FIRST WEST AFRICAN INTERNATIONAL WORKSHOP ON COASTAL LAND SUBSIDENCE

THEME:

Coastal Land Subsidence in Africa: the Emerging Trends

4th to 8th November 2024
University of Ghana
Accra - Ghana

FINAL REPORT

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PREFACE

This report for the First West African International Workshop on Coastal Land Subsidence, hosted by the University of Ghana in Accra captures the essence of the workshop. The workshop brought together researchers, policymakers, practitioners, and stakeholders to address one of West Africa's most pressing environmental challenges: the irreversible loss of coastal areas due to subsidence.

Within this report, you will find a comprehensive synthesis of keynote lectures, technical presentations, and collaborative dialogues that highlight emerging research, innovative monitoring techniques, and actionable strategies to mitigate the impacts of coastal land subsidence. The workshop underscored the interconnected threats of subsidence and sea-level rise, particularly in vulnerable low-lying coastal regions.

This initiative marks a pivotal step toward fostering regional resilience. By bridging scientific expertise, policy frameworks, and community-driven solutions, the workshop exemplified the power of interdisciplinary collaboration. We extend our deepest gratitude to the University of Ghana for hosting this landmark event; the French Development Agency (AFD) for funding it; and the local/international planning committee, presenters, panellists, and participants whose contributions shaped this collective effort.

Together, we advance toward a future where coastal zones are safeguarded through knowledge, innovation, and shared commitment.

Signed
ENGULF Team

EXECUTIVE SUMMARY

The First West African International Workshop on Coastal Land Subsidence (4th–8th November 2024), a key deliverable of the ENGULF Project (*Coastal Land Subsidence in the Gulf of Guinea: Assessing Relative Sea-Level Rise and Land Subsidence of Coastal Mega-Cities and River Deltas*), convened 57 interdisciplinary experts, policymakers, and practitioners from academia, government, and NGOs to address the increasing threats of coastal subsidence in West Africa. Held over five days at the University of Ghana, the workshop blended scientific discourse, technical training, policy dialogues, and community engagement to advance regional resilience against compounding risks of land subsidence and sea-level rise.

Day 1 focused on foundational knowledge, with technical lectures on subsidence mechanisms, impacts, and monitoring techniques, followed by hands-on training in InSAR and GNSS data processing and elevation modelling. Day 2 marked the official opening, featuring keynote addresses from stakeholders and scientific oral presentations (selected from 28 submitted abstracts) under two themes: Measuring & Monitoring Subsidence and Mechanisms of Subsidence. The scientific oral presentations continued on Day 3 under two themes: Impacts & Hazards of Subsidence and Modelling & Mitigation Techniques, complemented by an interactive poster session (11 submissions) fostering participant engagement. Each theme, however, concluded with discussion sessions where participants engaged in further deliberations. Day 4 transitioned to policy, with high-level discussions on governance frameworks and the inauguration of a GNSS station at the University of Ghana to bolster regional geospatial monitoring. The workshop concluded on Day 5 with a field visit to Ghana's vulnerable low-lying Volta Delta, where participants observed subsidence impacts firsthand in Adina and Keta townships and explored mangrove restoration efforts, as a Nature-based Solution (NbS) to coastal hazards, led by the Forestry Commission.

Key outcomes highlighted persistent challenges: (1) data scarcity in elevation and subsidence monitoring, (2) gaps between research and policy implementation, and (3) disproportionate vulnerabilities of coastal communities. Future priorities include dynamic modelling to integrate temporal subsidence variability, scaling NbS like mangrove restoration, and fostering transboundary collaboration through shared geodetic networks and open-data policies. The workshop underscored the urgency of coordinated action, advocating for investments in monitoring infrastructure, mainstreaming subsidence into national climate agendas, and empowering communities through participatory governance. By bridging science, policy, and local knowledge, this initiative sets a precedent for sustainable coastal management in West Africa's low-lying zones, where subsidence risks compound sea-level rise.

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1.0 INTRODUCTION

The Gulf of Guinea's densely populated, low-lying coastline—home to megacities like Lagos, Accra and Dakar—faces a range of coastal hazards, including erosion, flooding, and saltwater intrusion. Subsidence, the gradual sinking of land, exacerbates these risks, amplifying the impacts of sea-level rise and coastal flooding. Despite its severity, subsidence remains poorly quantified and understudied in the region, leaving policymakers and communities ill-equipped to respond effectively to the accelerating environmental pressures driven by urbanization and climate change.

In light of these challenges, the First West African International Workshop on Coastal Land Subsidence emerged as a key deliverable of the ENGULF Research Programme (*Coastal land subsidENce in the GULF of Guinea: Assessing relative sea-level rise and land subsidence of coastal mega-cities and river deltas along the Gulf of Guinea*). Funded by the French Development Agency (AFD), this multidisciplinary initiative seeks to address critical knowledge gaps by investigating the drivers and processes of subsidence, particularly in coastal megacities and deltas[1]. The Programme also aims to raise awareness of relative sea-level rise (rSLR) in the region, supporting sustainable development and adaptation projects.

Stemming from this awareness-raising agenda, the First West African International Workshop on Coastal Land Subsidence was held at the University of Ghana, Accra, from 4th to 8th November 2024. This groundbreaking event brought together researchers, practitioners, policymakers, and funders to address the critical issue of coastal land subsidence in West Africa (Plate 1). The workshop aimed to bridge the gap between scientific research and practical policy solutions, emphasizing the need for sustainable management of coastal zones in the face of rising sea levels and subsidence.

The primary objectives of the workshop were to:

- Build a subsidence Community of Interest (COI) for the region, and bring local and international experts, and policymakers together.
- Build capacity among participants through expert-led training sessions, fostering the skills necessary to address the pressing issue of coastal land subsidence.
- Share knowledge and experiences, initiate regional discussions on land subsidence, and consolidate the COI for future projects.
- Explore the latest research, share insights, and develop collaborative strategies to mitigate the impacts and ensure sustainable coastal management for future generations.

The workshop created a platform for dialogue, learning, and collaboration, reflecting the shared commitment to addressing the multifaceted challenges of coastal land subsidence, particularly

[1]https://www.afd.fr/en/carte-des-projets/engulf-Programme-assessing-exposure-relative-sea-level-rise-along-gulf-guinea

in vulnerable low-lying areas along the West African coast. This event set the stage for future initiatives aimed at building sustainable and resilient coastal communities across the region.

Plate 1: Group photograph of workshop participants

2.0 PARTICIPATION

The First West African International Workshop on Coastal Land Subsidence attracted a diverse and interdisciplinary group of participants, reflecting the global and regional significance of the issue. A total of fifty-seven (57) participants attended the workshop, representing a wide range of institutions, including universities, research organizations, government agencies, and development partners.

2.1 INSTITUTIONAL REPRESENTATION

The workshop saw strong participation from both international and local institutions, numbering a total of twenty-three (23) institutions and underscoring the collaborative nature of the workshop. This diverse representation facilitated cross-border knowledge exchange and fostered partnerships to address coastal subsidence in West Africa. Key participating organizations, categorized under either international or local, are shown in Fig 1.

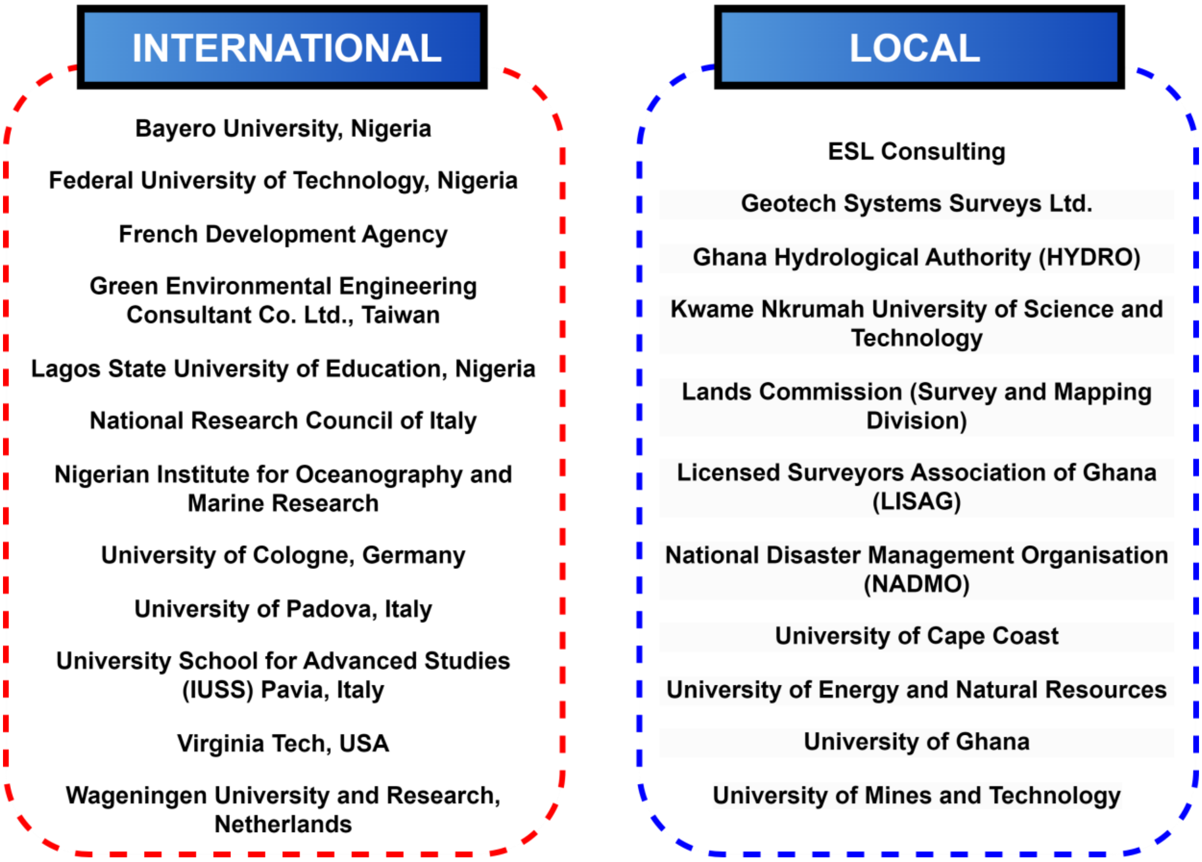

Figure 1: Key participating universities, research organizations, government agencies, and development partners

2.2 DEMOGRAPHIC BREAKDOWN

The workshop achieved a fairly balanced representation of gender and geographic diversity, as illustrated in Figure 3. Out of the fifty-seven participants, there were nineteen (19) female participants. The participation of 19 female attendees (representing 33% of the total number) highlighted the workshop's commitment to inclusivity and gender balance in addressing environmental challenges. In terms of geographic diversity, there was representation from ten (10) countries spread across Africa, Europe and Asia (Figure 2).

