded between the assumed date of culvert blockage (24 April 2024) and the dam-break event (29 April 2024).

Rainfall Data Processing

Rainfall data were obtained from W3S platform as cumulative daily. The Rainfall data for ten consecutive days leading to 29/04/2024 from the four Rain stations around the catchment were daily averaged and disaggregated into continuous incremental time series using a gamma distribution approach (Koskei, 2013). The composite hyetograph formed provides a realistic temporal distribution of rainfall inputs for hydrological modelling and was then applied to TELEMAC2D model.

Terrain Processing and Boundary Condition Files

A 30 m resolution SRTM DEM was used to delineate the River Tongi catchment in ArcMap. The resulting catchment and river shapefiles were subsequently imported into BlueKenue, where an unstructured computational mesh was generated using the resampled catchment shapefile as the domain boundary and the River Tongi centreline as soft lines. Local mesh refinement was applied around the railway crossing over River Tongi to improve numerical accuracy, as this location corresponded to the observed landslide dam formation, subsequent reservoir development, and eventual dam-break breach location.

BlueKenue was also used to generate the boundary condition (BC) files for both the hydrodynamic and morphodynamic models from the mesh bathymetry (BOTTOM). A single open boundary was specified at the downstream end of River Tongi. For the hydrodynamic simulations, a discharge–water level (Q–H) rating curve was prescribed at the downstream boundary, while a free sediment discharge boundary condition was adopted for the morphodynamic simulations.

Calculating Volume of Landslide Generated Sediments

The satellite imagery acquired on 12/05/2024 was imported into Google Earth Pro and georeferenced. The slope failure zones were delineated using the Add Polygon tool, and the total landslide-affected area was estimated to be approximately 128,000 m² (≈32 acres). The River Tongi catchment is characterized by steep terrain and extensive rock outcrops, where the overlying soil mantle is generally shallow. This geomorphological setting supports the assumption of a relatively shallow landslide failure depth.

Accordingly, an average failure depth of 0.5 m was assumed to estimate the volume of landslide-displaced material, consistent with similar geomorphological

settings. It was further assumed that 80% of the dislodged material was transported downstream and accumulated upstream of the railway embankment, resulting in culvert blockage and the formation of a temporary impoundment. The deposited material was represented as a sediment layer with an assumed porosity of 0.6.

Source code modification

Within the TELEMAC-2D framework, several user subroutines were modified to incorporate the required process representations. The USER_CORSTR.f subroutine was updated to include the friction closure formulation described in Equation (2.7). The USER_CORPOR.f subroutine was modified to define the porosity of the sediment deposited within the temporary reservoir formed upstream of the blocked culverts at the embankment. The RUNOFF_SCS_CN.f subroutine was adapted to specify the rainfall type and define the source of Curve Number (CN) parameters based on the SCS Curve Number method. In addition, FRIC1.f subroutine was modified to reduce depth of water required to initiate surface runoff to 1mm.

All modified subroutines were consolidated into a single 'user_Fortran' folder and linked to the TELEMAC-2D model via the steering file, enabling compilation and execution during simulation.

Hydrological Modelling

Rainfall-runoff modelling was performed using TELEMAC-2D, applying the SCS Curve Number method. A composite hyetograph, developed from averaged daily rainfall records from four rainfall stations surrounding the catchment, was used as the rainfall input to the model. The hyetograph represents the consecutive rainfall events preceding 29/04/2024 and was applied to simulate the progressive filling and inundation of the temporary reservoir formed upstream of the blocked railway embankment due to the accumulation of landslide-derived debris.

The assumed timing of the landslide within the rainfall sequence was treated as a calibration parameter and iteratively adjusted until the simulated inundation extent from the reservoir storage closely matched observed field evidence.

Wet antecedent moisture conditions (AMC III) and the standard initial abstraction ratio were adopted in all simulations and the Q-H relation was prescribed to downstream boundary.

Morphological modelling

Morpho dynamic simulations were performed using the Sisyphe model, which was dynamically coupled with the hydrodynamic solver to capture sediment transport

and bed evolution processes. A free outflow condition was prescribed at the sediment boundary to allow unrestricted downstream transport. Bedload transport was computed using the Meyer-Peter and Müller (MPM) formulation under the assumption of non-cohesive sediment, consistent with the coarse material characteristics observed in the debris flow. The initial hydraulic condition was defined based on the ponded water volume upstream of the debris-induced dam. Sediment properties were specified with a median grain size (D50) of 0.0006 m and a sediment density of 2650 kg/m³, while the critical Shields parameter was set to 0.04. Settling velocity was estimated using Stokes' law to represent particle fall dynamics.

Model Calibration and Validation

The model was calibrated by comparing the simulated inundation extent with the inundation boundary digitized from post-event satellite imagery acquired on 12/05/2024. Additional validation was undertaken using field survey data collected on 20/10/2024, during which the spatial extent of flooding, erosion and deposition sites, and riverbed characteristics were documented. Geographic coordinates and field measurements of selected inundation limits were recorded, while elevation data collected along and across the river channel using a GPS-enabled mobile phone were used to refine the riverbed topography within the computational model.

Results and Discussion

Reservoir Formation Prior to Dam Break

The numerical simulations assumed that landslide-derived debris accumulated upstream of the railway embankment, completely blocking the culverts and forming a temporary debris dam with a nearly horizontal crest elevation of 2184 m above mean sea level (asl). Since the railway crossing is situated at approximately 2204 m asl, the impounded reservoir could store water to a maximum depth of about 20 m before overtopping. The deposited material was represented as a highly porous sediment mass with an assumed porosity of 60%, reflecting the loose and poorly consolidated nature of freshly deposited colluvial deposits. Runoff water was assumed to accumulate above the deposited debris, forming a temporary reservoir whose storage volume was generated through rainfall-runoff simulations in TELEMAC-2D (SCS-CN method) using disaggregated rainfall hyetographs representing 2-, 3-, 4-, and 5-day antecedent rainfall preceding the dam-break event. The results demonstrate that antecedent rainfall is a critical factor governing the hydraulic loading of temporary landslide dams, as it directly determines the volume of water available for release during dam failure (see Fig 2)

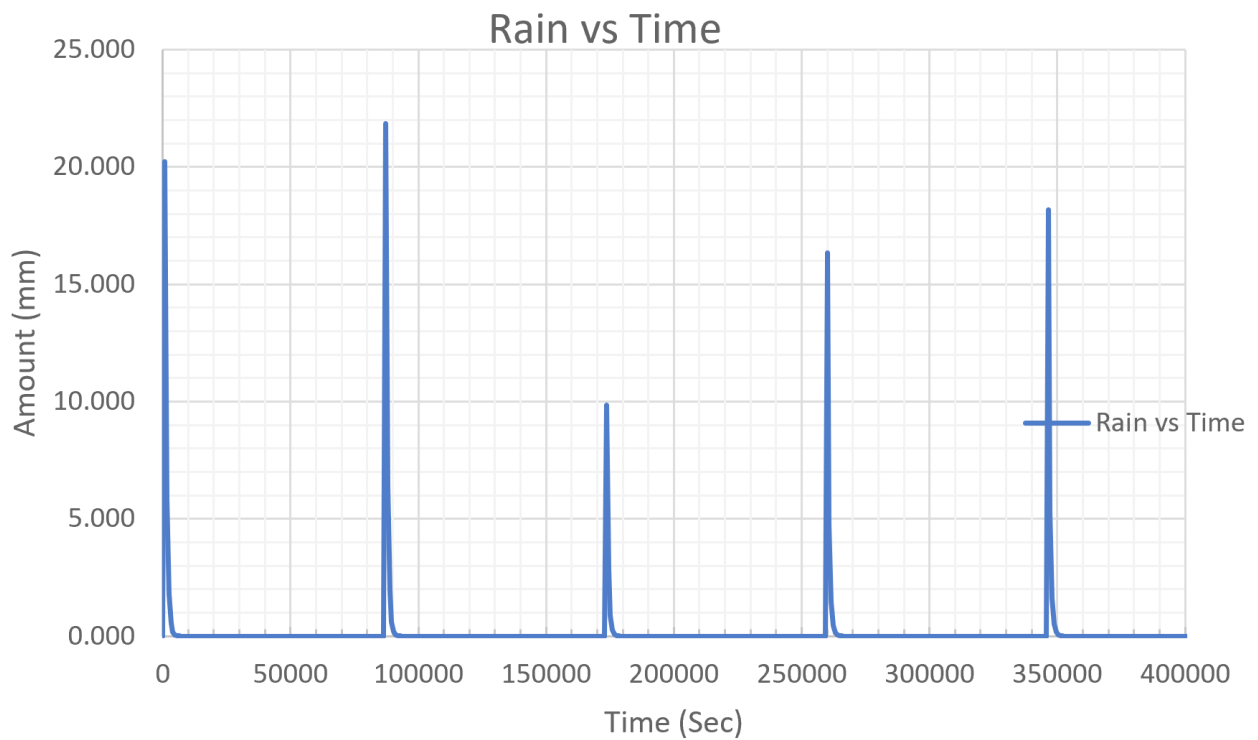


Fig 2: 5-day disaggregated rainfall hyetograph (5LR)

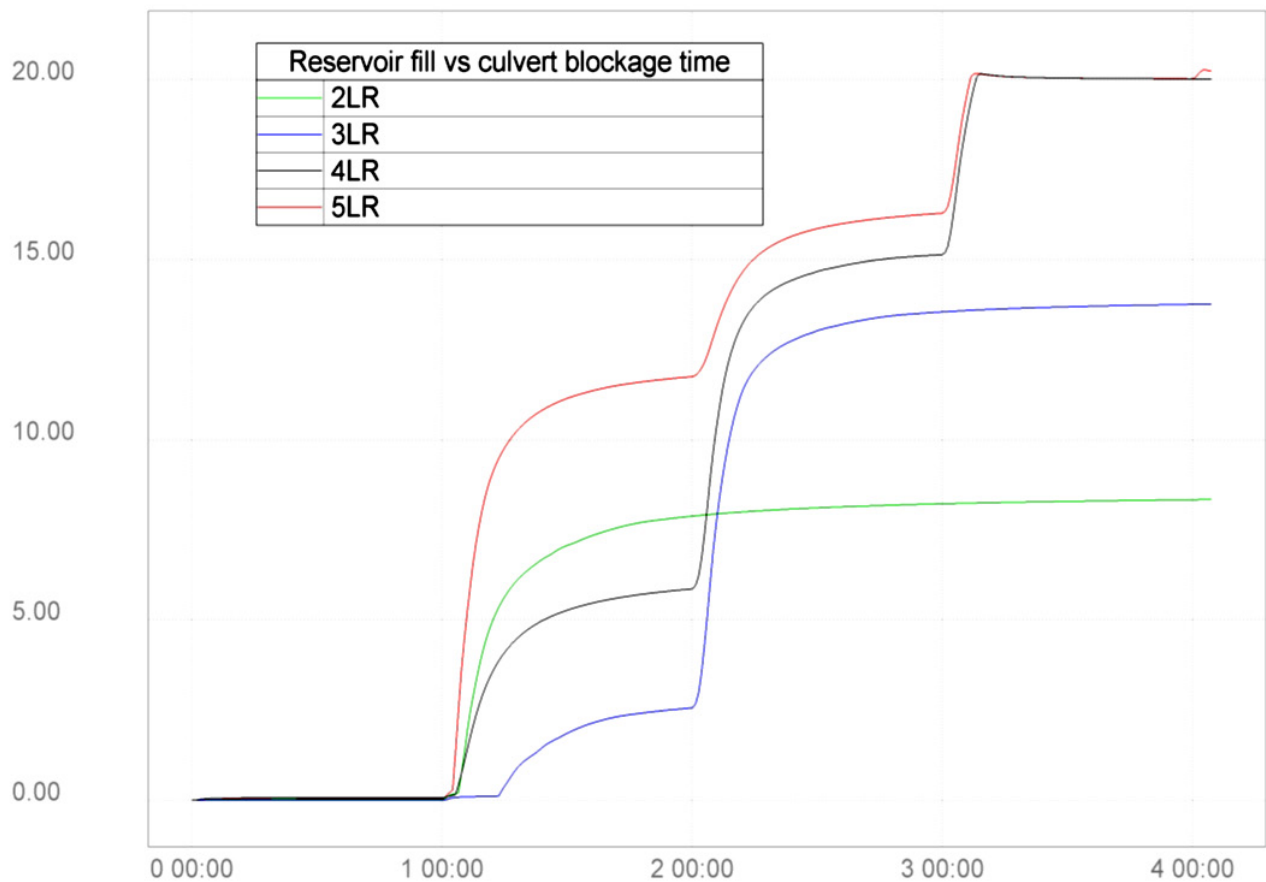


Figure 3: Variation of temporary reservoir fill with number of antecedent rainfall events

Influence of Antecedent Rainfall on Embankment failure and Dam-Break Flooding

The reservoir volumes generated under the four antecedent rainfall scenarios were used as the initial conditions for the coupled TELEMAC-2D-SISYPHE simulations to investigate dam-break flooding and the associated sediment transport. The temporal maximum flood extents simulated for each scenario were compared with the inundation boundary delineated from post-event satellite imagery acquired on 12 May 2024.

The comparison revealed significant differences in the simulated flood extents among the four rainfall scenarios. The 2-day and 3-day antecedent rainfall scenarios underestimated the observed inundation extent, indicating that the temporary reservoir did not store sufficient water to reproduce the magnitude of the Mai Mahiu flood (Figure 4&5). In contrast, the 4-day and 5-day antecedent rainfall scenarios resulted in complete filling of the temporary reservoir before failure (Figure 3), suggesting that prolonged rainfall was necessary to generate the observed impoundment conditions.

For the scenarios in which the reservoir reached full capacity, an instantaneous structural failure of the embankment produced flood extents that substantially exceeded those observed in the satellite imagery (Figure 6), indicating that sudden collapse was unlikely to represent the actual failure mechanism. Consequently, an alternative overtopping-induced breach scenario was evaluated. The progressive erosion associated with overtopping generated flood extents that closely matched the satellite-derived inundation boundary (Figure 7), suggesting that overtopping was the more probable mechanism responsible for embankment failure during the 29 April 2024 event.

These findings indicate that both the duration of antecedent rainfall, which controlled reservoir storage, and the mode of embankment failure, which governed the rate of reservoir release, were critical factors influencing the magnitude and spatial extent of the resulting dam-break flood.

Flood Wave Propagation

The simulated flood hydrographs indicate rapid downstream propagation of the flood wave following failure of the temporary landslide dam. The leading edge of the flood wave reached the Naivasha Highway crossing at Mai Mahiu approximately 25 minutes after dam failure, while the peak flood depth at this location reached approximately 3.5 m. The flood wave continued downstream and reached the Narok Highway crossing approximately five minutes later, where the simulated peak water depth reached approximately 5.0 m (see Figure 8).

The short travel time demonstrates the highly destructive nature of dam-break floods within steep mountain catchments. The confined valley geometry and relatively steep steep longitudinal channel slope promoted rapid acceleration of the flood wave, leaving very little time for warning or evacuation of downstream populations. The increase in peak water depth downstream is attributed to local channel geometry and constricted box culvert at the Narok highway which temporarily impounded flow and increased water depths.

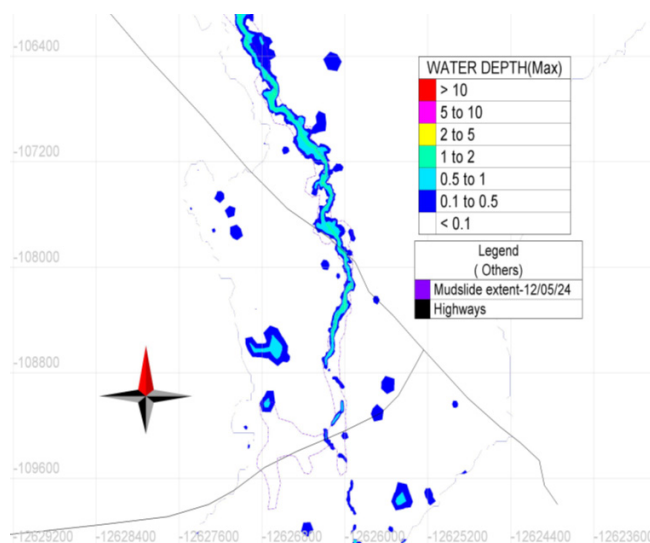


Fig 4: Simulated flood inundation in Mai Mahiu Town resulting from 2-day antecedent rainfall followed by an abrupt structural failure of the railway crossing embankment. The simulated inundation extent underestimates the observed flood extent.

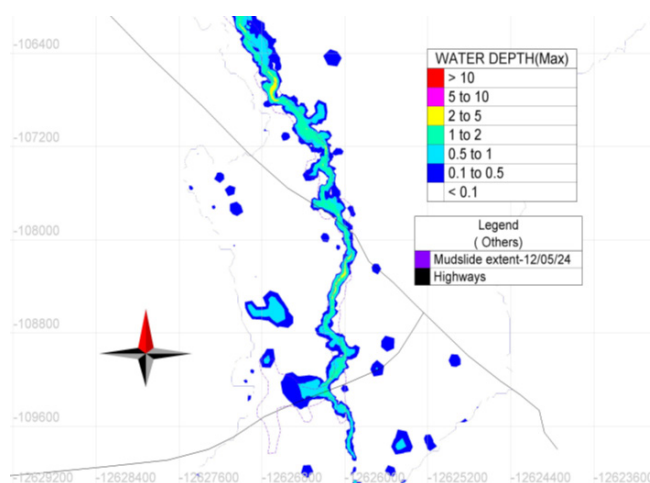


Fig 5: Simulated flood inundation in Mai Mahiu Town resulting from 3-day antecedent rainfall followed by an abrupt structural failure of the railway crossing embankment. The simulated inundation extent underestimates the observed flood extent.

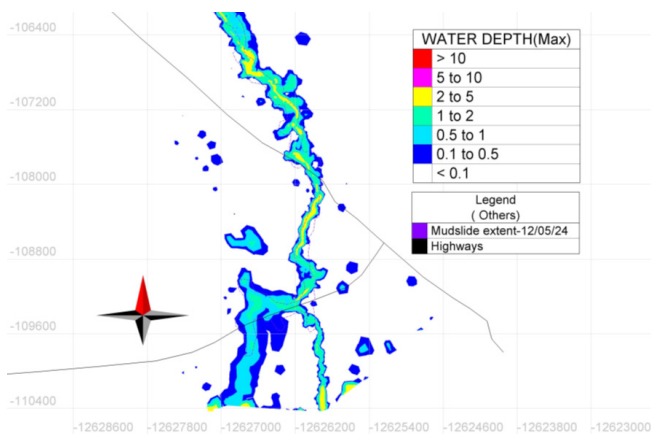


Figure 6. Simulated flood inundation in Mai Mahiu Town following an abrupt structural failure of the railway crossing embankment. The simulated inundation extent considerably exceeds the observed flood extent.

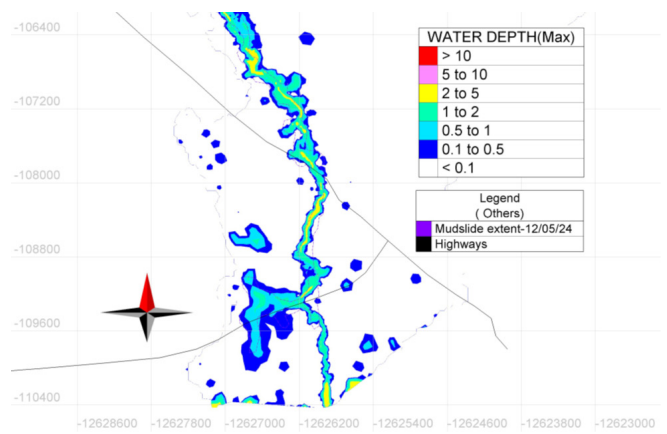


Figure 7. Simulated flood inundation in Mai Mahiu Town following overtopping-induced failure of the railway embankment, showing close agreement with the observed flood extent

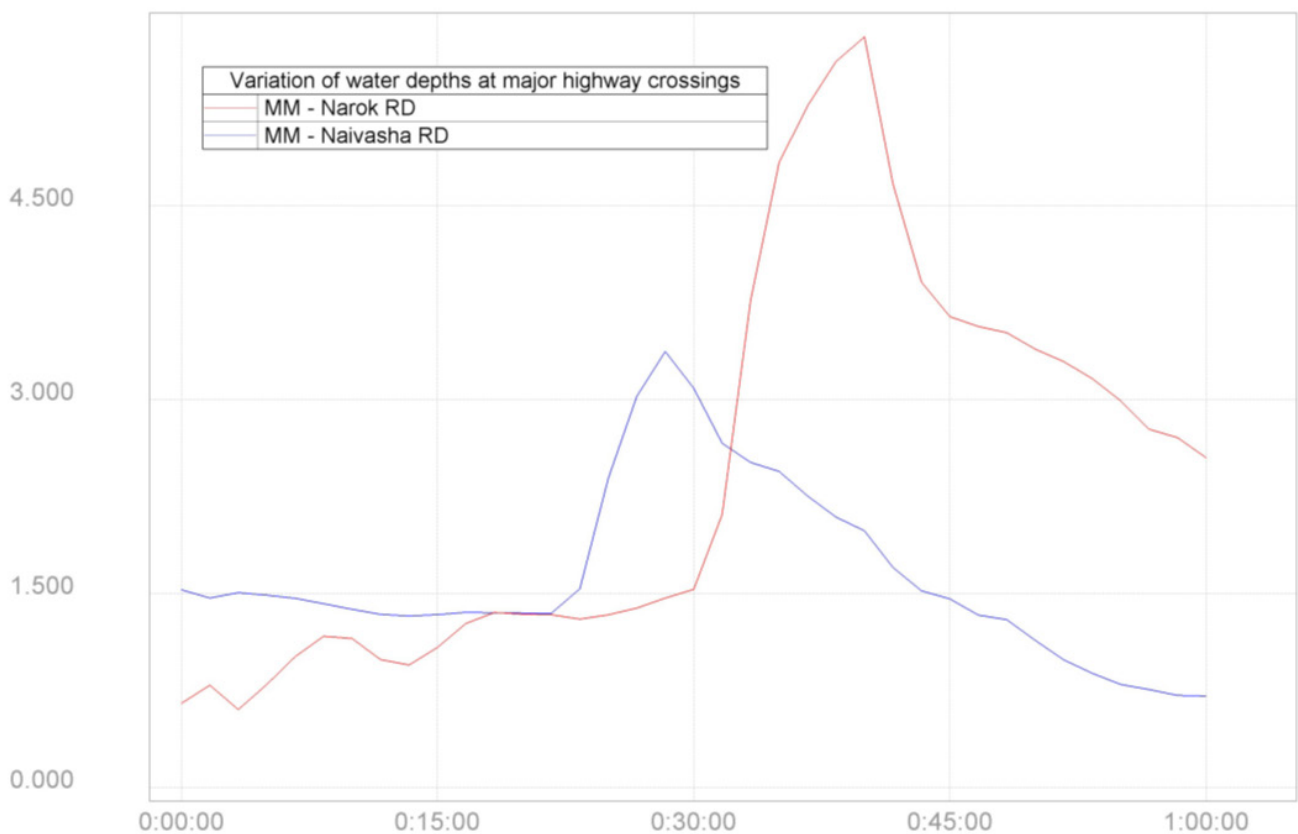


Figure 8. Variation of river stage at the major highway crossing in Maai Mahiu town

Relationship Between Simulated Flooding and Observed Damages

The spatial distribution of simulated flooding corresponds well with the areas that experienced the greatest loss of life and destruction of infrastructure during the Mai Mahiu disaster. Severe impacts were concentrated within Mai Mahiu town, where residential buildings, commercial developments, and transport infrastructure are located immediately adjacent to the River Tongi channel.

The concentration of damages within the riparian corridor illustrates the significant influence of floodplain encroachment on disaster risk. Development close to river channels substantially increases human exposure to extreme flood events, particularly in steep

catchments where flood waves propagate rapidly and with little warning. Although the magnitude of the flood largely resulted from the sudden failure of the temporary landslide dam, the severity of the disaster was amplified by the location of settlements within the active floodplain.

These findings reinforce the importance of enforcing riparian buffer regulations and incorporating flood hazard assessments into land-use planning in rapidly developing urban centres situated along mountain rivers. Numerical flood simulations such as those presented in this study provide valuable information for identifying high-risk zones and supporting evidence-based planning decisions aimed at reducing future flood losses.

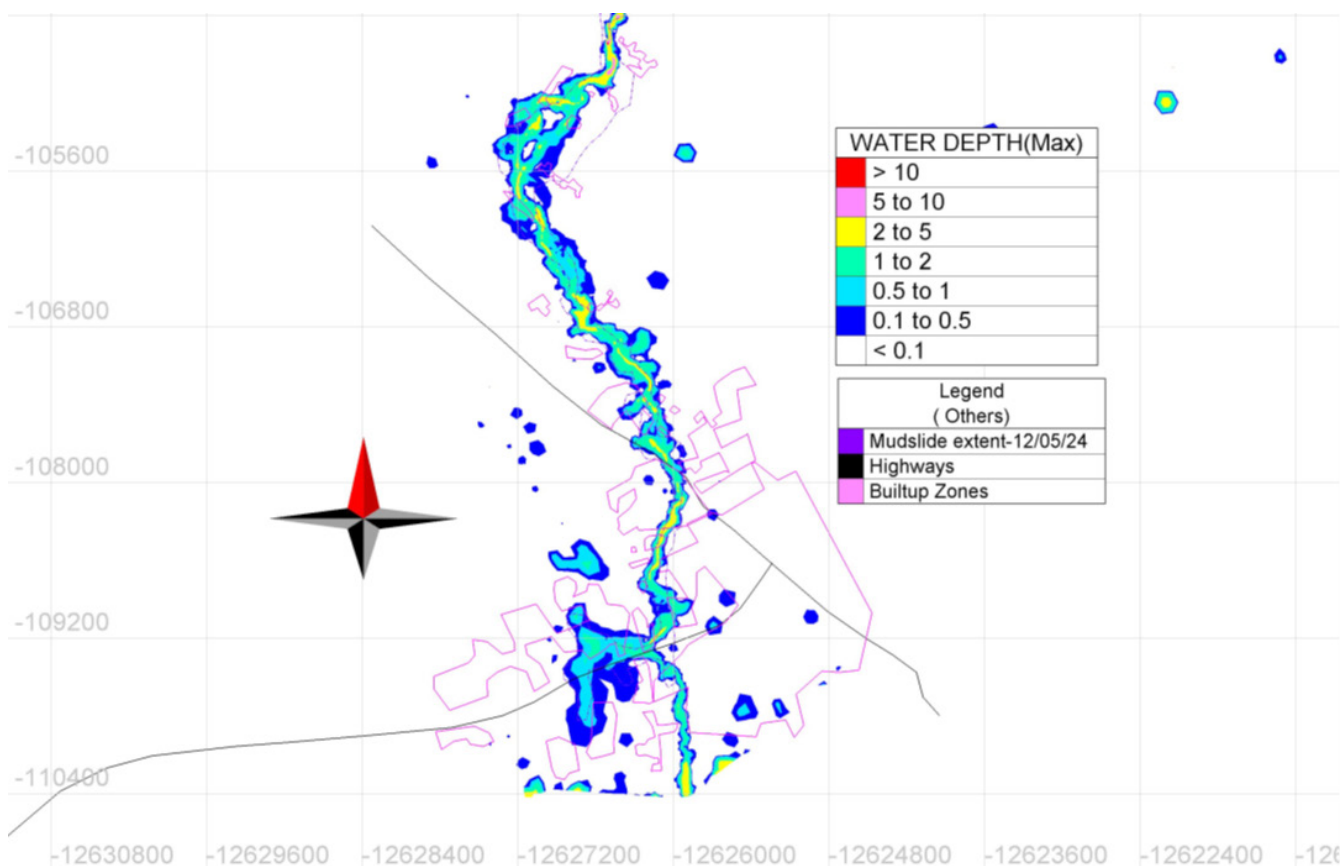


Figure 9. Map showing the flood-affected areas in Mai Mahiu Town following the 29 April 2024 dam-break event.

Sediment Erosion and Deposition Zones

The coupled TELEMAC-2D-SISYPHE simulations successfully reproduced the principal erosion and deposition patterns generated during the dam-break flood. Erosion was predominantly concentrated along steep reaches of the river channel, where flow velocities and bed shear stresses were highest. These sections experienced substantial bed degradation due to the increased transport capacity of the rapidly flowing water released during dam failure.

In contrast, sediment deposition occurred primarily in zones where flow velocities decreased abruptly. Significant deposition was observed upstream of road crossings and bridge structures, where hydraulic backwater effects reduced flow competence and promoted sediment settling. Additional deposition occurred along relatively low-gradient channel reaches where the reduction in transport capacity allowed suspended and bed-load sediments to accumulate.