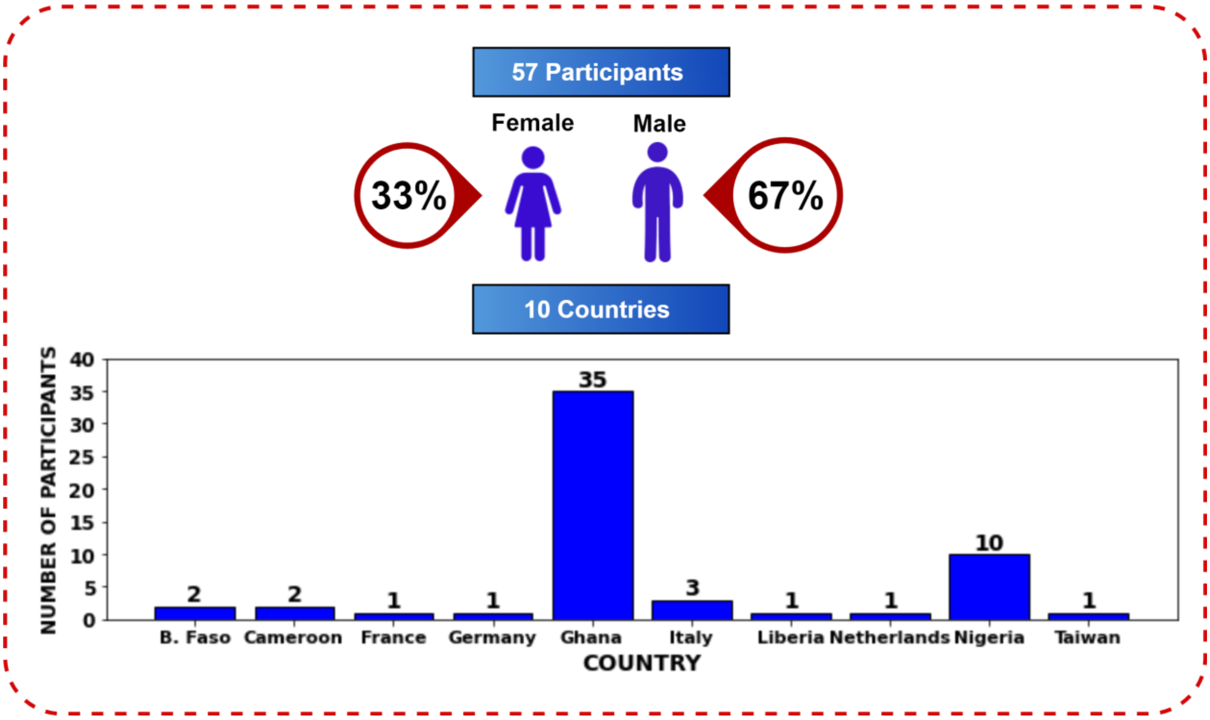

Figure 2: Gender and geographic diversity of the workshop's participants.

2.3 PARTICIPANT ENGAGEMENT

Participants actively engaged in all aspects of the workshop, including:

- Technical Lectures: Gaining insights into subsidence mechanisms, monitoring techniques, and mitigation strategies.
- Hands-On Training: Learning to process and interpret InSAR and GNSS data for subsidence analysis.
- Policy Dialogues: Contributing to discussions on integrating subsidence into national adaptation plans.
- Field Visits: Observing firsthand the impacts of subsidence in communities like Adina and Keta.

The workshop also provided opportunities for networking and collaboration, with participants exchanging ideas and exploring potential partnerships for future research and projects.

3.0 DAY 1: PRE-WORKSHOP TECHNICAL LECTURE & TRAINING

3.1 TECHNICAL LECTURES ON SUBSIDENCE

The first day of the Workshop commenced with participant registration (Plate 2), setting a collaborative tone for the sessions ahead. The day was designed to introduce attendees to the fundamentals of subsidence and equip them with practical tools for its analysis.

Morning lectures delivered by experts like Professor Pietro Teatini, Dr. Philip Minderhoud, and Dr. Roberta Bonì, explored the definition, impacts, and monitoring of subsidence. These presentations highlighted its irreversible nature, significant risks to infrastructure and ecosystems, and the importance of integrated monitoring techniques.

In the afternoon, participants engaged in a hands-on training session led by Dr. Bonì and Ms. Katarina Seeger (Plate 3). This session focused on using Digital Elevation Models (DEMs) and InSAR data to analyse and correct elevation datasets for accurate subsidence assessments. It emphasized integrating diverse datasets and addressing uncertainties in elevation models.

By blending participant engagement, theoretical insights, and practical applications, the first day provided a comprehensive foundation for understanding and addressing the challenges of subsidence in coastal regions.

Plate 2: Participants registering for the workshop in preparation for the first lecture

Plate 3: Participants from various institutions gathered on the first day of the workshop

3.1.1 Lecture One: Why Does the Land Subside?

Plate 4: Introductory lecture by Prof. Teatini

Prof. Pietro Teatini from the University of Padova commenced his presentation with a fundamental question: **"What is land subsidence?"** He defined it as the downward motion of the land surface, emphasizing that it results from processes occurring below the surface. He highlighted subsidence as a silent phenomenon, often unnoticed for years or even decades until it suddenly causes irreversible damage to communities and ecosystems.

To contextualize subsidence historically, Prof. Teatini referenced the first documented case at the Goose Creek oil field near Galveston Bay, Texas, in the 1920s. Using a historical map, he demonstrated how resource extraction contributed to measurable land sinking, offering an early understanding of the interplay between human activities and subsidence.

Mechanisms and Drivers of Land Subsidence

Prof. Teatini explained that land subsidence is a global issue, driven by both natural and anthropogenic factors. Presenting data from coastal cities across Asia, he highlighted its widespread occurrence and the significant risks it poses to urban areas.

A key part of his lecture focused on the geo-mechanical processes underlying subsidence. He introduced Terzaghi's principle, which describes how groundwater extraction reduces pore water pressure, increasing the effective stress on soil particles. This stress causes soil compaction and subsidence. Illustrating this with detailed diagrams, he showed how the geostatic load (total pressure from overlying soil and structures) shifts when groundwater is extracted, leading to land sinking.

He also described the cone of depression formed by pumping wells, which lowers the water table and accelerates subsidence over time. Through examples of confined and unconfined aquifer systems, he demonstrated how declines in piezometric heads contribute to measurable decreases in land elevation.

Factors Influencing Subsidence

Prof. Teatini outlined the conditions that exacerbate subsidence, including:

- Highly compressible deposits in alluvial, shallow marine, or lacustrine environments.
- Shallow burial depth of pumped formations.
- Significant declines in pore pressure.
- Large thicknesses of depressurized water-bearing strata.

He emphasized that subsidence is often irreversible, especially in fine-grained soils like clays and silts, where compaction causes permanent deformation. Even with groundwater level restoration, the damage to soil structure cannot be undone, as illustrated by long-term subsidence data from cities like Tokyo.

Global Impacts and a Call to Action

Prof. Teatini concluded with a stark warning: **“Don’t make cities and coastlands subside. The loss of elevation is irrecoverable.”** He stressed the critical importance of managing groundwater resources to mitigate subsidence. Highlighting its irreversible nature, he urged for proactive measures to preserve elevation and protect urban and coastal areas from long-term consequences.

This lecture set the stage for understanding the critical mechanisms and global impacts of subsidence, laying a scientific foundation for the workshop's subsequent discussions and activities.

3.1.2 Lecture Two: What are the Impacts of Land Subsidence?

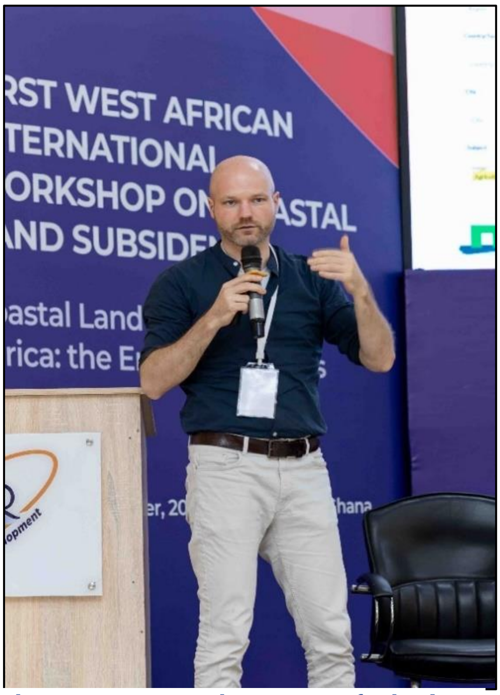

Plate 5: Lecture on the impacts of subsidence by Dr. Minderhoud

Dr. Philip Minderhoud, Assistant Professor at Wageningen University and Research, delivered an insightful presentation titled **"What Are the Impacts of Land Subsidence? And How Can We Project Them?"** His lecture delved into the immediate and long-term consequences of subsidence on urban infrastructure, ecosystems, and local populations while examining case studies of deltas experiencing accelerated subsidence worldwide.

Impacts on Infrastructure and Communities

Dr. Minderhoud began by highlighting the severe damage subsidence inflicts on buildings, infrastructure, sewage systems, gas pipelines, and electrical cables, often resulting in costly repairs and heightened safety risks. Using visual evidence, he demonstrated how differential subsidence, where the land sinks unevenly, leads to cracked walls, misaligned pipelines, and buckled roads, further increasing maintenance challenges.

He emphasized flooding as a critical consequence of subsidence, explaining that a lowering land surface causes the relative sea level to rise, thereby heightening the risk of coastal flooding. Presenting cumulative subsidence maps of Jakarta (1974–2010), he illustrated how some areas have sunk so significantly that they are now permanently below sea level, leaving them highly susceptible to frequent inundation. "Relative sea-level rise is intensified by land subsidence," he noted.

Environmental and Ecosystem Impacts

Dr. Minderhoud explored the broader environmental implications of subsidence, including:

- The salinization of groundwater threatens water quality and agricultural productivity.
- Greenhouse gas emissions from peat oxidation in drained areas, contributing to climate change.
- Loss of fertile soils and biodiversity, especially in subsiding deltas.

He used the Netherlands as an example, explaining how centuries of peat drainage for agricultural use have caused significant land subsidence, reduced soil fertility, and released carbon emissions, showcasing the long-term environmental cost.