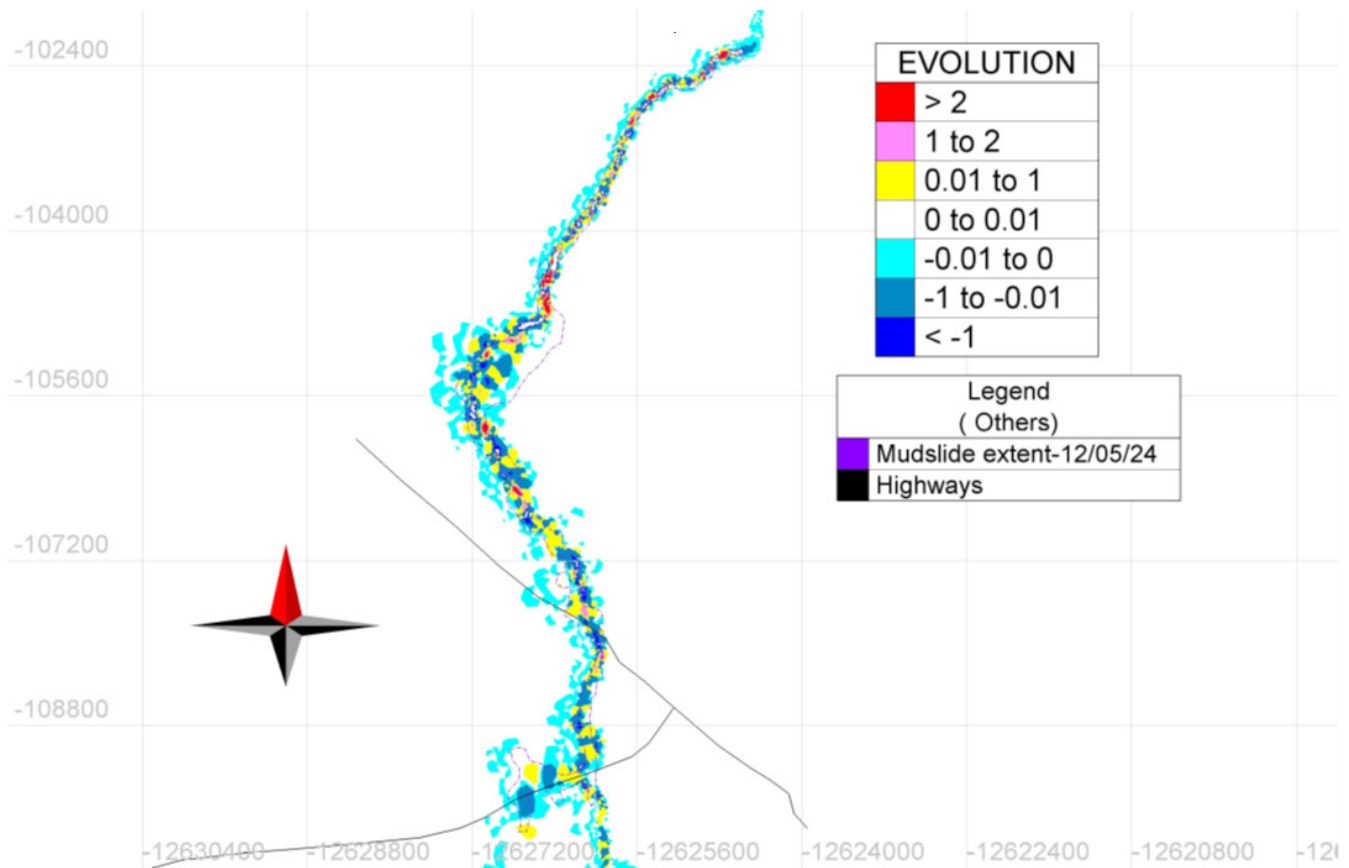


Figure 10. Map illustrating the spatial distribution of erosion and sediment deposition along the Tongi River channel following the dam-break event

Conclusion

This study developed a coupled TELEMAC-2D-SISYPHE modelling framework to reconstruct the sequence of processes that culminated in the 29 April 2024 Mai Mahiu landslide dam-break disaster, including temporary dam formation by landslide-derived debris, rainfall-driven reservoir impoundment, embankment failure, downstream flood propagation, and sediment redistribution. The simulation results demonstrated that antecedent rainfall exerted a significant control on reservoir storage and the resulting flood magnitude. The 2-day and 3-day antecedent rainfall scenarios underestimated the observed inundation extent, indicating insufficient reservoir storage, whereas the 4-day and 5-day antecedent rainfall scenarios resulted in complete filling of the temporary reservoir prior to failure.

Comparison of alternative breach

mechanisms further showed that an instantaneous structural failure produced flood extents substantially larger than those observed, while an overtopping-induced breach, characterized by progressive erosion of the embankment, closely reproduced the satellite-derived inundation extent. These findings indicate that prolonged antecedent rainfall was required to fill the temporary reservoir and that overtopping-induced erosion was the most probable mechanism responsible for failure of the railway embankment during the Mai Mahiu disaster.

The coupled hydrodynamic and morphodynamic simulations successfully reproduced the principal erosion and deposition patterns along River Tongi, with erosion concentrated in steep, high-velocity reaches and sediment deposition occurring in low-velocity sections and upstream of bridges and culverts. The simulated flood wave reached the Naivasha Highway

crossing at Mai Mahiu approximately 25 minutes after embankment failure, highlighting the rapid onset of landslide dam-break floods and the limited time available for emergency response.

Overall, the close agreement between the simulated and observed flood extents demonstrates the capability of the coupled TELEMAC-2D-SISYPHE framework to reproduce complex landslide dam-break processes in data-scarce environments. Beyond reconstructing the 2024 Mai Mahiu disaster, the modelling framework provides a practical tool for evaluating future landslide dam-break scenarios under varying rainfall conditions and breach mechanisms. Its ability to estimate flood arrival times, inundation extents and depths, erosion-prone reaches, and sediment deposition zones provides valuable information for flood hazard mapping, early warning systems, emergency preparedness,

hydraulic infrastructure design, and land-use planning in mountainous catchments vulnerable to cascading landslide and flood hazards.

Future research should focus on integrating high-resolution topographic datasets, detailed characterization of sediments and breach evolution. Incorporating real-time rainfall observations would further enhance the framework's capability for operational flood forecasting, risk assessment, and disaster preparedness in regions susceptible to landslides.

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Smart Cities, Digital Twins, and Spatial Data Integration

Developing Interoperable Geodetic and Semantic Models for Municipal Infrastructure in Kenya



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The Operational Reality of Urban Infrastructure

Kenya's urban centers are experiencing an intense phase of growth. The rapid expansion of Nairobi, Mombasa, Kisumu, Nakuru, and Eldoret has placed heavy operational demands on municipal infrastructure. Historically, roads, water reticulation, power distribution, and telecommunication networks have been planned, designed, and managed in isolation. Each utility maintains its own asset records, often stored as static paper drawings, isolated CAD files, or uncoordinated spreadsheets.

This fragmentation creates significant operational and financial challenges. When public road reserves are excavated for road widening or drainage installation, contractors frequently strike underground assets. Buried water pipes are punctured, high-voltage feeder cables are cut, and trunk optical fiber lines are severed. According to the Water Services Regulatory Board (WASREB), non-revenue water losses across

Kenyan urban centers average 42%, with physical leaks in unmapped underground mains forming a major share of this loss. In road construction, unanticipated utility relocations consistently account for 8% to 15% of total project costs, leading to contractual claims, cost overruns, and severe traffic disruption.

Resolving these recurring failures requires moving past the concept of static as-built documentation. Infrastructure assets change continuously throughout their operating life. To manage modern cities efficiently, the engineering community must connect physical infrastructure with accurate, georeferenced virtual models, a concept known as the Urban Digital Twin.

2. Demystifying the Digital Twin in Civil and Municipal Engineering

In technical terms, a Digital Twin is a computable, georeferenced virtual model of a physical asset or network that remains synchronized with its physical counterpart through structured data streams. It is not simply a 3D visual rendering. While a 3D CAD drawing displays how an asset was designed, a digital twin reflects how that asset is behaving under real operating conditions, real mechanical loads, and real environmental stresses.

A practical engineering digital twin comprises three functional layers:

- **Geodetic Reference Frame:** Establishes unambiguous physical positioning on the earth's surface using defined coordinates, elevation baselines, and spatial boundaries.

- **Semantic Asset Model:** Contains engineering properties such as pipe materials, nominal diameters, pressure ratings, transformer capacities, structural sections, and installation dates.
- **Operational State Telemetry:** Ingests real-time measurements from field instrumentation (SCADA, flow meters, pressure transducers, weather stations, and traffic detectors) to evaluate operational status.

Digital twins evolve through four functional tiers: Descriptive (static geometric and cadastral data), Informative (integrated asset records and maintenance logs), Predictive (physics-based simulation and early warning algorithms), and Autonomous (automated closed-loop controls, such as adaptive traffic signals or pressure-reducing valves).

3. The Technical Bridge: BIM, GIS, and Spatial Data Integration

A central engineering challenge in creating municipal digital twins is bridging the gap between Building Information Modeling (BIM) and Geographic Information Systems (GIS). Structural, mechanical, and electrical engineers design assets in millimeter-level detail using local Cartesian coordinate systems. Geospatial engineers and urban planners operate at regional scales using geodetic coordinate reference systems. Harmonizing these two environments requires standardized interoperability.

Technical Parameter	Building Information Modeling (BIM)	Geographic Information Systems (GIS)
Primary Industry Standards	IFC (ISO 16739-1), Revit, LandXML	OGC CityGML 3.0, 3D Tiles, GeoPackage
Coordinate Reference Frame	Local Cartesian (Origin at site or building corner)	National / Global Geodetic Datum (e.g., UTM / WGS84)
Geometric Scope and Tolerance	Micro-scale: Millimeter precision for fabrication	Macro-scale: Meter/centimeter topographic networks
Geometric Modeling Approach	Constructive Solid Geometry (CSG), parametric solids	Boundary Representation (B-Rep), vector topologies
Primary Engineering Focus	Interior structural elements, MEP plant, clash detection	Surrounding terrain, network connectivity, catchment context

Managing Levels of Detail (LoD) in Municipal Models

Directly loading complex BIM models into city-scale GIS databases overloads computing hardware with unnecessary geometric detail. Conversely, flattening 3D models into 2D maps removes essential engineering attributes. The standard solution is an automated Spatial ETL (Extract, Transform, Load) workflow structured across five Levels of Detail (LoD):

- **LoD 0:** 2.5D Digital Elevation Models and surface footprints for regional catchment analysis.
- **LoD 1:** Prismatic block models used for macro-scale zoning, bulk density, and shadow modeling.
- **LoD 2:** Detailed exterior roof shapes and outer wall boundaries for solar irradiance and municipal stormwater runoff calculations.
- **LoD 3:** Architectural facades, structural openings, and bridge decks for micro-climate and sight-line analysis.
- **LoD 4:** Full interior architecture, MEP plant rooms, pipe networks, and subsurface chambers for operations and maintenance.

The Geodetic Coordinate Foundation in Kenya

A major technical risk during spatial integration in Kenya is coordinate datum incompatibility. Historical land surveys and infrastructure plans were often documented in local Cassini-Soldner coordinates or the Arc 1960 datum (Clarke 1880 modified ellipsoid). Modern GNSS positioning, drone surveys, and satellite imagery operates on the WGS84 ellipsoid or the International Terrestrial Reference Frame (ITRF).

Importing historical Arc 1960 data directly into a WGS84 GIS environment without rigorous datum transformation results in positional shifts between 80 and 320 meters on the ground. In congested road

reserves, an uncorrected error of two meters can place a buried gas pipeline or high-voltage cable in the middle of a drainage trench. All engineering deliverables must be standardized to the Kenya Geodetic Reference Frame (KGRF) and projected to UTM Zone 36N or Zone 37S using validated 7-parameter Helmert transformations tied into the Survey of Kenya's Continuous Operating Reference Stations (KENCORS).

Reference System	Mathematical Parameters	Engineering Application / Scope
Arc 1960 (Clarke 1880)	$a = 6378249.145 \text{ m}$ $1/f = 293.465$	Legacy cadastral plans, Survey of Kenya topo sheets, historical road alignments.
WGS84 / ITRF2020	$a = 6378137.000 \text{ m}$ $1/f = 298.257223563$	GNSS positioning, UAV LiDAR surveys, satellite imagery, modern GIS platforms.
Standard Transformation (Kenya General)	$dX = -160.0 \text{ m}$ $dY = -6.0 \text{ m}$ $dZ = -302.0 \text{ m}$	Regional baseline shift. Must be refined using local 7-parameter Helmert models for sub-meter utility alignment.

4. Practical Engineering Implementations in Kenya

Spatial data integration and digital twins provide immediate, measurable returns across municipal infrastructure sectors:

Urban Water Distribution and Leak Management

Water service providers, including the Nairobi City Water and Sewerage Company (NCWSC) and the Kisumu Water and Sanitation Company (KIWASCO), are dividing distribution networks into District Metered Areas (DMAs). By equipping DMA boundaries with electromagnetic bulk meters and high-frequency pressure transducers, flow telemetry is fed directly into spatial databases. When pressure drops abnormally at a downstream node without a corresponding increase in demand, the integrated hydraulic model (running EPANET or SWMM engines) computes the probable burst location within a 50-meter radius, allowing maintenance crews to respond immediately.

Intelligent Transport Systems (ITS) and Pavement Monitoring

Under the Nairobi Intelligent Transport System (NITS) implemented by the Kenya Urban Roads Authority (KURA), traffic control is moving from fixed-time signal cycles to adaptive control. In-pavement inductive loops, radar sensors, and cameras supply real-time traffic volumes to a spatial traffic simulation engine. The model optimizes green-light splits across key junctions (such as along Kenyatta Avenue, Yaya Centre, and Ring Road Kilimani) to minimize total network delay.

Concurrently, highway agencies utilize Mobile Laser Scanning (MLS) vehicles to capture road surface point clouds at driving speeds, automatically calculating the Pavement Condition Index (PCI) and rutting depths across thousands of lane-kilometers.

Multi-Utility Tunnels at Konza Technopolis

Konza Technopolis demonstrates how spatial data integration operates when built into greenfield infrastructure. The city's Phase 1 development houses water mains, electrical power distribution, fiber ducts, and automated pneumatic refuse collection lines inside accessible underground concrete Multi-Utility Tunnels (MUT). Every linear segment, valve, and cable tray is mapped in a unified 3D BIM-GIS registry under ISO 19650 guidelines. Fiber-optic acoustic and temperature sensors along the tunnel walls provide continuous monitoring, detecting thermal overloads on electrical cables or joint leaks without disrupting surface roads.

Hydrodynamic Flood Modeling along Urban Basins

Flash flooding along the Nairobi River basin, Ngong River, and flat terrains in western Kenya causes recurring structural damage. By integrating 0.25-meter Digital Terrain Models captured via airborne LiDAR with rainfall data from the Kenya Meteorological Department, civil engineers deploy 2D hydrodynamic simulation models (such as HEC-RAS 2D). The system predicts flood wave arrival times and inundation depths hours in advance, giving county authorities the precise data needed to secure vulnerable road crossings and evacuate flood-prone settlements.

5. Governance, Contract Specifications and Data Security

While technical modeling tools are well established, successful implementation requires clear governance and standardized procurement specifications. Road agencies, power utilities, water service providers, and telecommunication companies must operate within a coordinated spatial data exchange.

The Physical and Land Use Planning Act (PLUPA 2019) and the Kenya National Spatial Data Infrastructure (KNSDI) policy framework provide the statutory basis for shared spatial registries. However, this must be enforced through project specifications in public works contracts.

Contractual Integration: Model Specification Clause

To operationalize digital twin deliverables on the ground, procuring entities and their appointed design and supervising engineers must embed explicit digital submission requirements into project tender documents and Employer's Information Requirements (EIR under ISO 19650). Below is an illustrative model clause that can be adapted into the Particular Technical Specifications or Conditions of Contract of standard civil works tenders:

Illustrative Sample Clause (For Particular Specifications / As-Built Submissions):

"Clause XX.X. Digital As-Built Submissions: The Contractor shall furnish, as a mandatory condition for the issuance of the Substantial Completion Certificate, fully georeferenced 3D digital as-built models in IFC (ISO 16739-1) and OGC CityGML 3.0 or GeoPackage format. All linear and subterranean assets shall be referenced to the official Kenya Geodetic Reference Frame (KGRF) tied to KENCORS datum control, with spatial vertical and horizontal tolerances not exceeding plus or minus 25 mm for structural elements and plus or minus 50 mm for buried pressure utilities. Unreferenced 2D PDF drawings or unscaled CAD files shall not be accepted as valid as-built records."