Case Study: Mekong Delta, Vietnam

A key focus of the lecture was the Mekong Delta, a vital agricultural region in Southeast Asia home to over 18 million people. Groundwater extraction in the delta has risen by 500% since 2000, contributing to subsidence rates of up to 6 cm per year in some areas. Given the delta's low elevation (often less than one meter above mean sea level), even minor vertical changes exacerbate flooding and environmental challenges.

Future projections, based on various levels of groundwater extraction, revealed alarming scenarios under non-mitigation approaches, where continued subsidence could dramatically worsen flooding and environmental degradation. Dr. Minderhoud stressed, "Groundwater extraction is not free—you pay with elevation and salinization."

Mitigation and Adaptation Strategies

Dr. Minderhoud introduced mitigation strategies to combat subsidence, emphasizing the need for a holistic approach:

1. Avoiding subsidence drivers such as excessive groundwater extraction.
2. Mitigating subsidence through smart water management and controlled resource use.
3. Adapting to unavoidable subsidence by allowing natural sedimentation to build elevation.

He presented a case study of a Nature-Based Solution (NBS) project in northern Java, Indonesia, which aimed to use mangrove restoration to combat erosion. However, rapid subsidence—driven by groundwater extraction rates of up to 20 cm per year—caused the mangroves to drown, rendering the project ineffective. This highlighted the critical need to address subsidence directly in tandem with NBS initiatives. "Human-accelerated subsidence turned out to be the main driver of coastal retreat," he emphasized.

Conclusion

Dr. Minderhoud concluded with a call for managing subsidence within a broader system perspective, integrating local drivers and global environmental impacts. He stated the importance of combining adaptation and mitigation strategies to address subsidence effectively, warning that failure to do so would compound its long-term social, economic, and ecological costs.

3.1.3 Lecture Three: How Can We Monitor Land Subsidence?

Dr. Roberta Bonì, an assistant professor in physical geography and geomorphology at the University School for Advanced Studies in Pavia, Italy, delivered a detailed presentation on monitoring land subsidence using a combination of in situ and remote sensing technologies. Her talk emphasized the importance of understanding subsidence dynamics, identifying affected areas, and implementing targeted mitigation measures through effective monitoring.

Plate 6: Lecture on monitoring subsidence by Dr. Boni

Monitoring Techniques

Dr. Bonì categorized subsidence monitoring methods into two main approaches:

1. In Situ Techniques:
    - Spirit Levelling: Measures vertical displacement along linear infrastructure, providing precise data for localized areas.
    - Borehole Extensometers: Identify the depth and rate of aquifer compaction, which is crucial for understanding subsurface dynamics.
    - GNSS Stations: Offer geodetic measurements of both vertical and horizontal ground movements, helping to track subsidence over time.
2. Remote Sensing:
    - Synthetic Aperture Radar (SAR): Enables large-area monitoring with high temporal and spatial resolution. Techniques such as Persistent Scatterers (PS) and Small Baseline Subset (SBAS) generate time series and average rates of deformation.
    - Digital Elevation Models (DEMs): Aid in analysing subsidence trends and identifying regions at risk, particularly in low-lying coastal zones.

Challenges and Integrated Approaches

Dr. Bonì discussed the limitations of individual methods, particularly challenges in interpreting SAR data in vegetated regions or areas with nonlinear subsidence trends. She recommended combining ascending and descending SAR data to differentiate vertical and horizontal deformation components. Additionally, integrating in situ measurements with satellite data was highlighted as essential for achieving accurate and reliable assessments.

Applications and Case Studies

To illustrate the practical application of these methods, Dr. Bonì shared examples of subsidence monitoring projects from Europe and Africa, including the ENGULF project, which focuses on assessing subsidence in vulnerable regions. She emphasized how historical data and geological information play a pivotal role in validating current findings and informing future monitoring strategies.

Conclusion

Dr. Bonì concluded by stressing the importance of a multidisciplinary approach to monitoring subsidence, combining advanced technologies with historical and geological insights. She highlighted the need for continuous refinement of methods and collaborative efforts to improve the accuracy and effectiveness of subsidence monitoring, thereby enabling more informed decision-making and mitigation strategies.

3.2 PRACTICAL SESSIONS

3.2.1 Practical Lesson: Post-processing and Interpretation of InSAR Data for Land Subsidence

Dr. Roberta Bonì led a hands-on session focused on using QGIS for analysing land subsidence data, with a case study centred on Lagos, one of the study sites in the ENGULF project. This practical training aimed to equip participants with the skills needed to process and interpret subsidence data effectively.

Key Activities and Tools

Participants were guided through the following tasks:

1. Data Import and Conversion:
    - Importing delimited text files containing InSAR vertical displacement data, hydrogeological units, and land cover maps.
    - Converting text files into shapefiles and assigning appropriate coordinate reference systems.
2. Visualization and Mapping:
    - Creating visually informative maps using customized symbology to identify subsidence hotspots.
    - Overlaying subsidence data with hydrogeological and land use maps to analyze correlations between geological features, land cover, and subsidence rates.
3. Statistical Analysis:
    - Utilizing tools like box plots to compare subsidence across different hydrogeological units and lithologies.

Emphasis on Reproducibility and Open Resources

Dr. Bonì emphasized the importance of reproducibility in research workflows. She provided detailed, step-by-step instructions for each process and shared open-source data resources, encouraging participants to replicate the methods for their study areas.

Key Takeaways

The session highlighted:

- The critical role of integrating diverse datasets for a comprehensive understanding of subsidence impacts.
- The value of combining spatial analysis with statistical tools to uncover patterns and drivers of land subsidence.
- The potential of open-source platforms like QGIS to make advanced analysis accessible to a wide range of users.

By the end of the session, participants gained practical experience in post-processing and interpreting InSAR data, equipping them with valuable tools to monitor and analyze subsidence in their respective regions.

3.3 PRACTICAL SESSION 2

3.3.1 Using Open-Source Elevation Data in Coastal Lowlands - Correct Processing and Addressing Uncertainties

Plate 7: Lecture on using open-source elevation data in addressing hazards by Ms. Seeger

Ms. Katarina Seeger led a comprehensive session on the critical role of land elevation data in assessing hazards such as relative sea level rise and flooding in coastal lowlands. She emphasized how vertical land motion exacerbates sea-level rise impacts, making regions like river deltas especially vulnerable.

Understanding Elevation Models

Ms. Seeger outlined the key differences between:

- Digital Surface Models (DSMs): Representing elevations that include surface features like buildings and vegetation.
- Digital Terrain Models (DTMs): Representing bare ground elevations.

She highlighted the commonly used SRTM DSM (2000) and its limitations, contrasting it with more accurate recent models, such as the Delta Terrain Model (DTM, 2024), which accounts for corrections to vegetation and buildings. She also discussed how global elevation models often rely on different vertical reference systems (geoids or ellipsoids), which create challenges in aligning datasets for sea-level rise assessments.

Practical Demonstration: Elevation Data Processing

Ms. Seeger guided participants through step-by-step procedures to ensure accurate and consistent elevation data processing:

1. Dataset Import and Alignment:
    - Using QGIS, participants imported elevation datasets and aligned them to local mean sea level (MDT).
    - Raster calculations were applied to adjust for vertical offsets caused by discrepancies in reference systems.
2. Error Identification and Exclusion:
    - Participants learned to identify and exclude erroneous elevation values, such as extreme negatives, which could skew results.
3. Comparison of Models:
    - The session concluded with a comparison of original and corrected elevation models for areas such as Greater Accra and the Volta Delta, showcasing the significant improvements in identifying low-lying zones vulnerable to flooding and sea-level rise.

Key Takeaways

Ms. Seeger emphasized:

- The importance of selecting the appropriate elevation model based on the study region's specific requirements.
- The need for consistent vertical references to ensure accurate hazard assessments.
- The value of correcting and validating elevation datasets to minimize uncertainties.

Encouragement for Independent Practice

Participants were encouraged to practice independently using the workshop data and methods. By providing hands-on experience in correcting and aligning elevation datasets, this session equipped attendees with the technical expertise needed to address uncertainties in sea-level rise and flooding assessments effectively.

3.4 DISCUSSION SESSION: EXPLORING THE DYNAMICS AND IMPACTS OF LAND SUBSIDENCE

The discussion session provided a platform for participants to engage deeply with the concepts of land subsidence, addressing its dynamics, drivers, and impacts on coastal processes. Expert responses enriched the dialogue, clarifying complex issues and offering insights into practical solutions.

Key Topics and Insights

1. Isostatic Rebound vs. Rapid Subsidence:
    - Participants inquired about the role of isostatic rebound in recovering subsided areas. Prof. Pietro Teatini explained that rebound occurs at a slow, millimetric rate, making it insufficient to counteract the rapid subsidence caused by groundwater extraction.
    - He also clarified the relationship between subsidence and coastal erosion, noting that subsidence lowers elevations, which exacerbates erosion but does not directly result from it.
2. Seawater Intrusion and Aquifer Pressure:
    - Discussions explored the indirect effects of seawater intrusion on subsidence. Prof. Teatini highlighted how seawater intrusion reduces aquifer pressure, but emphasized that its impact is secondary to the effects of groundwater extraction.
3. Vertical Land Motion vs. Elevation Change:
    - Participants sought clarification on the distinction between vertical land motion and elevation change. Prof. Philip Minderhoud explained that processes such as sedimentation can offset subsidence, leading to a net elevation gain. However, he stressed the importance of quantifying these processes to develop effective local interventions.
4. Impact of Dams on Subsidence and Sedimentation:
    - Questions about dams highlighted their role in blocking sediment flow, affecting natural elevation processes. Prof. Minderhoud noted that while dams do not directly cause subsidence, they disrupt sedimentation needed to counterbalance land subsidence.

Technical Monitoring and Data Challenges

1. Accuracy of GPS and SAR-based Data:
    - Dr. Roberta Bonì addressed questions about the reliability of GPS and SAR data for monitoring subsidence. She discussed calibration techniques to enhance accuracy and strategies to address challenges such as reduced coherence in vegetated areas.
2. Historical Benchmarks:
    - The value of historical benchmarks in trend analysis was highlighted, but Dr. Bonì cautioned against temporal mismatches when using older data for current assessments.
3. Custom Elevation Models:
    - Participants expressed interest in generating custom elevation models using Sentinel-1 data. Dr. Katarina Seeger emphasized the importance of vertical data corrections and explained the differences between global elevation models like SRTM and newer models such as the Delta Terrain Model.

Key Takeaways

- The discussions showed the need for precise elevation data, interdisciplinary collaboration, and tailored solutions to address subsidence challenges.
- Experts advocated for transitioning from qualitative to quantitative assessments to better understand system dynamics and evaluate the effectiveness of solutions.
- Open-access tools and data were highlighted as valuable resources for advancing subsidence monitoring and mitigation efforts.

This session reinforced the importance of integrating technical expertise, localized knowledge, and collaborative efforts to develop sustainable solutions for managing subsidence in vulnerable coastal regions.

4.0 DAY 2: MAIN SCIENTIFIC WORKSHOP I

4.1 OPENING CEREMONY

4.1.1 Introduction

The opening ceremony of the Coastal Land Subsidence Workshop commenced with a vibrant cultural dance performance by the Ghana Dance Ensemble, celebrating the rich cultural heritage of the host nation (Plate 8). This captivating display set a warm and engaging tone for the event, fostering a sense of unity and collaboration among participants.

The ceremony also featured remarks from key stakeholders, including representatives from the French Development Agency (AFD) and UNESCO, highlighting the importance of addressing coastal subsidence in West Africa. The speakers highlighted the global and regional implications of subsidence and the importance of interdisciplinary collaboration in tackling this complex issue.

The ceremony effectively set the stage for the workshop’s discussions and activities, providing participants with an inspiring introduction to the critical themes of subsidence, its impacts, and the need for actionable solutions.

Plate 8: Cultural dance display at the workshop

4.1.2 Welcome Remarks and Introduction of the Chairperson

Plate 9: Welcome address and introduction of chairperson by Prof. Kwasi Appeaning Addo

The welcome address and introduction of the Chairperson for the ceremony were delivered by Professor Kwasi Appeaning Addo, who warmly acknowledged the contributions of the Chair to both academia and the field of earth sciences. He expressed gratitude for the leadership and expertise that the Chairperson, Professor Sandow Mark Yidana, brings to the event, emphasizing the importance of his role in guiding discussions on critical issues such as subsidence.

Professor Yidana, a distinguished academic and the Provost of the College of Basic and Applied Sciences at the University of Ghana, is an esteemed expert in Hydrogeology, with a specialization in numerical modelling of groundwater flow and solute transport. His extensive experience in geostatistics and advanced statistical applications in earth sciences has positioned him as a leading figure in his field. He had previously served as the Dean of the School of Physical and Mathematical Sciences and the Head of the Department of Earth Sciences at the University of Ghana. Holding a PhD in Environmental Management from Montclair State University, USA, and with a prolific record of scholarly publications, he was a fitting choice to chair the proceedings.

4.1.3 Remarks Chairperson

The Chairperson emphasized the University of Ghana's dedication to its five-year strategic plan, which focuses on producing impactful research, influencing policy, and driving positive change. He drew attention to the critical issue of coastal subsidence, highlighting its role in intensifying climate change impacts such as sea-level rise and the resulting vulnerabilities faced by affected communities.

Plate 10: Remarks by Prof. Yidana, Provost of the College of Basic and Applied Sciences

He specifically addressed the challenges in the Volta Basin, where communities depend heavily on groundwater for irrigation. The Chairperson pointed out the lack of research and focus in this area, stressing the urgency of addressing these gaps to mitigate the compounded risks of climate change and subsidence.

Commending the Department of Marine and Fisheries Sciences for organizing the workshop, he expressed confidence in its potential to raise awareness and catalyse impactful policy changes. He concluded with a warm welcome to the participants, encouraging their active engagement and collaboration in tackling these pressing challenges.

4.1.4 Remarks by Dean of the School of Biological Sciences

Plate 11: Prof. Gbogbo delivering remarks on behalf of the Dean of the School of Biological Sciences

Prof. Francis Gbogbo, representing Professor Augustin Ocloo, extended the Dean's apologies for being unable to attend the First West African International Workshop on Coastal Land Subsidence due to other university commitments. Speaking on behalf of the Dean, he warmly welcomed participants to this significant event, hosted by the Department of Marine and Fisheries Sciences at the University of Ghana.

Prof. Gbogbo highlighted the pressing nature of coastal land subsidence, describing its far-reaching effects, including intensified climate change impacts, flooding, habitat loss, and agricultural damage, particularly in low-lying coastal regions. He emphasized the importance of convening scientists, experts, and policymakers to address this complex issue and noted the University of Ghana's commitment to impactful research aimed at solving such challenges.

He acknowledged the workshop as a critical platform for fostering interdisciplinary collaboration and developing sustainable solutions. Prof. Gbogbo conveyed the Dean's gratitude to the organizers, participants, and partners for their contributions to making the workshop a reality.

In closing, Prof. Gbogbo expressed hope that the discussions would yield valuable insights to improve livelihoods and influence policy. He extended a warm welcome to international participants and wished everyone fruitful deliberations and a memorable experience in Ghana.

4.1.5 Funder's Message

Dr. Marine Canesi, representing the French Development Agency (AFD), addressed the workshop participants with gratitude for the warm welcome extended by the University of Ghana. She commended the efforts of Professor Kwasi Appeaning Addo, Dr. Selasi Yao Avornyo, and Ms. Annette Ankrah for their pivotal roles in organizing the workshop.

Plate 12: Message from the funders delivered by Dr. Marine Canesi

Dr. Canesi highlighted AFD's mission to finance and support projects that reduce poverty and promote sustainable development. She emphasized the agency's commitment to research-driven approaches that inform public policy and benefit both local communities and ecosystems.

Focus on the ENGULF Programme

Dr. Canesi elaborated on the objectives of the ENGULF Programme, coordinated by AFD, which aims to:

- Assess the vulnerability of coastal communities in the Gulf of Guinea.
- Measure current subsidence rates, understand their drivers, and predict future trends, with a particular focus on megacities and delta regions.
- Provide open-access data, reports, and scientific publications to raise awareness and guide public policy and adaptation plans for mitigating the impacts of subsidence.

She stressed the importance of ENGULF's role in equipping stakeholders with the knowledge and tools necessary to build resilience in West Africa's coastal regions.

Call for Collaboration

Dr. Canesi spoke about the need for collaboration among researchers, practitioners, and policymakers in addressing coastal subsidence effectively. She expressed optimism that the workshop would foster knowledge-sharing and regional cooperation to tackle this pressing issue.

In her concluding remarks, Dr. Canesi expressed appreciation to the Programme coordinators, researchers, and the Ghana team for their dedication to the Programme's success. While acknowledging the challenges that remain, she reaffirmed AFD's commitment to advancing these efforts and thanked all participants for their contributions.

4.1.6 Message from UNESCO/ LaSII

Prof. Teatini provided an overview of LaSII, a UNESCO initiative under the International Hydrological Programme. Established in the 1970s, LaSII has focused on advancing the scientific understanding of land subsidence and fostering international collaboration. He highlighted the initiative's expansion over the decades, reflecting the growing global prevalence of subsidence. Despite decades of research, he stressed that groundwater mismanagement remains a persistent and significant driver of subsidence.

Collaboration through the ENGULF Project

Prof. Teatini also introduced the ENGULF project, a collaborative effort supported by AFD and LaSII, which aims to:

- Assess the vulnerability of coastal communities in the Gulf of Guinea.
- Measure current subsidence rates and understand their drivers.
- Provide open-access resources to inform public policy and guide adaptation strategies.

He emphasized the importance of collaborative research and data-sharing to increase awareness and build resilience in vulnerable coastal regions.

In his closing remarks, Prof. Teatini outlined LaSII's six-step approach for managing land subsidence:

- Monitoring subsidence to establish accurate baselines.
- Understanding the mechanisms driving subsidence.
- Developing models to predict future trends.
- Implementing mitigation strategies to address identified drivers.
- Re-monitoring to evaluate the effectiveness of these interventions.
- Refining strategies based on continuous feedback.

He emphasized that this iterative process is crucial for developing sustainable solutions to manage land subsidence effectively. Reaffirming UNESCO LaSII's commitment to the ENGULF project, he called for strengthened global efforts and collaboration to address this critical issue.

4.1.7 Overview of the ENGULF Project

Dr. Philip Minderhoud presented an overview of the ENGULF Project, emphasizing its vision to address coastal land subsidence and its significant role in exacerbating relative sea-level rise. He explained that the project was developed to fill critical knowledge gaps in the Gulf of Guinea region, where data on vertical land motion and subsidence are limited. While global sea-level rise projections are well-documented, they often overlook the compounding effects of subsidence, which can drastically accelerate coastal sinking. Hosting the First West African Workshop on Coastal Land Subsidence at the University of Ghana marked a significant step in tackling this oversight.

Causes and Regional Context

Dr. Minderhoud outlined the causes of land subsidence, attributing it to both natural and human-induced processes such as:

- Groundwater extraction.
- Surface water drainage.
- Infrastructure loading.

He noted that human activities tend to accelerate subsidence, drawing comparisons to Southeast Asia, where rapid subsidence is well-documented. Similarly, the Gulf of Guinea faces high risks due to urban expansion, a growing population, and unconsolidated coastal sediments. Despite these challenges, the region remains under-researched, underscoring the importance of ENGULF's mission.

Objectives and Tools

The ENGULF Project aims to:

1. Map vulnerable hotspots affected by subsidence.
2. Assess coastal elevation changes.
3. Understand the driving forces behind subsidence.

Dr. Minderhoud highlighted the use of advanced technologies, including:

- InSAR technology for detecting land motion.
- GNSS stations to measure vertical land movement with high precision.

Preliminary findings indicate that cities like Lagos are already experiencing vertical land motion, though the rates remain manageable compared to global hotspots. This provides an opportunity to implement preventive measures and develop mitigation strategies before the situation worsens.

Collaborative Efforts and Milestones

Dr. Minderhoud pointed out the collaborative nature of the ENGULF Project, emphasizing its commitment to:

- Raising awareness about coastal subsidence.
- Fostering regional cooperation to address the issue.

He celebrated the installation of a GNSS station at the University of Ghana, a significant milestone for improving satellite-derived measurements in the region.

Conclusion

Dr. Minderhoud concluded by expressing hope that the workshop would serve as a catalyst for ongoing dialogue, research, and policy development. He described it as a crucial first step toward building a regional coalition to address the challenges of coastal land subsidence in West Africa, emphasizing the need for continued collaboration and knowledge-sharing to mitigate future risks effectively.

4.1.8 Closing Remarks by Prof. Sandow Mark Yidana

In his closing remarks, Prof. Sandow Mark Yidana emphasized the critical need to prioritize research on coastal subsidence, particularly its underlying causes, such as groundwater extraction. He highlighted the essential role of groundwater in maintaining land stability, warning that excessive extraction for domestic use, agriculture, and salt mining poses significant threats to coastal regions. He noted that much of the land loss often attributed to seawater encroachment stems not from sea-level rise, but from human activities that destabilize the land.