Cyber-Physical Security and Critical Infrastructure Protection

As municipal assets connect to digital networks, cyber-physical security becomes a core engineering responsibility. Compromising a digital twin that controls physical switchgear or water valves can lead to direct structural and public safety hazards. Engineering teams must apply unidirectional data diodes between SCADA networks and external web dashboards, enforce encrypted mutual TLS authentication on all field sensor gateways, and ensure that spatial registries detailing critical national infrastructure remain hosted on sovereign data centers within Kenyan borders, in full compliance with Section 48 of the Data Protection Act (2019).

Action Area	Lead Stakeholders	Implementation Mandate
Geodetic Datum Harmonization	Survey of Kenya, EBK	Enforce KGRF / KENCORS tie-in on all public infrastructure design tenders.
Utility Coordination Clearinghouse	KeNHA, KURA, KPLC, WSPs etc	Establish a mandatory 3D subsurface spatial registry before road excavation.
Digital Procurement Standards	PPRA, State Dept of Roads	Adopt ISO 19650 and OGC open data deliverables as contractual closeout criteria.
Capacity Building and Training	EBK CPD, Kenyan Universities	Incorporate Spatial ETL, PostGIS, and IoT telemetry into continuing engineering education.

The Engineer's Role in Building Resilient Cities

The development of smart cities and digital twins is not an IT exercise; it is an evolution of civil, mechanical, electrical, and geospatial engineering practice. By integrating accurate geodetic frameworks with detailed asset models and real-time telemetry, engineers gain complete visibility into how municipal infrastructure behaves throughout its lifecycle.

For the members of the Institution of Engineers of Kenya, taking the lead in spatial data integration is essential to protecting capital investments and improving public service delivery. By mandating shared coordinate standards, embedding digital as-built clauses in public tenders, and breaking down inter-agency silos, Kenyan engineers will ensure that our expanding urban centers are engineered for long-term safety, efficiency, and economic vitality.

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The development of smart cities and digital twins is not an IT exercise; it is an evolution of civil, mechanical, electrical, and geospatial engineering practice.

Seeing Kenya from Above: Remote Sensing, Smart Agriculture and Climate Resilience



By Eng. Dr. Joseph K. Sang

Bio Data: : Eng. Dr. Joseph K. Sang is a professional engineer, lecturer and researcher in the field of water and environmental engineering. He is a former Dean of the School of Biosystems and Environmental Engineering at the Jomo Kenyatta University of Agriculture and Technology (JKUAT), where he continues to contribute to teaching, research and mentorship as a senior lecturer. He holds a doctorate degree in Geology from Baylor University, USA, and an MSc from JKUAT. His areas of expertise include watershed management, hydrology, environmental modelling, remote sensing, Geographic Information System (GIS) and *réservoir sédimentation* management. His research mainly focuses on applying geospatial and environmental technologies to agriculture, water resource management, climate resilience and sustainable development.

When we talk about remote sensing, many people immediately think about rockets being launched into space or satellites orbiting far above the Earth as popularized in media. Yet the real value of remote sensing is not how far away the technology is, but how effectively the information it provides can support decisions on the ground.

Geospatial technology gives us an opportunity to look at the Earth from a spatial perspective. To see where things are on the ground and how they relate to each other. It helps us understand where our resources are, where risks are concentrated and where we should direct our efforts and investments. For Kenya, this is particularly important since each we confront the challenges

of climate change, food insecurity, water shortages, flooding and we must use our natural resources more sustainably.

My own journey has allowed me to witness a significant transformation in the way environmental data is accessed and used. When I was a student at Jomo Kenyatta University of Agriculture and Technology (JKUAT), GIS and related technologies were still relatively new. Access was a major challenge. There were few computers, computing capacity was limited and environmental data was not readily available. I remember having to physically visit the Kenya Meteorological Department (KMD) to digitize data for my master's research.

Later, during my studies at Baylor University in Texas, I became more involved in watershed management and modelling, including the use of the Soil and Water Assessment Tool (SWAT), a model that estimates how land use and rainfall move water and soil through a catchment. At that time, communication and access to technical assistance were also very different and limited.

Today, an engineer can communicate with a fellow engineer or researchers anywhere in the world almost instantly through email, online meetings and other digital platforms.

The data environment has also changed significantly. Kenya now has automated rainfall stations,



telemetry systems that report readings automatically, and other modern monitoring infrastructure, while satellite observations provide environmental information across large areas. We have therefore moved from asking, "Where can I get the data?" to asking, "How can we use this data effectively?"

This shift presents a major opportunity for agriculture. For example, farmers in the Rift Valley, Central Kenya, Western Kenya and other agricultural regions, remote sensing and associated geospatial technologies should become an everyday decision-making tool rather than a distant satellite technology.

Satellite and environmental data can help farmers determine when conditions are favorable for planting, monitor crop health and anticipate potential pest and disease outbreaks. Climate information can also help farmers prepare for climate patterns such as El Niño and make better decisions before the rains arrive. If environmental conditions indicate that a particular pest or disease is likely to occur, farmers can take preventive action instead of waiting until the problem becomes severe.

Prevention is often cheaper than treatment. Through work with farmers, including a project in Machakos, we have seen how information on pest occurrence can contribute to reduced pesticide use. Reducing unnecessary agrochemical application, which

benefits both the farmer and the environment.

The next step is to move beyond monitoring and begin using geospatial information to support agricultural investment decisions. Imagine a farmer who wants to grow watermelon in Garissa. The farmer should be able to access information on water availability, environmental suitability, potential production, input costs and market conditions before making the investment.

This would move agriculture from guesswork towards informed decision-making. We should eventually be able to estimate the likely production potential of different parts of the country and provide farmers with information that answers a simple question: If I invest here and produce this crop, what is the likely outcome?

However, having data is not enough. We must convert data into information that people can understand and act upon. A farmer may not need to know that a particular rainfall event is 10 millimeters. A farmer does not need the figure of 10 millimeters. The farmer needs to know whether that is enough for the crop, whether to plant now, and whether more rain could bring flooding.

This is where interpretation becomes critical. The KMD's increasingly localized forecasts and map-based communication demonstrate the value of presenting information in a form that people

can relate to. When information is presented clearly, using maps, color codes and local-level forecasts, its usefulness increases.

There is also a need to bridge the gap between universities and communities. Researchers can produce sophisticated models and technical reports, but these will have limited impact if the intended users cannot understand or access them. Extension officers, who advise farmers directly, together with local experts and community-based technology users can help translate scientific information into practical recommendations and, where necessary, local languages.

The same principle applies to the technologies themselves. Many geospatial and climate models were developed in Europe or North America. These tools are valuable, but they must be adapted to Kenyan conditions. Agricultural practices, soils, climate patterns, farm sizes and other local conditions may differ considerably from those for which a model was originally developed.

The solution is not to reject international technologies or reinvent every tool. We should adapt, calibrate and validate them: in other words, adjust the settings and test the results against reliable local data. At the same time, Kenya is increasingly developing its own solutions. Researchers and students are working on locally relevant applications, including pest monitoring, crop-yield prediction and environmental assessment.



Geospatial technology is equally important in managing climate-related disasters. Kenya has experienced severe droughts as well as destructive floods. We have the capacity to model river basins, identify flood-prone areas and estimate the likely extent of flooding. That capacity exists, but it has not yet been applied across the whole country. The challenge is moving from prediction to action.

If modelling shows that a particular area is likely to flood, we should not wait until the disaster occurs before responding. Flood-prone areas can be identified during planning and, where appropriate, reserved for uses such as parks or other open spaces. The technology can show us the flood line, the point the water is expected to reach, but planners, policymakers and communities must act on that information.

Water security provides another powerful application. Reservoir sedimentation, the build-up of silt behind a dam, is often a silent problem. When soil is eroded from farms, farmers lose productive topsoil while the sediment is transported downstream into reservoirs. The farmer may respond by using more fertilizer, while the reservoir simultaneously loses storage capacity.

Regular reservoir sedimentation assessment therefore provides information that can guide decisions on water supply, desilting (removing accumulated silt), treatment and future infrastructure. County governments and water institutions can work with universities to generate this information and incorporate it into long-term planning.

If I were given the opportunity to address one major national infrastructure challenge using geospatial technology, I would focus on quantifying Kenya's water resources. We need to know how much water we have in our dams, rivers and groundwater, and where it is. We also need to know its quality, and how much will still be there in future.

Water drives agriculture, energy, industry and domestic life. Once we know what we have, we can make informed decisions about how to use it sustainably.

The future will also require engineers who can combine fundamental engineering knowledge with rapidly changing technologies. I do not believe that GIS, GPS, automation or artificial intelligence will necessarily make traditional engineering roles redundant. Technology has historically transformed professions rather than simply eliminating them.

However, engineers must understand the fundamentals before relying on the tools. AI can improve the work of an engineer who understands surveying, analysis and technical writing, but it becomes dangerous when it replaces understanding rather than enhancing it. Students should therefore learn the principles first and then use technology to become more productive.

Ultimately, the future of geospatial engineering in Kenya is not about producing more maps. It is about making better decisions. The technology can show us where our resources are, where risks exist and where interventions are needed. Our responsibility is to transform that information into decisions that farmers, engineers, communities, institutions and policymakers can understand and act upon.

Kenya has the technology, increasingly better data and a growing pool of young people capable of using it. What we need now is to connect these elements through stronger collaboration between universities, government, industry and communities. If we do that effectively, geospatial engineering can become a critical foundation for smarter agriculture, better water management and stronger climate resilience.

Mapping a Resilient Future: Geospatial Intelligence for Climate Action, Environmental Monitoring and Disaster Risk Reduction



By Clement Rono

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The next climate battle may be won or lost not only in forests, farms and cities, but on computer screens displaying maps. Across Kenya, satellite imagery, remote sensing, Geographic Information Systems (GIS), community-generated data and scientific research are creating a new generation of climate intelligence. Maps are no longer passive representations of landscapes; they are increasingly becoming tools for saving lives, protecting ecosystems and directing public investment.

For a country whose economy and livelihoods remain closely connected to rainfall, forests, water, agriculture and rangelands, knowing where climate risks are emerging and how they are changing is critical. GIS can reveal where floods are most likely to strike, where drought is deepening, where watersheds are deteriorating and where restoration could generate the greatest ecological and social returns.

Climate change has made static maps increasingly inadequate. Floods can alter river channels

within hours, drought can transform pasture conditions within weeks, while settlements can expand into hazard-prone areas before conventional maps are updated.

Kenya's government and development partners are responding by placing evidence-based planning and environmental monitoring at the center of climate action. The National Landscape and Ecosystem Restoration Strategy (NLERS) 2023–2032 targets restoration of 10.6 million hectares of degraded landscapes and an increase in national tree cover to 30 percent by 2032.

The United Nations Development Programme (UNDP) has supported this transition by strengthening GIS capacity within Kenya's devolved planning system. Its GIS needs assessment examined county-level hardware, software, human resources and spatial-data requirements, with the goal of strengthening spatial planning and integrating climate considerations into county development.

Turkana provides a powerful example of how geospatial intelligence can influence development decisions. UNDP worked with the Turkana County Directorate of Disaster Management and the National

Drought Management Authority to develop the Turkana County Hazard Atlas, combining meteorological and topographical information to identify hazards and guide development planning. Similar support extended to other counties.

The significance goes beyond disaster response. GIS enables planners to ask not simply where can we build? but where can we build safely? A road constructed across a flood-prone corridor or infrastructure located without adequate knowledge of environmental risks can become tomorrow's public-finance and humanitarian crisis.

In Tana River, the next generation of climate intelligence is emerging through community participation. UNDP's Accelerator Lab, with partners including Nesta's Centre for Collective Intelligence Design, explored how farmers and pastoralists could contribute information about water access, water levels and water use.

The Collective Intelligence for Climate Action initiative sought to combine community-generated information with satellite imagery and government datasets. This approach recognizes that satellites see landscapes from above while

communities experience environmental change from within. A farmer observing an unusual river pattern or a pastoralist noticing a rapidly drying water source holds valuable information. Combining local knowledge with scientific observation can produce richer and more responsive environmental intelligence.

Kenya's 15 billion Tree Growing Programme demonstrates the scale of the country's restoration ambition. Yet planting seedlings is only the beginning. The more important questions are whether trees survive, whether forest canopy increases, whether watersheds recover and whether communities' benefit.

This is why the Kenya Landscape and Ecosystem Restoration Monitoring Framework and the National Forest Monitoring System (NFMS) are important. The NFMS integrates satellite-based land monitoring, the National Forest Inventory and forest information systems to track changes in forest cover and carbon stocks. Such evidence is increasingly essential for climate accountability and climate finance.

The Kenya Watershed Services Improvement Project (KEWASIP) further illustrates the value of spatial thinking. Implemented by the State Department for Forestry with the World Bank, the five-year programme seeks to restore degraded landscapes, improve watershed services and strengthen climate resilience across 12 counties.

Its watershed approach reflects an important reality: nature does not respect administrative boundaries. A degraded upper catchment can affect farms, towns and industries far downstream. GIS helps institutions visualize these connections and coordinate action.

The same principle applies to disaster risk reduction. Floods, droughts and landslides are not merely humanitarian emergencies; they are development shocks. GIS can identify repeatedly damaged roads, vulnerable settlements and infrastructure requiring priority investment, helping governments shift from emergency response towards anticipatory risk reduction.

The next frontier is moving from asking "Where?" to asking "What next?" Artificial intelligence and machine learning can analyze vast quantities of satellite imagery to detect environmental changes and potentially identify emerging risks.