Prof. Yidana called for more focused research to guide effective policies, emphasizing the importance of research-driven models for the sustainable management of groundwater resources. He stressed that understanding and addressing the root causes of subsidence is vital for safeguarding vulnerable coastal regions.

Call to Action

Expressing confidence in the workshop's outcomes, Prof. Yidana encouraged participants to:

- Develop a comprehensive report or paper on the state of coastal regions.
- Use such outputs to stimulate policy interest and drive actionable initiatives to protect these areas.

He concluded by thanking the organizers, facilitators, and participants for their contributions, highlighting the importance of collaborative efforts in addressing coastal subsidence and its associated challenges. Prof. Yidana reiterated his belief that the workshop would serve as a platform for generating innovative ideas and fostering actionable outcomes to mitigate the impacts of subsidence.

4.1.9 Vote of Thanks

Plate 13: Vote of thanks by Dr. Angela Lamptey on behalf of the Head of Department of Marine and Fisheries Sciences

Dr. Lamptey, delivering the vote of thanks on behalf of the Head of the Department of Marine and Fisheries Sciences, expressed profound gratitude to all contributors to the success of the opening ceremony and the workshop.

Acknowledgement of Key Supporters

She began by recognizing the vital role played by donor partners, including AFD and UNESCO, and supporting partners from various universities and research institutions, in making the event possible. Special thanks were extended to the management of the University of Ghana, particularly:

- The Vice-Chancellor,
- The Provost of the College of Basic and Applied Sciences, and
- The Dean of the School of Biological Sciences, represented by Prof. Gbogbo, for their unwavering support.

Dr. Lamptey also acknowledged the contributions of Prof. Kwasi Appeaning Addo, the principal investigator of the ENGULF project, along with his research team, co-researchers, and co-chairs, for their leadership and dedication.

Dr. Lamptey expressed heartfelt thanks to the facilitators and instructors of the international workshop for sharing their expertise and warmly welcomed them to Ghana. She also thanked the Director of ISSER, Prof. Quartey, for providing the venue, as well as the faculty, staff, students, and national service personnel, whose collective efforts ensured the smooth organization of the event.

Dr. Lamptey gave special recognition to the cultural group for their vibrant performances, which added a rich African flavour to the occasion, creating an engaging and memorable atmosphere.

She concluded by expressing gratitude to all attendees for their active participation, emphasizing that their presence was integral to the event's success. Dr. Lamptey highlighted the importance of their contributions to the meaningful deliberations and outcomes of the workshop.

4.2 ORAL PRESENTATIONS: SESSION 1- MEASURING AND MONITORING SUBSIDENCE

4.2.1 Monitoring Land Subsidence in Taiwan: an Integrated Approach

Plate 14: Presentation on monitoring land subsidence in Taiwan by Dr. Hung

Dr. Wei-Chia Hung from Green Environment Engineering Consultant Co., Ltd. presented an integrated approach for monitoring land subsidence in Taiwan, highlighting advanced technological methods and monitoring systems designed to mitigate and understand subsidence effects in both coastal and inland regions.

Causes and Impacts of Land Subsidence in Taiwan

Dr. Hung explained that excessive groundwater extraction is the primary cause of land subsidence in Taiwan, leading to a "silent land crisis" with severe consequences, including:

- Structural damage to critical infrastructure such as Taiwan's high-speed rail.
- Increased flooding and seawater intrusion in subsiding areas.

He emphasized that proactive monitoring is crucial to prevent worsening impacts, especially in vulnerable coastal and inland regions.

Monitoring Systems and Technologies

Taiwan employs a multi-sensor monitoring system to achieve high-accuracy subsidence tracking, integrating the following key technologies:

- GNSS: Provides daily measurements with a spatial resolution of 10–15 km and an accuracy of 1 cm.
- InSAR (Interferometric Synthetic Aperture Radar): Uses Sentinel satellite images to detect subsidence over large areas, calibrated with GNSS data for enhanced accuracy.
- Spirit Levelling: Conducted annually, achieving high spatial resolution (1.5–2 km) and 0.5 cm accuracy.
- Multi-Layer Compaction Monitoring Wells (MLCW): Measures subsurface deformation across layers, providing detailed insights into the rate and depth of compaction.

Data Integration and Mapping

Dr. Hung demonstrated the utility of data fusion for improving measurement precision, combining the density of InSAR data with the accuracy of spirit levelling. This method significantly reduces measurement error, with RMSE values improving from 0.79 cm/year to

0.15 cm/year, enabling precise identification of differential subsidence zones. He showcased subsidence maps for Taiwan's Central Reclaimed Agricultural Farmland (CRAF) region, which highlighted "hot zones" of cumulative subsidence from 1992 to 2023 and illustrated shifts in subsidence centres over time.

IoT Technology and Real-Time Monitoring

Dr. Hung introduced the integration of IoT technology to connect monitoring stations and transmit real-time data to a centralized cloud-based platform. This system provides immediate access to data for decision-makers via web GIS platforms, enabling the analysis of subsidence trends by integrating:

- GNSS data.
- Groundwater monitoring wells.
- Extensometers and MLCWs.

This IoT-enabled system offers timely insights to policymakers, supporting sustainable groundwater extraction management and rapid responses to critical subsidence trends.

Case Study: Pingtung County

Dr. Hung presented a detailed case study from Pingtung County, showcasing the use of InSAR and GNSS data to monitor subsidence accurately. The analysis of 143 Sentinel images revealed precise subsidence rates, with GNSS data verifying findings. Horizontal calibration further enhanced the accuracy, demonstrating the effectiveness of Taiwan’s long-term monitoring systems.

Seasonal Variations in Subsidence

Dr. Hung noted that subsidence rates vary with seasonal water use:

- Greater subsidence occurs during Taiwan’s dry season (November to April).
- Partial rebound is observed during the wet season (May to October).

In some regions, however, subsidence persists year-round, indicating that groundwater extraction exceeds natural replenishment. These areas are identified as priorities for management intervention.

Conclusion

Dr. Hung emphasized the importance of integrated monitoring systems in managing land subsidence effectively. By combining advanced technologies like InSAR, GNSS, spirit levelling, and IoT platforms, Taiwan has developed a comprehensive framework to track and address subsidence. He spoke about the need for sustainable groundwater management and proactive policymaking to mitigate the long-term impacts of subsidence on infrastructure, ecosystems, and communities.

4.2.2 A Review of Two Major Threats to Nigerian Coastal Populations: Land Subsidence and Sea-Level Rise

Plate 15: Presentation on the impacts of subsidence and SLR to Nigerian coastal regions

Dr. Femi Emmanuel Ikuemonisan of Lagos State University delivered an insightful review of land subsidence and sea-level rise (SLR), focusing on their combined threats to Nigerian coastal regions. Collaborating with colleagues Philip Minderhoud, Roberta Bonì, Marie-Noëlle Woillez, and Pietro Teatini, Dr. Femi highlighted the vulnerabilities of Nigeria's coastal populations and infrastructure to these twin challenges.

Nigerian Coastal Context

Dr. Femi began by noting Nigeria's 853 km coastline, the longest along the Gulf of Guinea, and highlighted key issues affecting the region:

- Nearly 900 operational oil wells in the Niger Delta.
- Groundwater extraction supplies 95% of water consumption for Lagos' 23 million residents.
- Predominantly coastal soil types like alluvium and peat, are highly prone to compaction and subsidence.

Study Objectives and Methodology

The study aimed to assess:

1. Current knowledge on land subsidence along Nigeria's coastlines.
2. The impact of relative sea-level rise (RSLR) on the region.
3. Research gaps in understanding subsidence and RSLR.

Using the PRISMA-ScR Framework (Preferred Reporting Items for Systematic Review and Meta-Analysis Extension For Scoping Reviews), Dr. Femi's team:

- Formulated research questions.
- Reviewed relevant studies.
- Synthesized and charted data.

Key research questions included:

1. What is known about land subsidence along Nigeria's coastlines?
2. How does existing literature reflect Nigeria's vulnerability to RSLR?

3. Is there sufficient evidence linking land subsidence with RSLR?
4. What are the knowledge gaps in the current literature?

Key Findings

- Subsidence Rates: Spatial distribution of subsidence rates ranged from 10 mm to 95 mm per year along Nigeria's coast, with monitoring techniques such as InSAR and GPS yielding consistent results.
- Primary Drivers:
    - In Lagos, excessive groundwater extraction is the leading cause of subsidence.
    - In the Niger Delta, subsidence is primarily driven by oil extraction.
- Spatiotemporal Trends: In urban centres like Port Harcourt and Lagos, subsidence impacts vary based on geological conditions and extraction practices.

Impacts of Subsidence and RSLR

The interplay between land subsidence and rising sea levels significantly increases the risks of:

- Flooding, due to lower land elevations.
- Seawater intrusion, degrading soil and groundwater quality.
- Loss of agricultural productivity, particularly in areas vulnerable to salinization.

Knowledge Gaps

Dr. Femi identified major knowledge gaps:

- Lack of comprehensive studies linking subsidence directly to RSLR.
- Limited hydrogeological data on subsurface lithology.
- Absence of active GNSS/GPS stations for accurate InSAR validation, leading to uncertain subsidence measurements.

Efforts to Address Gaps

Dr. Femi's team collaborated with institutions such as the Lagos State Water Corporation, Nigerian Geological Survey Agency, and Nigerian Hydrological Services Agency, analysing 109 well logs with depths of 40 to 400 meters. These logs provided insights into Lagos' subsurface stratigraphy.

A public survey revealed low awareness of land subsidence and RSLR, with only 21% of respondents demonstrating knowledge of these issues.

Conclusion and Recommendations

Dr. Femi concluded by emphasizing the need for:

- Increased research to explore the relationship between subsidence and RSLR in Nigeria.
- Greater public engagement to raise awareness.
- Policy measures to mitigate future risks.

He called for expanded regional studies, improved monitoring infrastructure, and collaborative efforts to protect Nigeria's vulnerable coastal populations from the compounded threats of subsidence and sea-level rise.

4.2.3 Land Subsidence and Coastal City Vulnerability: Elevation Data Challenges in Douala Coastland, Cameroon

Mr. Gergino Chounna Yemele, from the University of Padova, Italy, presented the vulnerability of Douala, Cameroon, to land subsidence, focusing on the challenges of obtaining accurate elevation data in this region. The presentation, a collaborative effort with contributions from Philip Minderhoud, Leonard Ohenhen, Katharina Seeger, Manoochehr Shirzaei, and Pietro Teatini, highlighted the compounded risks of urban expansion, subsidence, and sea-level rise in Douala's coastal lowlands.

Plate 16: Presentation on the vulnerability of Doula, Cameroon to land subsidence

Key Research Questions

The presentation posed several critical questions about Cameroon's low-lying coastlands:

- How can we improve our understanding of coastal and delta dynamics?
- What are the rates, causes, and patterns of subsidence in Cameroon's deltas?
- How do subsidence, sea-level rise, and human activities combine to affect coastal vulnerability?

Objectives

The study aimed to:

1. Investigate current subsidence rates and the factors influencing them.
2. Assess coastal elevation to determine vulnerability to sea-level rise.
3. Quantify and model land subsidence in Douala's coastal lowlands.
4. Propose adaptation or mitigation measures to enhance resilience against subsidence and

sea-level rise.

Methodology

The research utilized:

- InSAR analysis (2018–2022): Persistent and Distributed Scatterers were analysed to detect vertical land motion.
- Land-use data analysis (1992–2022): Focused on Douala's urban expansion and its morphological characteristics.
- Comparison of DEMs: Different Digital Elevation Models were evaluated to assess elevation data accuracy and its impact on vulnerability analyses.

Findings

1. Vertical Land Motion (VLM):
    - The average VLM rate in Douala from 2018 to 2023 was approximately -2.9 mm per year, with subsidence prevalent across much of the region.
2. Correlation with Urban Growth:
    - Subsidence correlated strongly with urban expansion, particularly in reclaimed wetlands. Subsidence intensified in newly urbanized areas, where infrastructure development altered soil compaction dynamics.
3. Differential Subsidence:
    - Industrial buildings experienced higher subsidence rates than domestic structures, likely due to heavier foundations.
    - Shorter buildings showed greater movement compared to taller structures, which are more structurally stable against shallow subsidence.
4. Elevation Data Challenges:
    - The study revealed that the choice of DEMs significantly impacts vulnerability evaluations. Lower-elevation urban zones showed higher subsidence rates, correlating with increased flood risk.
    - Accurate DEMs estimated that:
        - 1.4 million people live below 2.5 meters of elevation.
        - 2.3 million people reside below 10 meters, making them highly vulnerable to subsidence and sea-level rise.
5. Urbanization Trends:
    - Douala's urbanized area increased from 0.96% in 1992 to 4.72% in 2022, intensifying the region's susceptibility to subsidence.

Future Research and Recommendations

Mr. Yemele proposed several future research directions:

- Investigate the role of surface hydrology, groundwater dynamics, and natural compaction in subsidence.
- Develop a land subsidence model for Douala using deep-learning techniques.
- Combine subsidence and sea-level rise data to project short- and long-term impacts.

Conclusion

Mr. Yemele concluded that Douala's coastal lowlands are extremely vulnerable due to both natural and anthropogenic subsidence factors. The city's rapid urbanization, compounded by inaccurate elevation data, poses significant risks to its population and infrastructure. He emphasized the need for improved data quality and adaptive measures to mitigate subsidence-related challenges.

4.2.4 Coastal Erosion and Land Subsidence in Lagos, Nigeria

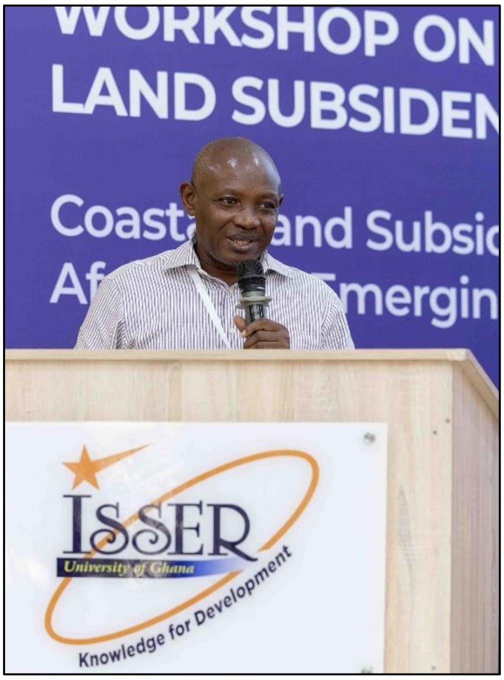

Plate 17: Presentation on the interconnected challenges of coastal erosion and land subsidence in Lagos, Nigeria

Mr. Daniel Oguwuike Imo of the Nigerian Institute for Oceanography and Marine Research (NIOMR) delivered a detailed presentation on the interconnected challenges of coastal erosion and land subsidence in Lagos, Nigeria. His talk covered definitions, causes, evidence from field monitoring, and proposed mitigation strategies, focusing on the Barrier Lagoon Complex (BLC) along Lagos State's coastline.

Overview of Nigeria's Coastline

Mr. Imo described Nigeria's 853 km coastline, divided into four geomorphic zones:

1. Barrier Lagoon Complex (BLC)
2. Mahin Mud Coast (MMC)
3. Niger Delta Coast (NDC)
4. Strand Coast (STC)

The Barrier Lagoon Complex, spanning 200 km of Lagos State's coastline, consists of unconsolidated sands, making it highly susceptible to both erosion and subsidence. This zone formed the primary focus of Mr. Imo's analysis.

Defining Coastal Erosion

Mr. Imo defined coastal erosion as the process by which coastlines are worn away by natural forces such as waves, tides, and currents, which can lead to land loss and impact ecosystems and infrastructure. He categorized the causes of erosion into:

1. Natural Causes:
    - Wave action.
    - Sea-level rise.
    - Climate change.
2. Anthropogenic Causes:
    - Sand mining.
    - Engineering constructions that interfere with sediment dynamics.

Evidence of Erosion and Subsidence in the Barrier Lagoon Complex

Drawing from field monitoring data, Mr. Imo emphasized the significant role of human activities, particularly sand mining, in exacerbating coastal erosion. Key findings included:

- Increased shoreline retreat and loss of beach profiles, endangering both infrastructure and communities.
- Disruption of sediment supplies reduces the natural defence against wave action.
- Subsidence effects, compound the impact of erosion and lowering land elevation.

Monitoring Activities by NIOMR

Mr. Imo highlighted his team's establishment of erosion monitoring stations within the BLC, employing methods such as:

1. Levelling: Measuring shoreline changes and elevation loss.
2. Nearshore Dynamics Studies: Monitoring wave action and tidal currents.
3. Sediment Sampling: Analysing sediment composition and its susceptibility to erosion.

Results from these activities revealed:

- Persistent shoreline retreat.
- A decline in beach stability due to reduced sediment supply and anthropogenic disturbances.

Mitigation Strategies

Mr. Imo proposed several strategies to address the worsening impacts of coastal erosion and subsidence in Lagos:

1. Reducing Sand Mining:
    - Limiting sand mining activities to stabilize coastal sediments and prevent further erosion.
2. Constructing Protective Barriers:
    - Installing barriers to shield vulnerable areas from wave action.

3. Implementing Coastal Zoning Regulations:
    - Restricting construction in erosion-prone zones to preserve natural habitats and reduce risks.

Conclusion

Mr. Imo concluded that coastal erosion and subsidence in Lagos are ongoing and likely to intensify without timely intervention. He emphasized the need to balance developmental needs with environmental preservation, calling for urgent implementation of mitigation strategies to protect both natural ecosystems and urban infrastructure. His findings underscore the critical importance of proactive management to address these interconnected challenges in Lagos' coastal regions.

4.3 ORAL PRESENTATIONS: SESSION 2- MECHANISM AND UNDERSTANDING OF SUBSIDENCE

4.3.1 Land Subsidence Risk Caused by Groundwater Exploitation in Italy

Dr. Roberta Bonì presented insights into the risks of land subsidence due to groundwater overexploitation in Italy. Her presentation, part of the SubRISK+ project funded by the Italian Ministry of University and Research, focused on developing sustainable urban management strategies to mitigate the impacts of subsidence.

Challenges in Groundwater Management

Dr. Bonì highlighted that a critical challenge in achieving sustainable groundwater management is understanding the hydrologic implications of various strategies on subsidence risk. Drawing from historical studies, she identified Italy's most affected regions:

- Po Plain
- Rome & Tiber River Plain
- Florence-Prato-Pistoia Plain
- Volturno Plain

SubRISK+ Project Objectives

The SubRISK+ project aims to:

1. Develop risk mapping products based on Earth Observation (EO) data to assess subsidence impacts on infrastructure, including buildings and transport networks.
2. Create 3D numerical models that integrate groundwater flow and geomechanical data to quantify subsidence effects from groundwater usage.
3. Assess the socio-economic impacts of subsidence and predict how factors like climate change may influence subsidence-induced risks by 2050 and 2100.

Methodology and Tools

The project evaluated the efficacy of Copernicus Sentinel-1 European Ground Motion Service (EGMS) data for monitoring subsidence in Italy. Key objectives included:

- Identifying hot spots of subsidence.
- Analysing ground deformation trends using time series.
- Correlating InSAR-based ground deformation data with changes in groundwater piezometric levels.

Dr. Bonì's team employed EGMS data combined with Independent Principal Component Analysis (IPCA) to distinguish between:

- Linear trends: Indicating sustained subsidence.
- Non-linear trends: Reflecting episodic or irregular subsidence.
- Seasonal trends: Linked to variations in groundwater extraction.

Key Findings

1. High-Impact Areas:
    - Subsiding areas exceeding 50 mm/year were identified, particularly in densely populated regions.
2. Correlations with Groundwater Usage:
    - Linear subsidence trends correlated strongly with sustained deformation velocities in monitored areas, signifying consistent groundwater extraction in high-risk zones.
3. Seasonal Subsidence:
    - A parabolic seasonal distribution was observed, influenced by seasonal groundwater extraction rates.

Applications and Future Directions

Dr. Bonì emphasized that SubRISK+ outputs would be made publicly accessible, allowing local authorities and stakeholders to integrate findings into risk management strategies. She highlighted ongoing efforts in the Emilia-Romagna region, where outputs are being integrated into regional planning.

Future developments include:

- Expanding the project's control room capabilities to enable real-time risk management.
- Providing stakeholders with tools to incorporate EO-based subsidence data into their workflows for proactive decision-making.

Conclusion

Dr. Bonì concluded by stressing the importance of open-access data for improving urban resilience to subsidence. She emphasized the need for interdisciplinary collaboration and innovative technologies to address the challenges posed by groundwater exploitation and subsidence, ensuring the sustainable management of Italy's urban and coastal regions.

4.3.2 Assessing Future Flood Risks in African Coastal Cities: The Role of Land Subsidence and Climate-Driven Sea-Level Rise

Plate 18: Mr. Dasho´s presentation on the assessment of flood risk in African coastal cities

Mr. Oluwaseyi Dasho presented an assessment of flood risks in African coastal cities, emphasizing the compounded impacts of land subsidence and climate-driven sea-level rise (SLR) on vulnerable populations. His presentation highlighted the pressing need for accurate data and strategic planning to mitigate increasing flood hazards.