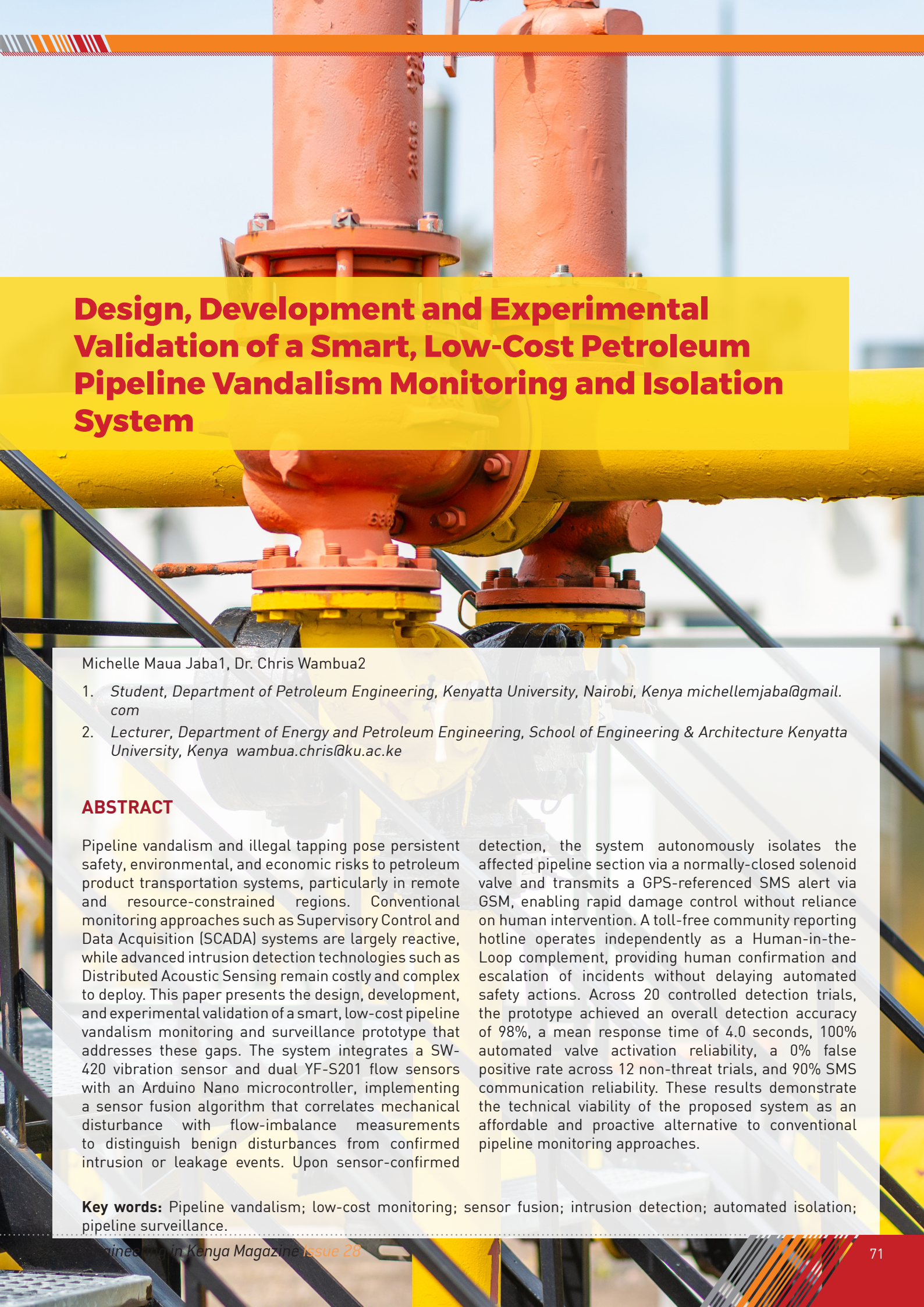
But technology alone will not create resilience. Kenya must overcome fragmented datasets, strengthen institutional data-sharing, build county capacity and ensure communities participate in generating and validating information. Otherwise, the country risks becoming data-rich but decision-poor.

Kenya's resilient future will therefore depend on seeing the country more clearly from space, from the ground, through science, communities and data. The map is no longer simply a picture of Kenya. It is increasingly becoming a blueprint for how the country survives, adapts and prospers in a changing climate.

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Design, Development and Experimental Validation of a Smart, Low-Cost Petroleum Pipeline Vandalism Monitoring and Isolation System

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ABSTRACT

Pipeline vandalism and illegal tapping pose persistent safety, environmental, and economic risks to petroleum product transportation systems, particularly in remote and resource-constrained regions. Conventional monitoring approaches such as Supervisory Control and Data Acquisition (SCADA) systems are largely reactive, while advanced intrusion detection technologies such as Distributed Acoustic Sensing remain costly and complex to deploy. This paper presents the design, development, and experimental validation of a smart, low-cost pipeline vandalism monitoring and surveillance prototype that addresses these gaps. The system integrates a SW-420 vibration sensor and dual YF-S201 flow sensors with an Arduino Nano microcontroller, implementing a sensor fusion algorithm that correlates mechanical disturbance with flow-imbalance measurements to distinguish benign disturbances from confirmed intrusion or leakage events. Upon sensor-confirmed

detection, the system autonomously isolates the affected pipeline section via a normally-closed solenoid valve and transmits a GPS-referenced SMS alert via GSM, enabling rapid damage control without reliance on human intervention. A toll-free community reporting hotline operates independently as a Human-in-the-Loop complement, providing human confirmation and escalation of incidents without delaying automated safety actions. Across 20 controlled detection trials, the prototype achieved an overall detection accuracy of 98%, a mean response time of 4.0 seconds, 100% automated valve activation reliability, a 0% false positive rate across 12 non-threat trials, and 90% SMS communication reliability. These results demonstrate the technical viability of the proposed system as an affordable and proactive alternative to conventional pipeline monitoring approaches.

Key words: Pipeline vandalism; low-cost monitoring; sensor fusion; intrusion detection; automated isolation; pipeline surveillance.

Introduction

Petroleum product pipelines are a critical component of energy transportation systems worldwide, providing an efficient and economical means of conveying refined products such as petrol, diesel, kerosene, and jet fuel over long distances. Despite their efficiency, pipeline systems remain highly vulnerable to vandalism, illegal tapping, and accidental leakages, particularly in regions where pipelines traverse remote or socio-economically challenged areas. Unauthorized interference often results in significant product losses, environmental pollution, fires, and loss of human life. Conventional monitoring systems, most notably SCADA, are designed primarily for operational control rather than security, and are largely reactive, detecting anomalies only after measurable changes in flow or pressure occur, by which time substantial damage may already have been done. Advanced intrusion detection technologies offer improved real-time detection accuracy but are associated with high capital costs, complex installation requirements, and the need for specialized expertise, limiting their accessibility in developing regions and for resource-constrained operators.

A growing body of research has explored low-cost, microcontroller-based alternatives to conventional pipeline monitoring. Ezech et al. (2014) developed an SMS-based alert system that notified operators of suspected vandalism but provided no automated response, leaving the isolation decision entirely to human intervention after the alert was received. Ogujor et al. (2013) implemented a microcontroller-based system using an insulated copper cable sensor wrapped around the pipeline to detect sabotage and display the affected zone on an LCD, but the system was wired and localized, with no remote alerting or GPS localization capability. Ajao et al. (2018) advanced

this line of work with an Internet of Things-enabled system using GSM and GPS to transmit sensor node positions and geographic coordinates as SMS alerts, though the prototype was tested over a short 10 m pipeline section and, like its predecessors, stopped at notification rather than physical isolation. Ofualagba and Ejofodomi (2020) proposed a geophone-based sensing unit combining an Arduino microcontroller, GSM/GPRS/GPS shield, and LoRa communication in a sealed anti-corrosion enclosure to detect the earth vibration signature of ground digging, improving field durability but again without an automated shutdown mechanism. Aba et al. (2021) and Aibinu et al. (2021) both explored Internet of Things platforms for pipeline monitoring, using pressure-pulse and flow-based sensing communicated to cloud platforms such as Thing Speak; these systems demonstrated the feasibility of low-cost, internet-connected monitoring but relied on continuous connectivity and, similarly, did not incorporate physical response mechanisms. Most recently, Ekeu-Wei and Ekeu-Wei (2024) validated the technical feasibility of a combined vibration-and-flow sensing approach using Arduino, GPS, and WiFi modules linked to the Thing Speak IoT platform, distinguishing operational leaks from vandalism-induced spillage and proposing a citizen-science-based field validation framework using KoboToolBox. However, this system likewise depended on constant internet connectivity for communication, lacked an autonomous power supply for remote deployment, and stopped at detection and alerting rather than automated isolation of the pipeline.

Across this body of work, a consistent gap emerges: existing low-cost prototypes are capable of detecting vandalism or leakage and communicating an alert, but none incorporate an automated physical response that isolates the pipeline without waiting for human intervention — a gap also

noted in the broader pipeline-monitoring literature (Adegboye et al., 2019). Several also depend on continuous internet connectivity for alert delivery, which is not reliably available along remote pipeline corridors, and none combine sensor-based detection with a structured community reporting channel for independent human confirmation. Separately, citizen-science and community-based reporting have been shown to be a viable complement to technical monitoring in the Niger Delta context, where Zabbey et al. (2021) demonstrated that community-driven environmental monitoring can meaningfully improve response to environmental incidents when integrated with technical detection systems. This study extends the existing low-cost detection literature by proposing an enhanced prototype that integrates sensor-based detection, automated shutdown and response via a fail-safe solenoid valve, GSM-based alerting that does not depend on internet connectivity, and a tollfree community reporting framework into a single hybrid human-machine surveillance ecosystem, addressing the need for a low-cost, proactive system that can detect intrusion-related activity in real time, operate independently in remote locations, and initiate rapid response to minimize losses.

The general objective of the study was to design, develop and validate a smart, low-cost petroleum pipeline vandalism monitoring and surveillance system. The specific objectives were to: (i) design and develop a low-cost, sensor-based pipeline monitoring prototype using vibration and flow sensors integrated with a microcontroller; (ii) develop a tollfree-based community reporting framework for post-detection confirmation and incident escalation; (iii) incorporate an automated response mechanism to isolate the pipeline upon confirmed vandalism or leakage; and (iv) test and validate the prototype's performance under simulated vandalism scenarios.

2. Methodoloav

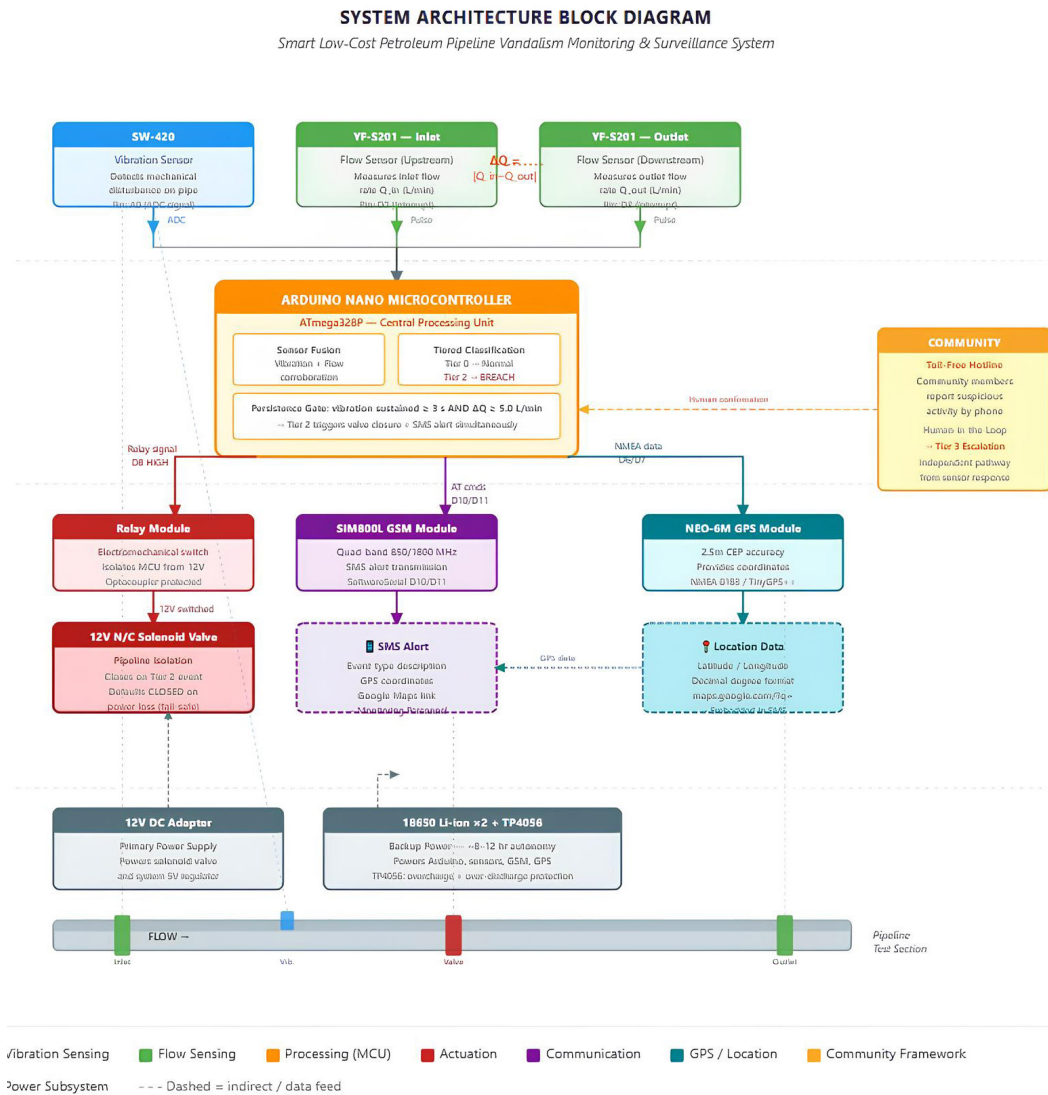


Figure 1. System Architecture Block Diagram

2.1 Research Approach

This study employed an experimental, design-based research methodology to design, construct, and validate the prototype. Knowledge was generated through iterative prototype development and controlled laboratory experimentation rather than surveys or secondary data analysis, consistent with established engineering design research practice. The methodology followed seven sequential phases with a feedback loop between testing and design refinement: (1) literature review and problem definition; (2) system design (hardware and software architecture); (3) prototype

development and assembly; (4) firmware coding of the sensor fusion algorithm; (5) community reporting framework design; (6) controlled experimental testing, looping back to phase 2 for threshold recalibration where performance metrics were not met; and (7) data analysis, results, and conclusions.

2.2 System Design and Sensor Fusion Approach

The prototype was designed using a modular embedded-systems architecture comprising four functional subsystems: (i) sensing — detection of physical anomalies at the pipeline; (ii) processing — execution of the sensor fusion and

decision-making algorithm; (iii) communication — transmission of alerts to monitoring personnel; and (iv) actuation — physical isolation of the pipeline upon confirmed breach. An Arduino Nano microcontroller forms the central processing unit, receiving inputs from the sensing subsystem, executing the tiered-response firmware, driving the GSM and GPS modules, and controlling the solenoid valve via a relay module.

Two detection mechanisms operate in parallel. A SW-420 vibration sensor mounted on the pipeline surface detects mechanical disturbances characteristic of tampering (hammering, drilling, sawing), reporting an analogue ADC

value (0–1023) rather than a binary trigger. The sensitivity potentiometer was calibrated to a vibration threshold corresponding to 30% of full sensor scale, empirically determined to discriminate tool-based impact from ambient disturbance; readings below 15% are classified Tier 0 (normal), 15–30% Tier 1 (warning), and above 30% a candidate Tier 2 trigger. A vibration event is confirmed only when the ADC reading continuously exceeds this threshold for a minimum of three consecutive seconds — a persistence gate empirically set because all tested environmental disturbances produced signals under one second while all genuine vandalism simulations exceeded five seconds. Independently, dual YF-S201 Hall-effect flow sensors at the pipeline inlet and outlet, connected to hardware interrupt pins to eliminate polling-related undercounting, continuously measure flow rate via the calibration $Q \text{ (L/min)} = \text{Pulse Count} \div 7.5$. The microcontroller computes the differential flow imbalance $\Delta Q = |Q_{\text{in}} - Q_{\text{out}}|$; a minor-anomaly threshold of 2.0 L/min and a confirmed breach threshold of 5.0 L/min were established through controlled calibration trials.

A standalone vibration sensor produces unacceptably high false-positive rates in field environments where traffic, machinery, and construction routinely generate detectable mechanical disturbance, while flow imbalance alone cannot reliably distinguish operational transients from a genuine breach. The sensor fusion algorithm therefore requires concurrent evidence from both mechanisms: a Tier 2 confirmed breach is declared only when persistent vibration ($\rightarrow 30\%$ for $\geq 3 \text{ s}$) and a flow imbalance $\Delta Q \geq 5.0 \text{ L/min}$ occur simultaneously. Table 1 summarizes the resulting four-tier classification and associated system response.