The Growing Risk in Low Elevation Coastal Zones (LECZ)

Mr. Dasho noted that by 2030, approximately 100 million people are projected to live in Africa's LECZ, with this figure doubling to 200 million by 2060 (Neumann et al., 2015). Rapid population growth in these areas increases flood exposure, as climate change accelerates SLR and land subsidence further lowers elevations.

He identified significant gaps in current flood risk assessments:

- The IPCC's Vertical Land Motion (VLM) estimates, based on sparse tide gauge data, lack the spatial resolution needed for reliable predictions in African cities.
- Africa's vulnerability is compounded by data scarcity, weak infrastructure, and limited funding for climate adaptation.

Study Objectives and Methodology

The primary goal of Mr. Dasho's study is to improve the quantification of relative sea-level rise (RSLR) in African coastal cities and assess future flood risks. To address critical data gaps, his team utilized InSAR (Interferometric Synthetic Aperture Radar) technology, which provides high spatial resolution measurements of VLM. This approach captures variations in subsidence rates that tide gauges and sparse datasets miss.

By integrating InSAR-based VLM data with sea-level rise projections, the team generated more precise estimates of RSLR and its impacts on vulnerable regions.

Key Findings

Mr. Dasho's analysis revealed the significant influence of VLM on flood risk:

1. Inundation Extent Maps:
    - High-risk areas were identified using spatially detailed VLM data, showing where land subsidence amplifies flood risks.
2. Population and Building Exposure:
    - The study quantified the number of people and structures at risk under various SLR scenarios, highlighting the urgency of targeted interventions.

Implications of Spatial Variability in VLM

The study demonstrated that spatial variability in VLM significantly affects flood risk assessments:

- Regions with higher subsidence rates face greater flood hazards, as sinking land exacerbates the impact of rising sea levels.
- Traditional models without detailed VLM data underestimate flood risks, leaving critical areas unprotected.

Conclusion and Recommendations

Mr. Dasho concluded with a powerful takeaway: Integrating InSAR-derived VLM data into flood models is essential to improve the accuracy of risk assessments and support targeted interventions. He emphasized the need for:

- Enhanced data collection and monitoring systems.
- Investments in adaptive infrastructure and early warning systems.
- Collaborative efforts to address resource gaps in African coastal cities.

By combining cutting-edge technologies with focused policy measures, Mr. Dasho's study offers a path forward for mitigating the growing risks posed by subsidence and sea-level rise in Africa's vulnerable coastal zones.

4.3.3 Coasts at Risk?! Towards Solving Challenges in Flood Hazard and Relative Sea-Level Rise Impact Assessments in Data-Sparse Coastal Lowlands

Ms. Katharina Seeger presented the challenges of assessing flood hazards and the impacts of relative sea-level rise (RSLR) in data-scarce coastal lowlands. Her research, developed in collaboration with institutions such as the Deltares Research Institute and East Yangon

University, focuses on coastal deltas in Asia and Africa, with broader implications for global risk management.

Flood Risk Projections in Coastal Deltas

Ms. Seeger referenced studies by Kirezci et al. (2020) and Nicholls et al. (2021), emphasizing that land elevation is a critical factor in understanding flood risks and the impacts of RSLR. She focused on vulnerable delta regions, including:

- The Ayeyarwady Delta in Myanmar.
- The Mekong Delta in Vietnam.
- West African deltas such as the Niger and Volta deltas.

These areas are at high risk due to a combination of sea-level rise, land subsidence, and increased precipitation-driven runoff.

Central Research Questions

Ms. Seeger highlighted two core questions driving her work:

1. How can flood exposure and RSLR impacts be assessed without access to local, high-quality data?
2. Which areas are most susceptible to monsoonal precipitation, storm surges, and/or sea-level rise-induced flooding?

Methodology and Approach

In data-sparse regions, accurate flood risk assessments are hindered by the lack of high-resolution elevation models. To address these gaps, Ms. Seeger's team employed open earth observation data and flood frequency mapping, categorizing flooding into:

- Frequent (annual) events.
- Episodic events (occasional).
- Long-term continuous flooding.

This method enabled the team to map various flood types and gain insights into flood frequency and flood-prone areas. Key findings included:

- In monsoon-affected areas, approximately 60% of the deltaic population (around 5.4 million people) is exposed to seasonal flooding.
- Over 70% of deltaic regions face combined risks from inland precipitation and coastal storm surges.
- In the Ayeyarwady Delta, nearly 2 million people live in zones highly exposed to both inland and coastal flood hazards.

Challenges in Elevation Data Accuracy

Ms. Seeger identified variability between global elevation models as a major challenge, with discrepancies of several meters significantly affecting flood risk assessments. She advocated for:

- Using multiple elevation models validated with ground-truth data where available.
- Prioritizing the acquisition and regular updating of high-accuracy elevation data to account for vertical land motion and sea-level rise processes.

Standardized, Integrative Approach

To address these challenges, Ms. Seeger proposed a standardized, integrative framework for flood hazard assessment in data-scarce coastal lowlands. This flexible framework:

- Supports risk-informed decision-making.
- Aids in developing multi-flood mitigation and adaptation strategies.
- Accounts for the interconnected processes of vertical land motion, elevation change, and sea-level rise.

Conclusion and Recommendations

Ms. Seeger concluded by emphasizing the importance of integrating various datasets into a cohesive risk management strategy. This approach:

- Provides a comprehensive understanding of combined flood risks.
- Helps policymakers in data-scarce regions create effective flood risk adaptation and mitigation plans.
- Lays the foundation for addressing the global challenges of flood hazards and RSLR impacts in vulnerable coastal areas.

4.3.4 Exploring the Possibility of Land Subsidence in Mining Areas

Mrs Harriet Ahosu, a PhD student from the Department of Geomatic Engineering, KNUST, presented a study on land subsidence in Obuasi, a mining town in Ghana's Ashanti Region. Her research investigates the areas most affected by subsidence in a region with over a century of gold mining activity, focusing on the potential impacts of mine collapse, groundwater extraction, and illegal mining activities.

Plate 19: Presentation on exploring the potential for land subsidence in mining areas by Mrs. Ahosu

Study Objectives and Methodology

The study aims to identify:

- Key areas of subsidence in Obuasi.
- The factors contributing to observed land displacement, include mining and groundwater extraction.

Using Synthetic Aperture Radar (SAR) data processed through the Alaska Satellite Facility's online platform, the study analysed:

- Vertical displacement and Digital Elevation Model (DEM) data between March and August 2020.

Preliminary Findings

Initial results revealed:

- Subsidence primarily occurs in low-lying areas, with significant vertical displacements ranging from 7 cm uplift to 10 cm subsidence.
- Clusters of displacement, though some results were affected by data noise, require further validation.

Next Steps and Planned Enhancements

Mrs Ahosu highlighted the need for additional analyses to strengthen the findings. Planned steps include:

1. Acquiring more SAR images to analyze long-term trends.
2. Integrating geological data and groundwater extraction records for a comprehensive assessment.
3. Using historical elevation data, LIDAR surveys, and mapping the proximity of subsidence hotspots to mining operations.

4. Conducting field visits to validate findings and understand whether human activities (e.g., mining) or natural processes drive the observed subsidence.

Significance of the Research

This study underscores the importance of assessing the effects of mining activities on land stability, particularly in regions with extensive gold mining history like Obuasi. By identifying and understanding the causes of subsidence, the research aims to:

- Inform strategies to mitigate risks associated with subsidence in mining communities.
- Contribute to the development of sustainable mining and land management practices.

Mrs Ahosu's work highlights the need for continued monitoring and data integration to address land stability concerns in Ghana's mining areas, ensuring the safety of both infrastructure and local communities.

4.4 DISCUSSION SESSION FOR SESSIONS 1&2

The questions and responses in relation to presentations given for sessions one and two of Day Two are shown in Table 1.

Table 1: Q&A session after the presentation for day 2

Question	Answer/Discussion
Does underground mining near Obuasi contribute to observed subsidence?	Mining-related activities, such as groundwater withdrawal and abandoned unsupported underground spaces, can exacerbate land instability. The role of illegal mining was also highlighted as an area for further investigation.
Are subsidence trends always linear, as assumed in sea-level rise projections?	Subsidence is often nonlinear and can accelerate or decelerate over time. Models should account for temporal variability in subsidence rates to improve the accuracy of sea-level rise and flood risk projections.
How does the choice of Digital Elevation Models (DEMs) impact subsidence studies?	The choice of DEM significantly influences exposure estimates. Uncertainty in elevation data often exceeds the uncertainty in vertical land motion projections, making the selection of accurate DEMs critical for vulnerability assessments.
What are the limitations of LiDAR in land subsidence studies?	While LiDAR is effective for collecting elevation data and mapping land changes, it cannot sense water surfaces, limiting its application in sea-level rise studies.
What methodologies are recommended for different types of regions in subsidence studies?	Persistent Scatterer Interferometry (PSI) is recommended for urban areas due to high coherence. Small Baseline Subset (SBAS) techniques are suited for vegetated regions to address lower coherence challenges.

Should vulnerability assessments include ecosystem impacts?	Yes, there is a need to integrate ecosystem services into subsidence impact studies. This includes studying effects on biodiversity and wetlands to provide a more comprehensive understanding of subsidence impacts.
What is the importance of interdisciplinary collaboration in subsidence studies?	Engaging biologists and other specialists helps broaden the scope of subsidence impact assessments, particularly for ecosystems and community vulnerabilities.

Plate 20: Interactive discussion during Q&A session

4.5 NETWORKING AND COCKTAIL EVENING

Day Two concluded with a vibrant cocktail reception (Plate 21), providing participants with an opportunity to unwind and network in a relaxed setting. The evening was spent enjoying food and drinks while engaging in meaningful conversations. This informal atmosphere allowed attendees to deepen connections, share insights, and address questions that couldn't be explored during the formal sessions due to time constraints. The networking event proved invaluable for fostering collaboration and enriching the overall learning experience.

Plate 21: Networking after the presentation session on the second day

5.0 DAY 3: MAIN SCIENTIFIC WORKSHOP II

5.1 INTRODUCTION

Day 3 of the workshop featured insightful presentations divided into two sessions, each addressing critical aspects of land subsidence. Session 1 focused on the Impacts and Hazards of Subsidence, examining its effects on urban infrastructure, ecosystems, and coastal vulnerability. Session 2 shifted to Modelling and Mitigation Techniques, highlighting innovative approaches and practical solutions for managing and reducing subsidence-related challenges. Together, these sessions provided participants with a comprehensive understanding of subsidence risks and actionable strategies to foster resilience in coastal regions. Key takeaways included the need for advanced modelling techniques, the integration of nature-based solutions, and the importance of community engagement in mitigation efforts.