Table 1. Tiered Event Classification — Trigger Conditions and System Responses

Tier	Status	Trigger Conditions	System Response
0	Normal	No vibration, or vibration intensity $\leq 15\%$	Monitor only — no action
1	Suspicion	Vibration 15–30% (warning zone), or $\Delta Q \geq 2.0 \text{ L/min}$ without confirmed vibration	Log event with timestamp and readings; continue monitoring; no valve action
2	Sensor-Confirmed Breach	Vibration sustained $\rightarrow 30\%$ for $\geq 3 \text{ s}$ AND $\Delta Q \geq 5.0 \text{ L/min}$	Close solenoid valve via relay; transmit GPS-referenced SMS; latch valve-closed flag; log event
3	Human-Confirmed	Tier 2 event corroborated by a toll-free community report	Escalate to emergency response; dispatch field team; maintain valve closure pending inspection

2.3 Hardware Architecture, Actuation and Power

Table 2 summarizes the core hardware components. The SIM800L quad-band GSM module was selected over WiFi/4G alternatives because SMS operates over widely deployed 2G/EDGE cellular infrastructure, giving far greater coverage along remote pipeline corridors than broadband internet — directly addressing a limitation identified in Ekeu-Wei and Ekeu-Wei (2024). Each breach alert includes the event type, GPS coordinates from a NEO-6M module (TinyGPS++, 2.5 m CEP under open sky), and a Google Maps hyperlink; a firmware fallback transmits the alert even without a GPS fix to avoid delaying the safety-critical message. The relay module's optocoupler isolation protects the microcontroller from inductive switching transients generated by the solenoid coil. The 12 V normally-closed (N/C) solenoid valve is the cornerstone of the fail-safe design: it requires continuous power to remain open and defaults to the closed (safe) state on any power loss, whether from grid failure, battery depletion, or deliberate sabotage — meaning an adversary who cuts power to the node inadvertently triggers the isolation response they sought to prevent.

A dual 18650 lithium-ion battery bank (3.7 V/2600 mAh each, TP4056-managed) provides 8–12 hours of backup power for the sensing, processing and communication subsystems (excluding the valve) during grid interruption.

Table 2. Core Hardware Components and Functional Roles

Component	Subsystem	Function / Key Specification
Arduino Nano	Processing	ATmega328P central MCU; executes sensor fusion firmware and controls all peripherals
SW-420 vibration sensor	Sensing	LM393 comparator; analogue 0–1023 ADC output; adjustable sensitivity; detects mechanical tampering
YF-S201 flow sensor $\times 2$	Sensing	Hall-effect, 1–30 L/min, 7.5 pulses/litre; inlet/outlet flow for ΔQ imbalance computation
SIM800L GSM module	Communication	Quad-band 850/900/1800/1900 MHz; AT-command SMS alerts with GPS link
NEO-6M GPS module	Communication	2.5 m CEP accuracy; NMEA 0183; provides coordinates for breach alerts
Relay module (1-ch)	Actuation	Optocoupler-isolated; switches 12 V solenoid circuit from MCU logic level
12 V N/C solenoid valve	Actuation	Normally-closed fail-safe; isolates pipeline on Tier 2 event or power loss
18650 Li-ion $\times 2$ + TP4056	Power	3.7 V/2600 mAh each; ~ 8 –12 h backup autonomy for MCU and sensors

2.4 Community Reporting Framework and Automated Response

The community reporting layer operates as a Human-in-the-Loop complement, independent of the automated sensor response. An initial USSD-based design was adapted to a toll-free hotline model after evaluation showed USSD gateway fees and short-code licensing exceeded the project budget, whereas a toll-free number requires no internet access and is fully intuitive via voice call. Community members report suspicious activity — fuel odors, visible excavation, unauthorized personnel — by calling the designated number; reports are logged by a monitoring operator. A report corroborating an existing Tier 2 sensor alert from the same segment upgrades the incident to Tier 3 (Human Confirmed) and triggers formal escalation, while reports without a concurrent sensor alert are logged as Tier 1 for heightened monitoring. This ensures community intelligence supplements, but never delays, the automated physical protection response.

Upon a Tier 2 classification, the microcontroller drives the relay to energize the solenoid, closing the valve within less than one second,

and simultaneously constructs and transmits the SMS alert — both actions occur autonomously within the same firmware loop iteration. The Tier 2 response is a one-way latch: once triggered, valve closure persists regardless of subsequent sensor readings, preventing a vandal from pausing activity to force a system reset. Restoration of flow requires a deliberate manual reset by authorized personnel following physical inspection.

2.5 Experimental Testing and Validation

A structured battery of controlled experiments was conducted in a laboratory setting using a scaled PVC pipeline test section, enabling precise manipulation of test conditions while trading off representativeness of real outdoor field performance (addressed in Section 4, Limitations). Six performance metrics were evaluated: detection accuracy (10 vandalism trials via sustained hammering/sawing, plus 10 leakage trials via controlled tap opening, each independently confirmed by a second observer); system response time ($t_{\text{alert}} - t_{\text{event}}$ for all correctly detected trials); automated valve activation (four simultaneous vibration-plus-flow imbalance breach scenarios); false positive rate (12 non-threat trials

— knocking, door slams, footsteps, incidental pipe contact, and similar); communication reliability (ten Tier 2 alert-generation trials monitored for SMS delivery, delivery time, and inclusion of GPS/Maps data); and fail-safe behavior (deliberate power disconnection during normal operation). Detection accuracy and false positive rate were computed as the percentage of correct outcomes over total trials, and average response time as the mean of ($t_{\text{alert}} - t_{\text{event}}$) across all valid detection trials; communication and valve-activation reliability were reported as success rates over their respective trial sets, and fail-safe behavior was assessed qualitatively by observed valve state and restart behavior.

3. Results and Discussion

3.1 Prototype Implementation

The prototype was assembled and bench-verified prior to formal testing: both YF-S201 sensors returned consistent flow readings under controlled flow, the vibration sensor produced stable at-rest ADC baselines, GPS fix acquisition succeeded indoors under partial signal, AT-command handshaking with the SIM800L module succeeded, and the solenoid valve opened and closed reliably in response to relay signals, confirming readiness for formal experimental testing.

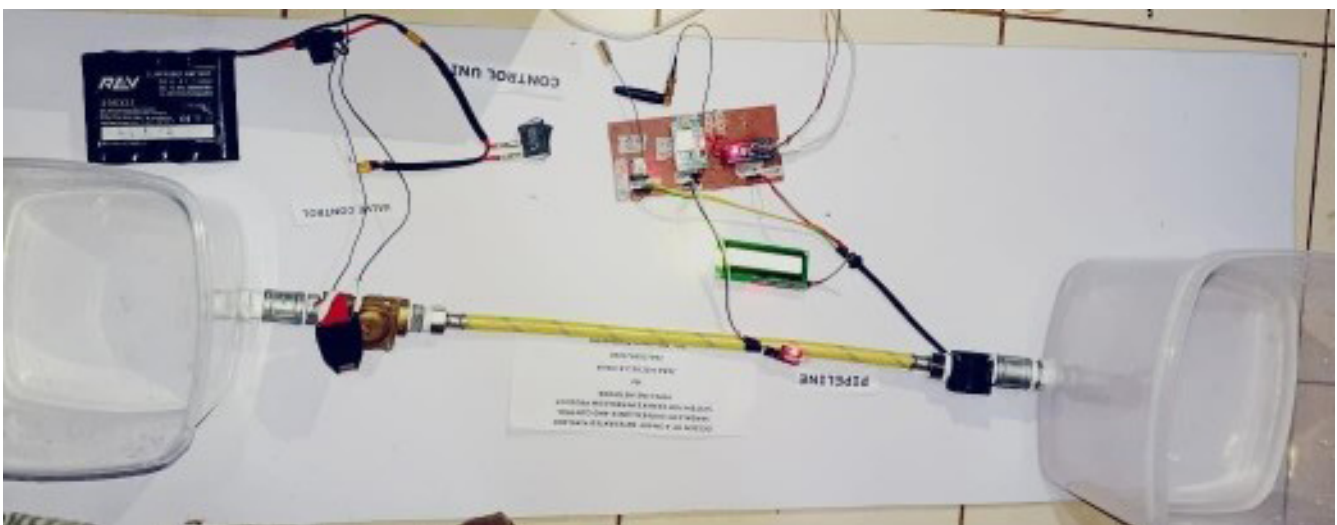


Figure 2. Assembled Prototype on the PVC Pipeline Test Section

3.2 Detection Accuracy

All ten vandalism trials (simulated by sustained hammering or sawing on the pipe) were correctly detected and classified, a 100% vandalism detection rate. Recorded vibration intensities ranged from 55.0% to 88.9% of full ADC scale — well above the 30% threshold, providing a comfortable detection margin — and durations of 3–12 seconds, with every detected event exceeding the three-second persistence gate. Of ten leakage trials, nine were correctly detected (90%); the single miss (Trial 10) occurred because the induced tap opening generated a ΔQ below the 2.0 L/min minor-anomaly threshold, classifying the event as Tier 0. This reflects a threshold-sensitivity limitation rather than a system malfunction: the threshold is deliberately set to avoid false positives from ordinary operational flow noise, so a very small, slow leak may not generate a signal large enough to clear it. Across all 20 trials, 19 were correctly detected and classified, an overall detection accuracy of 98% (19/20), exceeding the 90% target established for the prototype.

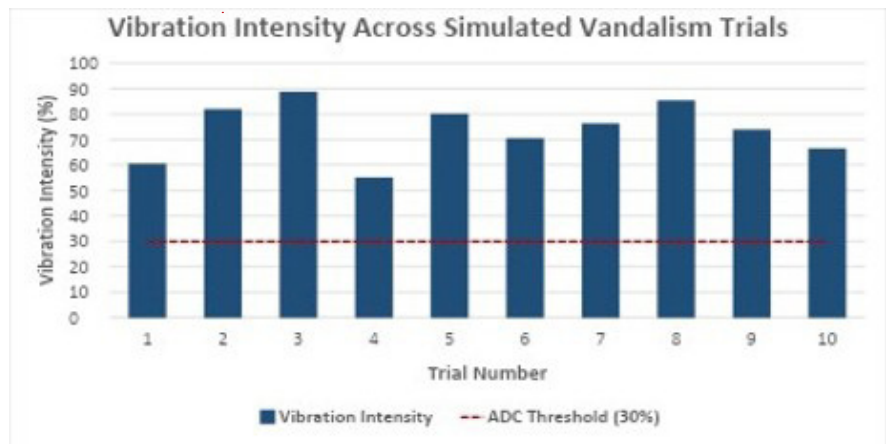


Figure 3. Vibration Intensity Recorded Across the Ten Simulated Vandalism Trials, Relative to the 30%

ADC Threshold

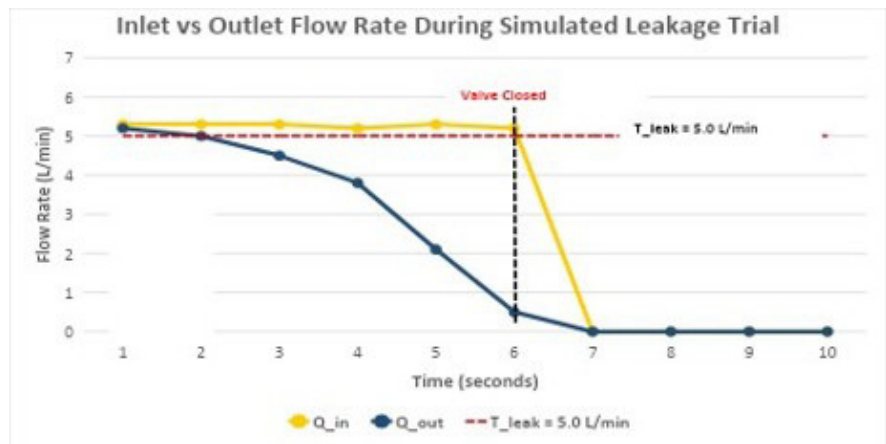


Figure 4. Inlet vs. Outlet Flow Rate During a Simulated Leakage Trial, Showing Valve Closure on Crossing the 5.0 L/min Threshold

3.3 System Response Time

Response time — the interval between disturbance onset (t_{event}) and SMS receipt (t_{alert}) — was recorded for all ten correctly detected trials and ranged from 3 to 5 seconds, with a mean of 4.0 seconds. Vibration-triggered events (3–4 s) were marginally faster than leakage events (4–5 s), plausibly because the three-second vibration persistence gate resolves confirmation earlier in the event timeline than the flow-differential accumulation required for leakage classification. Trial-to-trial variation is attributable to GSM transmission latency, microcontroller AT-command processing overhead, and the one-second loop sampling interval, which introduces up to one second of quantization delay. A 4.0-second average

response represents a substantial improvement over SCADA-based monitoring, which typically requires sustained anomaly accumulation over tens of seconds to minutes, and over manual patrol-based detection, which may take hours.

3.4 Automated Valve Activation

In all four confirmed-breach trials (simultaneous vibration and flow imbalance of $\Delta Q = 6.1$ – 9.3 L/min), the solenoid valve activated successfully, a 100% valve activation reliability. Physical observation confirmed flow ceased within less than one second of relay triggering in each trial, and the dashboard's displayed valve state matched the physical valve state in all four cases, confirming that detection, classification, and isolation occur within a single monitoring cycle and that the valve closed latch correctly

prevents duplicate activation events.

3.5 False Positive Rate

No false alarms were generated across the 12 non-threat trials (knocking, door slams, footsteps, table/chair movement, light tapping, incidental pipe contact, and dropped objects), a 0% false positive rate. This confirms that the vibration persistence gate and dual-sensor fusion requirement, operating together, effectively filter environmental disturbances of the type tested: their ADC amplitudes were either below threshold or, where above, not sustained for three consecutive seconds, and none generated a concurrent flow imbalance sufficient to escalate to Tier 2. This 0% rate under controlled conditions is a strong result, though the 12 scenarios tested are a subset of real field disturbances; sustained

sources such as road traffic or agricultural machinery operating for extended periods could, in principle, trigger the persistence gate outdoors, a constraint discussed further in Section 4 (Limitations).

3.6 Communication Reliability

Nine of ten Tier 2 SMS alerts were successfully delivered (90%), with GPS coordinates and a Google Maps link included in 100% of successful transmissions. The single failure (Trial 10) coincided with a temporary drop in GSM signal strength; no hardware or firmware fault was identified, and an immediate repeat of the trial under identical conditions transmitted successfully, confirming the transient nature of the failure. Average delivery time across successful transmissions was consistent with normal GSM latency (approximately 1–2 seconds of the total response time). The 10% failure rate attributable to signal instability highlights a genuine operational vulnerability for remote deployments where cellular coverage is less reliable than in the laboratory, motivating the recommendation (Section 5) for redundant communication channels such as LoRa or satellite messaging.

3.7 Fail-Safe Behavior

In three independent trials simulating an adversary cutting the monitoring node's power supply during normal operation, the solenoid valve immediately returned to its default closed position in all three cases, while the Arduino Nano and sensor modules continued operating from battery backup. On restoration of primary power, the system reinitialized and resumed normal monitoring in every trial, with no data corruption or abnormal behavior observed. These results confirm that the fail-safe design achieves its intended outcome: an adversary cutting power closes the pipeline valve rather than disabling protection.

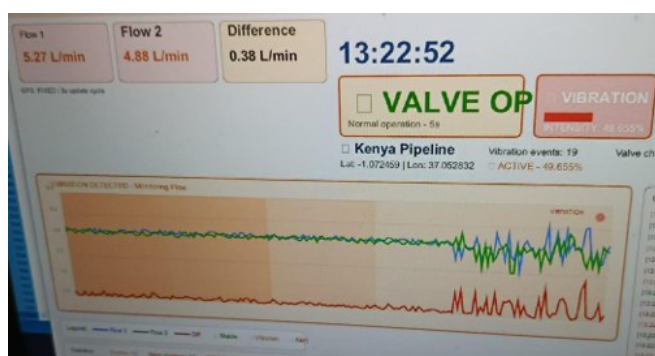


Figure 5. Live Monitoring Dashboard Showing a Vibration Event (49.7% Intensity) with the Valve Remaining Open, Illustrating the Warning State Prior to Flow-Imbalance Confirmation

3.8 Overall Performance Summary

Table 3. Consolidated Performance Summary — Achieved Values vs. Targets

Performance Metric	Result	Achieved	Target
Detection accuracy	19/20 trials correct	98%	90%
Vandalism detection rate	10/10 correct	100%	90%
Leakage detection rate	9/10 correct	90%	90%
Average system response time	Mean 4.0 s; range 3–5 s	4.0 s	← 10 s
Automated valve activation rate	4/4 confirmed breach trials	100%	100%
False positive rate	0/12 non-threat trials triggered	0%	← 5%
SMS communication reliability	9/10 alerts delivered	90%	90%
Fail-safe behaviour (power loss)	Valve defaulted closed in all trials	Pass	Pass

The prototype met or exceeded its performance targets across every evaluated metric, collectively validating dual sensor fusion with vibration persistence gating as an effective approach to low-cost pipeline vandalism and leakage detection under the tested conditions.

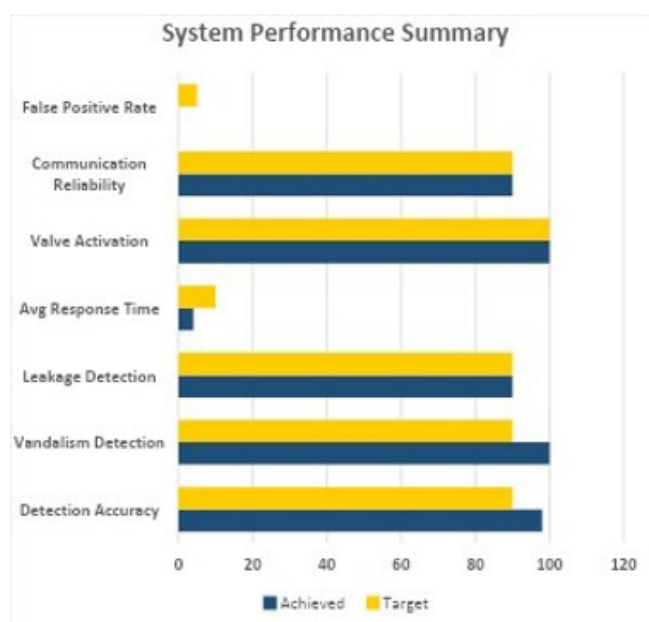


Figure 6. System Performance Summary — Achieved vs. Target

3.9 Discussion

The 98% overall detection accuracy is the most significant outcome, directly validating the primary project objective. The perfect vandalism detection rate demonstrates that the persistence gate is well-calibrated — it rejected all 12 nonthreat disturbances while capturing every genuine tampering simulation, including the lowest-intensity event (55.0% ADC, roughly 6 percentage points above threshold), indicating robust sensitivity without excessive conservatism. The single missed leakage detection reflects a genuine limitation of threshold-based detection for slow, gradual microleaks; in practice, however, illegal tapping typically creates openings large enough for economically viable extraction, generating flow imbalances substantially above the 5.0 L/min threshold, so the calibration remains appropriate for the primary threat scenario while acknowledging reduced sensitivity to incipient micro-leaks.

Compared with prior work, the 98% detection accuracy compares favorably with Ekeu-Wei and Ekeu-Wei (2024) and Ajao et al. (2018), neither of whom reported a quantified accuracy figure from a systematic, independently observed set of controlled trials; the present study's structured framework of 20 detection trials, 12 false-positive trials, and 10 communication trials represents a methodological advance in evaluation rigour for low-cost pipeline monitoring prototypes, extending the largely qualitative or single-demonstration validation approach used by Ofualagba and Ejofodomi (2020), Aba et al. (2021), and Aibinu et al. (2021). The 4.0-second mean response time improves on SCADA-based latency, which typically requires anomaly accumulation over tens of seconds to minutes (Adegboye et al., 2019), and is achieved without the fiber-optic infrastructure required by distributed acoustic sensing approaches (Yu et al., 2009). Automated valve closure further distinguishes this prototype

from earlier academic systems (Ezeh et al., 2014; Ogujor et al., 2013; Ajao et al., 2018; Ofualagba & Ejofodomi, 2020; Aba et al., 2021; Aibinu et al., 2021; Ekeu-Wei & Ekeu-Wei, 2024), none of which incorporate an automated physical response, instead stopping at detection and alert notification. The toll-free community reporting layer also operationalizes, in a low-cost pipeline-security context, the broader case made by Zabbey et al. (2021) that community-based reporting can meaningfully strengthen technical environmental monitoring in the Niger Delta. This work therefore advances beyond prior contributions by integrating sensor-confirmed detection, immediate autonomous valve closure, GPS-referenced alert communication that does not depend on internet connectivity, and a community engagement framework into a single, cohesive, low-cost system — a more complete and operationally practical solution than has previously been demonstrated in low-cost academic prototypes.

3.10 Cost Comparison

A central motivation for this study is affordability relative to conventional pipeline monitoring technologies. The prototype's bill of materials — an Arduino Nano, SW-420 vibration sensor, dual YF-S201 flow sensors, SIM800L GSM module, NEO-6M GPS module, relay module, 12 V solenoid valve, and dual 18650 battery pack with charge controller — totals approximately \$70–100 per monitoring node at typical retail component prices, excluding enclosure and installation labor. This compares favorably with distributed acoustic sensing (DAS) systems, whose interrogator units alone typically cost between \$150,000 and \$500,000 per unit, in addition to specialized fibre-optic cable costing approximately \$3–7 per metre, before installation. It is also substantially lower than the cost of periodic pipeline inspection by intelligent pigging, estimated at up to \$56,000 per kilometer (Aba et al., 2021). Even accounting for the

fact that a single DAS interrogator can continuously monitor tens of kilometers of pipeline whereas the proposed system is deployed as discrete point nodes — meaning the comparison is illustrative rather than a like-for-like cost-per-kilometer calculation — the difference in capital outlay is large enough to make sensor-node monitoring a realistic option for operators and communities that cannot justify DAS or SCADA investment, particularly across the shorter, high-risk segments of pipeline most exposed to illegal tapping. A full cost-benefit analysis incorporating node density, installation labour, and multi-year maintenance costs is recommended as future work before large-scale deployment is costed.

4. Limitations

Several limitations should be considered when interpreting these results. All testing was conducted in a controlled indoor laboratory using a scaled PVC pipeline test section, so performance on steel pipelines or under real outdoor field conditions — including temperature extremes, soil vibration, and weather exposure — may differ. GSM communication reliability may also be lower in remote deployments with consistently weaker cellular signal than observed in the laboratory environment, and the 8–12-hour battery backup autonomy is insufficient for long-term unattended remote operation without a renewable energy source. The USSD-based community reporting framework originally proposed could not be implemented within project scope due to the cost and institutional requirements of telecom-provider partnerships, and was replaced with the toll-free hotline design ultimately adopted and tested. Finally, the controlled false-positive trials ($n = 12$) and leakage-detection thresholds were validated against a defined set of simulated disturbances; sustained field disturbances such as prolonged traffic or machinery vibration, or very slow micro-leaks, were not represented in the test

set and may behave differently on deployment. The sample sizes used across all trial sets ($n = 10, 12, 4$, and 3) are consistent with a proof-of-concept prototype validation but are too small to support statistically powered claims; larger-scale field trials would be required to establish confidence intervals around the reported performance metrics.

5. Recommendations for Future Work

Several directions for future work would strengthen the system ahead of field deployment. Integrating a solar-powered charging system with the existing battery bank would support long-term autonomous operation and reduce reliance on manual battery replacement in

remote locations, while distributed multi-node deployment at strategic intervals along extended pipeline networks would increase coverage and improve localization of vandalism or leakage incidents relative to the single-node prototype tested here. Large-scale field testing under real environmental conditions — including temperature variation, soil vibration, weather, and communication fluctuation — is needed to refine threshold calibration and confirm reliability outside the controlled laboratory setting, and interfacing the monitoring unit with existing industrial SCADA platforms would allow real-time operational data to be combined with intrusion detection alerts for improved pipeline management.

Adding redundant communication channels such as LoRa or satellite messaging alongside GSM/SMS would help maintain alert delivery in areas with weak or unstable cellular coverage, addressing the single communication failure observed in this study. Finally, pursuing telecom-provider partnerships to implement the originally proposed USSD-based reporting channel would extend accessible community participation beyond the toll-free hotline implemented here, and a formal cost-benefit analysis incorporating node density and multi-year maintenance costs would help quantify the system's economic case for prospective adopters.

6. Conclusion

This study successfully designed, developed, and experimentally validated a smart, low-cost petroleum pipeline vandalism monitoring and surveillance prototype integrating a SW-420 vibration sensor, dual YF-S201 flow sensors, a SIM800L GSM module, a NEO-6M GPS module, a relay-actuated normally-closed solenoid valve, and a lithium battery backup, coordinated by an Arduino Nano executing a sensor fusion and tiered-response algorithm, complemented by a toll-free community reporting hotline operating as a Human-in-the-Loop layer. All four specific objectives were met: a sensor-based detection prototype was built and validated, a community reporting framework was developed, an automated isolation mechanism was incorporated, and prototype performance was evaluated across six quantitative metrics, achieving 98% overall detection accuracy, a 4.0-second mean response time, 100% automated valve activation reliability, a 0% false positive rate, and 90% SMS communication reliability — all meeting or exceeding defined targets. Whereas prior low-cost prototypes (Ezeh et al., 2014; Ogujor et al., 2013) offered alerting without physical response, and others (Ajao et al., 2018; Ekeu-Wei & Ekeu-Wei, 2024) demonstrated detection feasibility without automated isolation, this prototype integrates sensor-confirmed detection, autonomous valve closure, GPS-referenced communication, and community engagement into a single system, representing a more complete and operationally practical approach to low-cost pipeline vandalism surveillance.

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Pictorials



Eng. Kefa Seda, Director General, Public-Private Partnerships (PPP), representing the Chief Guest, Hon. FCPA John Mbadi Ng'ongo, EGH, CBS, Cabinet Secretary, National Treasury and Economic Planning, delivers the keynote address on "The Role of Engineers in Economic and Fiscal Planning" during the official opening of the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, Nairobi, on 30th July, 2026.



Prof. James Kungu, representing the Vice Chancellor of Kenyatta University, Prof. John Okumu, Ph.D., KNAS, delivers remarks during the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, emphasizing the role of research, innovation, and academia-industry collaboration in advancing circular economy solutions, resource efficiency, and sustainable development.



Eng. Prof. Lawrence Gumbe, Chairperson, Nuclear Power and Energy Agency (NuPEA), delivers the closing address at the 2nd AJERI Scientific Conference, calling for increased funding for local innovation, greater ownership of Africa's engineering agenda, and research that delivers tangible solutions in transport, healthcare, agriculture, and industry.

He commended the high quality of presentations and spirit of collaboration before officially declaring the conference closed. The conference concluded with a renewed call to transform engineering research into impactful solutions for Africa's sustainable development.



Eng. Hillary J. Nyaanga, CE, FIEK, MACEK, Chairperson, Caretaker Committee, IEK, delivers his remarks during the official opening of the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, Nairobi. His address underscored the role of engineering innovation, research, and collaboration in advancing a circular economy and promoting efficient and sustainable resource use.



Eng. Prof. Alex Munyasya Muumbo, Chairperson, IEK Editorial Board, delivers his remarks during the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, emphasizing the importance of engineering research, knowledge dissemination, and scholarly publishing in advancing innovation, resource efficiency, and sustainable engineering solutions.



Aarti Shah, CEO, Co-REGEN and panelist, contributes to the panel discussion on "The Role of Engineers in Economic and Fiscal Planning" during the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, sharing insights on how engineering expertise, innovation, and sustainable solutions can inform economic planning and drive resource-efficient development.



Elizabeth Wokabi, Engineering Principal, Linden Hof Limited and panelist, contributes to the panel discussion on "The Role of Engineers in Economic and Fiscal Planning" during the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, highlighting the importance of engineering expertise, innovation, and practical solutions in shaping sound economic planning and promoting sustainable resource use.



Eng. Dr. Lucas Mogaka, Treasurer, IEK Editorial Board, serves as the Master of Ceremonies and Moderator during Day One of the 2nd African Journal of Engineering Research and Innovation (AJERI) Scientific Conference at Kenyatta University, guiding the proceedings and facilitating meaningful engagement on engineering research, innovation, sustainability, and resource efficiency.



Eng. Dr. Caroline Matara, Secretary of the Editorial Board, delivers the closing remarks at the 2nd AJERI Conference, paying tribute to the former IEK Editorial Board for their visionary leadership, dedication, and pioneering role in establishing AJERI as a platform for advancing and sharing engineering research. She acknowledged their lasting legacy as the foundation upon which AJERI continues to grow and thrive.



Eng. Dr. Roy Orenge, Technical Editor, AJERI, delivers a plenary presentation during the 2nd AJERI Scientific Conference, providing insights into the **peer-review process for submitted manuscripts** and highlighting the **guidelines for authors** preparing papers for publication in the AJERI journal and presentation at the Scientific Conference. His session emphasized the importance of quality, integrity, and adherence to established publication standards in advancing engineering research.



From left: **Eng. Ekakoro Elizabeth Nabwire** and **Eng. Gladwell Wanjiku Nganga**, members of the IEK Editorial Board, served as **Session Chair and Assistant Session Chair**, respectively, during the breakaway sessions of the 2nd AJERI Scientific Conference. In their respective roles, they guided the proceedings, facilitated presentations and discussions, and supported meaningful engagement between researchers, practitioners, and participants.

Their contribution helped maintain productive dialogue and ensured that emerging research, engineering innovations, and practical solutions were effectively shared, discussed, and connected to the broader objectives of advancing engineering research and innovation.



Prof. Ezekiel Mugendi Njeru, representing DVC-RIO, **Prof. Caroline Thoruwa**, during the Closing Ceremony. He had the privilege of presenting the Certificate of Service to the Immediate Chairperson of the IEK Editorial Board and Chief Guest at the Closing Ceremony, Eng. Prof. Lawrence Gumbe, Chairman of the Nuclear Power and Energy Agency (NuPEA).



Joseph Anvar Alot, Policy Research and Partnership Manager, IEK, welcomes Eng. Barbara Adhoch, Chief Executive Officer, Association of Consulting Engineers of Kenya (ACEK), during the 5th ACEK Annual Conference 2026 at Sawela Lodge, Naivasha. The engagement reflects the continued collaboration between IEK and ACEK in advancing the engineering profession, promoting knowledge exchange, and strengthening partnerships within Kenya's engineering sector.



Eng. Barbara Adhoch, CEO, Association of Consulting Engineers of Kenya (ACEK), receives Engineering in Kenya Magazine (EiK) Issue 27: Women in Engineering from **Leonard Kigen, Publications Officer, IEK**, during the **5th ACEK Annual Conference 2026** at Sawela Lodge, Naivasha.

In this edition, Eng. Adhoch highlights **the future of consulting engineering in Kenya, key challenges, opportunities, and the growing influence of women in the profession.**



Eng. Barbara Adhoch, CEO, ACEK, proudly displays her featured article in EiK Issue 27, highlighting the future of consulting engineering in Kenya, key challenges and opportunities, and the growing influence of women in the profession, during the 5th ACEK Annual Conference 2026 held at Sawela Lodge, Naivasha.



From left: **Eng. J.R. Otieno Ogallo**, 2nd Vice President, IEK; **Eng. Harrison Kiplimo Keter**, President, IEK; **Eng. Maureen Victoria Auka**, Chief Executive Officer, IEK; and **Eng. Howard Ashihundu M'Mayi**, 1st Vice President, IEK, pose for a group photograph during the 5th ACEK Annual Conference 2026 held at Sawela Lodge, Naivasha.



Eng. Harrison Kiplimo Keter, President, IEK, delivers his remarks during the 5th ACEK Annual Conference 2026 at Sawela Lodge, Naivasha, highlighting the pivotal role of engineers in driving green growth, advancing smart infrastructure, and building resilient futures through innovation, sustainability, and strategic investment.



Eng. Howard Ashihundu M'Mayi, 1st Vice President, IEK, delivers his remarks during the 5th ACEK Annual Conference 2026 at Sawela Lodge, Naivasha, emphasizing the need for collaborative engineering solutions, sustainable infrastructure development, and innovative approaches to address emerging challenges and accelerate Kenya's transition towards a resilient and green economy.



Eng. Harrison Kiplimo Keter, President, IEK, and **Eng. Maureen Victoria Auka**, Chief Executive Officer, IEK, during a photo session following her remarks at the 3rd Future Leaders Summit, held during the 5th ACEK Annual Conference 2026 at Sawela Lodge, Naivasha.



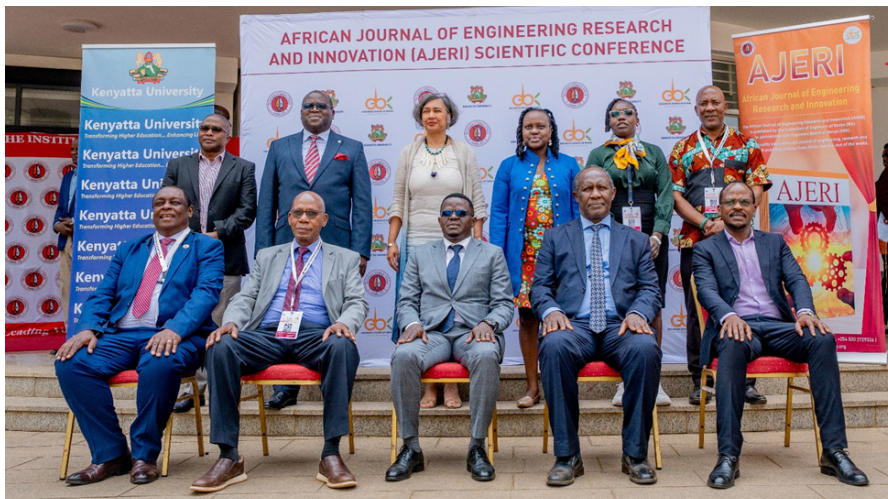
Mr. Davis Chirchir, EGH, Cabinet Secretary, Ministry of Roads and Transport, is presented with a copy of the latest edition of Engineering in Kenya (EiK) Magazine by **Eng. Harrison Kiplimo Keter**, President, IEK; at the IEK exhibition booth during the 5th ACEK Annual Conference 2026, held at Sawela Lodge, Naivasha.



Mr. Davis Chirchir, EGH, Cabinet Secretary, Ministry of Roads and Transport, joins **Eng. Gabriel Jabongo**, CE, FIEK, President, ACEK; **Eng. Harrison Kiplimo Keter**, President, IEK; **Eng. Joseph Mbugua**, Principal Secretary for Roads; **Eng. Howard Ashihundu M'Mayi**, 1st Vice President, IEK; **Eng. Hillary J. Nyaanga**, CE, FIEK, MACEK; **Eng. J.R. Otieno Ogallo**, 2nd Vice President, IEK; **Eng. Jane Mutulili**, Immediate Past President, ACEK; and **Eng. Fanuel Kiwinga Mwashigadi**, alongside other ACEK Council representatives, for a group photograph during the 5th ACEK Annual Conference 2026, held at Sawela Lodge, Naivasha.

AJERI SCIENTIFIC CONFERENCE 2026 PICTORIALS

DAY ONE



Eng. Kefa Seda, Director General, Public–Private Partnerships (PPP), representing the Chief Guest, **Hon. FCPA John Mbadi Ng’ongo, EGH, CBS**, Cabinet Secretary, National Treasury and Economic Planning, delivers the keynote address on *“The Role of Engineers in Economic and Fiscal Planning”* during the official opening of the **2nd AJERI Scientific Conference** at Kenyatta University, Nairobi, on 30 July 2026.

Following the opening ceremony, Eng. Seda joined the **Chairperson, Caretaker Committee; Eng. Hillary J Nyaanga, CE, FIEK, MACEK, Chairperson IEK Editorial Board; Eng. Prof. Alex Muumbo, PE, FIEK, Prof. James Kungu, Dr. Paul Magutu Njaria;** and other members of the **AJERI Sub-Committee** for a commemorative photo, marking the successful commencement of the conference and celebrating the collaborative leadership behind AJERI’s continued growth as a platform for engineering research and innovation.





Eng. Kefa Seda, Director General, Public-Private Partnerships (PPP), representing the Chief Guest, **Hon. FCPA John Mbadi Ng'ongo**, EGH, CBS, Cabinet Secretary, National Treasury and Economic Planning, receives copies of **AJERI journal publications** from **Eng. Hillary J. Nyaanga**, CE, FIEK, MACEK, Chairperson, Caretaker Committee, during a visit to the **IEK Exhibition Booths** at the **2nd AJERI Scientific Conference** held at Kenyatta University, Nairobi, on 30th July, 2026.

The presentation highlighted AJERI's role in promoting engineering research, innovation, and knowledge dissemination, while showcasing the Institution's commitment to advancing impactful engineering scholarship.

AJERI SCIENTIFIC CONFERENCE 2026 PICTORIALS

DAY TWO



Eng. Prof. Lawrence Gumbe, Chairperson, Nuclear Power and Energy Agency (NuPEA), joins members of the IEK Editorial Board and **2nd AJERI Scientific Conference Sub-Committee** for a group photograph following the closing ceremony of the **2nd AJERI Scientific Conference** at Kenyatta University, Nairobi.

Eng.Prof. Gumbe delivered the closing address, calling for increased investment in local innovation, greater ownership of Africa's engineering agenda, and research that translates into practical solutions in transport, healthcare, agriculture, and industry. The commemorative photograph captures the collective commitment of the conference leadership and organizing team to advancing engineering research, innovation, and sustainable development across Africa.





IEK AGM 2026: Celebrating Legacy, Embracing New Leadership

Daystar University | 19th August, 2026



Eng. Harrison Kiplimo Keter takes the oath of office as President of the Institution of Engineers of Kenya (IEK) for the 2026–2028 term during the official swearing-in ceremony at the IEK Annual General Meeting (AGM) 2026, held at Daystar University on 19th August, 2026.



Eng. John Robert Otieno Ogallo takes the oath of office as 2nd Vice President of the Institution of Engineers of Kenya (IEK) during the official swearing-in ceremony at the IEK Annual General Meeting (AGM) 2026, held at Daystar University on 19th, August 2026.



Eng. Ingaiza Annette Murambi takes the oath of office as Honorary Treasurer during the official swearing-in ceremony at the IEK Annual General Meeting (AGM) 2026, held at Daystar University on 19th August, 2026.



The newly sworn-in IEK President, **Eng. Harrison Kiplimo Keter**, poses for a photo with the Immediate Past President, **Eng. Shammah Kiteme** CE, FIEK, PMP, following the official swearing-in ceremony during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19th August, 2026.



Eng. Grace Muthoni Kagundu, PE, FIEK, Honorary Secretary, takes the oath of office during the official swearing-in ceremony at the IEK Annual General Meeting (AGM) 2026, held at Daystar University on 19th August, 2026.



The Treasurer, Caretaker Committee, **Eng. Fanuel Kiwinga Mwashigadi, PE, MIEK** presents the certificate to **Eng. Howard Ashihundu M'Mayi**, 1st Vice President, following his election to serve for the 2026–2028 term. The presentation took place during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19th August, 2026.



Chairperson, Caretaker Committee, **Eng. Hillary J. Nyaanga, CE, FIEK, MACEK**, presents the certificate to the newly elected IEK President, **Eng. Harrison Kiplimo Keter**, following his election to serve for the 2026–2028 term. The presentation took place during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19 August 2026.



Eng. Shammah Kiteme CE, FIEK, PMP, Immediate Past President (2024–2026), addresses members during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19 August 2026, reflecting on the key milestones, achievements and accomplishments of the IEK Council during the 2024–2026 term.



Eng. Muguru Wairimu, PE, MIEK, Secretary, Caretaker Committee, presents the Caretaker Committee's report, highlighting its key achievements and milestones during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19 August 2026.



The Honorary Treasurer, **Eng. Jeniffer Korir** (2024–2026), presents the IEK financial report during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19 August 2026, highlighting the Institution's financial performance and key financial milestones achieved during the 2024–2026 term.



Members of the newly sworn-in IEK Council 2026–2028 pose for a group photo following the official swearing-in ceremony during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19th August, 2026, marking the beginning of a new term of leadership and service to the engineering profession.



Members of the Future of IEK initiative, representing various universities across Kenya, pose for a group photo with the newly sworn-in IEK President, Eng. Harrison Kiplimo Keter, during the IEK Annual General Meeting (AGM) 2026 at Daystar University on 19th August, 2026.

Student Voices



Joe Kariuki Mumo, 23 years
Egerton University

Designation: (Chairperson,
Egerton engineering students'
association (EESA))

Course: BSc. Agricultural
engineering

Year of Study: 5th year.

Geospatial Engineering is increasingly becoming an important part of Kenya's development, influencing how we understand, plan and manage the spaces around us. From agriculture and infrastructure to urban development and environmental management, geospatial technologies are providing information that supports better decisions.

Through Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), remote sensing, satellite imagery and drone technology, geospatial engineering enables the collection, analysis and visualization of information about the Earth's surface. In agriculture, these technologies support precision farming, irrigation planning, crop monitoring and land-use analysis. In urban areas, they can improve transport planning, infrastructure development and the management of public services.

The growth of smart cities further demonstrates the potential of geospatial engineering. Spatial data can help cities understand population growth, monitor infrastructure, manage traffic and plan services more effectively. However, Kenya's transition towards spatially intelligent cities will require reliable data, appropriate digital infrastructure, skilled professionals and policies that promote inclusive and responsible use of technology.

Geospatial engineering is also playing an important role in understanding climate change. Satellite data can monitor vegetation, water resources, forests, agricultural conditions and changes in land cover over large areas. When combined with ground-based information, this data can support drought monitoring, environmental conservation, climate-risk assessment and better management of natural resources.

At the same time, the profession is creating new opportunities for young engineers. The future geospatial engineer will need skills beyond traditional mapping, including spatial data analytics, programming, artificial intelligence, cloud computing, 3D modelling and drone applications. These skills can open opportunities in agriculture, construction, mining, environmental management, transportation, water resources and urban planning.

With these opportunities come responsibilities. Spatial data can reveal sensitive information about people, properties and movements, making privacy, data security, ownership and accuracy important ethical considerations. Geospatial professionals must therefore combine technical competence with responsible data management.

As Kenya becomes increasingly data-driven, Geospatial Engineering will continue to evolve from simply mapping places to helping society understand, predict and manage change.

The future is not only about knowing where things are, but understanding what is happening there, why it is happening, and how better decisions can be made.

The Rise of Smart Cities: Is Kenya Ready for a Spatially Intelligent Future?

Kenya is steadily moving towards a smarter urban future, driven by technology, innovation and data. With the first phase of Konza Technopolis nearing completion, the country is demonstrating how digital infrastructure, education, research and innovation can support modern urban development. Private and county-led projects such as Tatu City and developments in Thika Town further demonstrate the growing interest in smart-city solutions.

But what makes a city smart, and is Kenya ready for a spatially intelligent future?

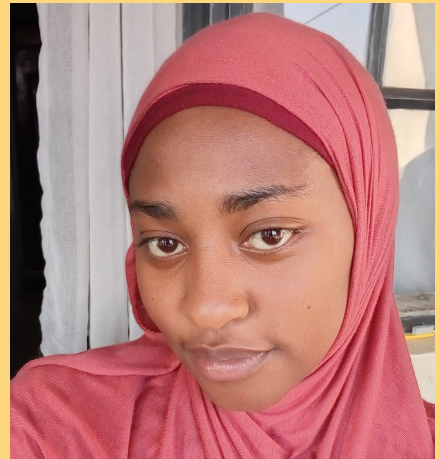
A smart city is built around seven interconnected pillars. Smart people promote social inclusion, digital literacy, education and lifelong learning, ensuring that citizens can participate in the digital economy. Smart living focuses on health, safety, housing and quality of life, areas where Kenya continues to face challenges such as low health insurance uptake and insecurity.

Smart economy promotes innovation, entrepreneurship, productivity and competitiveness, while smart environment uses technology and spatial data to manage natural resources, waste, forests and environmental risks. Smart mobility seeks efficient, connected and sustainable transportation. Kenya's growing adoption of electric motorcycles and bicycles demonstrates potential for cleaner urban mobility.

Smart infrastructure integrates sensors, software and real-time connectivity into roads, buildings, energy and water systems, enabling better monitoring and maintenance. However, unequal access to electricity, internet connectivity and digital devices remains a major barrier. Smart governance uses digital services, data and citizen participation to make public administration more transparent, efficient and responsive.

Geospatial engineering provides the foundation linking these pillars. Geographic Information Systems, surveying, remote sensing and spatial data enable planners, engineers, architects and policymakers to understand urban growth, manage infrastructure and make evidence-based decisions.

Kenya can achieve smart cities, but success will require investment in infrastructure, financing, digital inclusion, skills, reliable spatial data and supportive policies. The goal should not simply be technologically advanced cities, but inclusive, sustainable and spatially intelligent cities that improve the lives of all Kenyans.



Maria Mburu, 22yrs
Kenyatta university
Course: Aerospace engineering
Year of Study: 3rd year

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