5.2 ORAL PRESENTATIONS: SESSION 1- IMPACTS AND HAZARD OF SUBSIDENCE

5.2.1 Revisiting the Impact of Relative Sea-Level Rise on the Venice Lagoon Italy

Plate 22: Presentation on vulnerabilities of the Venice lagoon to RSLR

Dr. Luigi Tosi, from the Institute of Geosciences and Earth Resources at the National Research Council in Padova, Italy, presented the vulnerabilities of the Venice Lagoon to relative sea-level rise (RSLR). His work, co-authored with researchers from the University of Padova and other institutions, examined how subsidence and RSLR are reshaping Venice's historical landscapes and ecosystems.

Geological Setting and Subsidence

Dr. Tosi explained that Venice is situated in a foreland sedimentary basin between the Alps and the Apennines, making it naturally subsiding. Key factors include:

- Natural subsidence rates range from 0.5 to 3 mm per year, primarily caused by the compaction of Holocene deposits.
- Human interventions, such as hydraulic land reclamation, create a low-lying coastal plain susceptible to subsidence.

During the 1960s industrial boom, groundwater extraction for industrial use accelerated subsidence rates to nearly 10 mm per year. Following the Italian government's halt on groundwater exploitation in 1970, subsidence returned to natural rates, but by then, Venice had lost approximately 40 cm of elevation due to a combination of subsidence and RSLR.

Impact of RSLR on Flooding

The ground elevation loss and RSLR have significantly increased the frequency of exceptionally high tides, heightening Venice's flood vulnerability. While subsidence rates in Venice are lower than in some major coastal cities, the cumulative effect of RSLR has led to a growing number of high-water events.

To mitigate flooding, mobile barriers were installed at the lagoon inlets in 2020. These barriers effectively protect Venice's historic centre during high tides exceeding 110 cm, but they also restrict sediment flow, which is vital for the stability of the lagoon's salt marshes.

Ecosystem Vulnerabilities and Geodiversity

Dr. Tosi introduced a novel perspective on Venice's vulnerability to RSLR, emphasizing the importance of protecting the lagoon's tidal morphologies and ecosystem services rather than focusing solely on the historic centre. Key points included:

- The concept of "geodiversity", refers to the loss of morphological diversity in the lagoon, such as salt marshes and intertidal zones.
- These tidal morphologies are highly sensitive to RSLR and critical for sustaining the lagoon's biodiversity.

Vulnerability Mapping

Using an index-based method that integrates hazard and sensitivity indicators, Dr. Tosi's team created vulnerability maps for Venice Lagoon. Findings included:

- By 2050, approximately 40% of the lagoon is projected to face strong to extreme vulnerability.
- Increased frequency of RSLR-driven events is expected to result in marinization, with salt marshes likely converting to subtidal flats.

Key Takeaways

Dr. Tosi emphasized that even low subsidence rates (a few mm/year) can have severe consequences for coastal ecosystems, particularly in low-lying areas. He highlighted:

- The critical need for integrating RSLR and subsidence data into vulnerability assessments.
- The importance of safeguarding not just urban centres but also ecosystem functions and morphological diversity.

Conclusion

Venice's case serves as a vital example for other low-lying coastal systems worldwide, underscoring the need for:

- Comprehensive vulnerability assessments that combine subsidence and RSLR data.
- Decision-making tools for sustainable land-use and conservation policies. Dr. Tosi concluded that protecting coastal ecosystems requires a shift from purely urban-focused strategies to holistic approaches that account for both natural and human-induced drivers of change.

5.2.2 Satellite-Based Mapping of Coastal Land Subsidence and Sea-Level Rise Under Future Climate Scenarios for Predicting Coastal Hazards Across West Africa

Dr. Samuel Olumide Akande, from the Centre for Space Research and Applications at the Federal University of Technology, Akure, Nigeria, presented a study on using satellite-based techniques to map coastal land subsidence and sea-level rise (SLR) across West Africa. His research is part of the EARWAC initiative (Enhancing Adaptation and Resilience Against Multi-Hazards Along West Africa's Coasts), which aims to improve coastal hazard predictions under future climate scenarios.

Plate 23: Presentation on using satellite-based techniques to map coastal land subsidence and SLR across Wesst Africa

Drivers of Sea-Level Rise and Coastal Vulnerability

Dr. Akande identified the key drivers of SLR as:

1. Thermal expansion of seawater due to global warming.
2. Melting glaciers and ice sheets.
3. Groundwater extraction and tectonic activity, contribute to local land subsidence.

He highlighted the combined impact of these factors in West African coastal areas, where low-lying regions face heightened risks of inundation, erosion, and threats to infrastructure, livelihoods, and ecosystems.

Research Objectives

The primary goals of the study were to:

1. Quantify land subsidence and SLR using satellite-based techniques.
2. Identify areas vulnerable to coastal hazards.
3. Project future scenarios of SLR and subsidence under RCP 4.5 (moderate emissions)

and RCP 8.5 (high emissions) pathways, assessing potential impacts by 2050 and 2100.

Methodology

The study employed:

- Statistical downscaling for regional climate projections.
- Integration of satellite imagery and Digital Elevation Models (DEMs) for precise analysis.

Key data sources included:

- CMIP5 climate models for future climate scenarios.
- PSMSL Mean Sea Level Network and ODINAfrica/GLOSS stations for sea-level data.
- Satellite-based DEMs such as Tandem-X, ALOS DSM, ASTER GDEM, and SRTM for elevation mapping.

Findings

- Sea-Level Rise Projections:
    - Under RCP 4.5, cities like Takoradi (Ghana), Lagos (Nigeria), and Port Sonara (Cameroon) are projected to see SLR exceed 0.4 m by 2100.
    - Under RCP 8.5, these regions, along with Abidjan (Ivory Coast) and Sao Tome, could face SLR of over 0.8 m, significantly increasing flood risks.
- Lagos Case Study:
    - Analysis of land use and land cover changes (1972–2024) showed substantial urban expansion, heightening vulnerability to flooding.
    - DEM analysis identified lower-lying areas as particularly susceptible to subsidence and SLR.

Recommendations for Resilience

Dr. Akande emphasized the need for integrated approaches to enhance societal resilience, categorized into:

- Threshold, coping, recovery, adaptive, and transformative capacities.

He proposed measures such as:

1. Urban planning to regulate development in vulnerable areas.
2. Water conservation to reduce groundwater extraction and its contribution to subsidence.
3. Public awareness campaigns to engage communities and build resilience.

Conclusion and Tools

Dr. Akande highlighted the importance of satellite-based monitoring for predicting and preparing for future coastal hazards in West Africa. He introduced the EARWAC project dashboard, a tool designed to:

- Enable stakeholders to access and apply coastal risk data.
- Support informed decision-making for risk mitigation and resilience planning.

This research highlights the critical role of integrating climate projections, subsidence data, and SLR models to safeguard vulnerable coastal communities and ecosystems in West Africa.

5.2.3 *Impacts of Land Use and Coastal Development on Marine and Coastal Ecosystems*

Plate 24: Presentation on the environmental and socio-economic challenges affecting the coastline in Lagos

Ms. Temitope Adewale opened her presentation by addressing the urgent environmental and socio-economic challenges affecting the Ibeju-Lekki coastline in Lagos, Nigeria. Framing her study within the context of rapid urbanization and industrialization, she emphasized how activities such as vegetation removal, sand dredging, and site clearing are transforming the coastal landscape. These changes are not only reshaping ecosystems but also threatening biodiversity and livelihoods, particularly for communities dependent on small-scale fisheries. Adewale shared the critical need for understanding and mitigating these impacts to ensure the long-term sustainability of marine and coastal resources.

Land Use Change Dynamics (1984–2020)

Ms. Adewale presented compelling evidence of drastic changes in land use patterns over 36 years, illustrating the scale of transformation in the Ibeju-Lekki coastline. Ibeju-Lekki has seen forest cover drop by 14% and farmland shrink by 62%. Meanwhile, urban areas grew by 48%, and industrial developments exploded by 175%, driven by massive infrastructure projects like refineries and ports. These changes have dramatically altered the environment.

Impacts on Fisheries

The intensification of land use changes has had direct and measurable consequences for small-scale fisheries, a vital source of livelihood for local communities:

- Reduction in Fish Abundance: Ms. Adewale demonstrated how land use changes negatively impacted the catch per unit effort (CPUE) for key fish species, such as *Sardinella maderensis*. Her analysis revealed a significant reduction of 0.85 CPUE units ($p = 0.002$) directly linked to environmental degradation, highlighting the cascading effects on fish populations.
- Threat to Livelihoods: The decline in fish abundance poses serious risks to food security, income, and the socio-economic stability of fishing communities, underlining the need for urgent intervention to protect these resources.

Coastal Land Subsidence and Erosion

Ms. Adewale also highlighted the alarming evidence of land subsidence and coastal erosion along the Ibeju-Lekki coastline:

- Shoreline Retreat: Receding shorelines and the loss of coconut trees and mangroves were reported in 24 out of 30 surveyed communities, illustrating the severity of the problem.
- Community Displacement: Coastal erosion has forced fisherfolk to abandon traditional fishing areas, destabilizing community structures and livelihoods.
- Loss of Natural Buffers: The destruction of mangroves and other coastal buffers has amplified vulnerability to storm surges and flooding, further exacerbating the impacts of subsidence and erosion.

Discussion and Broader Implications

Ms. Adewale's findings revealed the complex interplay between economic development and environmental degradation in the Ibeju-Lekki region. While industrial projects offer significant economic opportunities, they also pose substantial risks to ecological sustainability and social stability. The rapid transformation of the coastal landscape underscores the urgent need for policies and interventions that balance economic growth with environmental protection.

Conclusion

Ms. Adewale called for the implementation of marine spatial planning and integrated coastal management policies to address the adverse impacts of land use changes:

- Preserve Ecosystems: Protect critical habitats such as mangroves and wetlands to maintain ecological balance.
- Safeguard Fisheries: Mitigate habitat loss and ensure sustainable resource use to support small-scale fisheries.
- Minimize Land Subsidence and Erosion: Implement strategies to reduce coastal subsidence and erosion through sustainable land-use practices.
- Promote Sustainable Development: Foster development strategies that integrate industrial growth with the conservation of natural resources and community livelihoods.

- Ms. Adewale's presentation served as a stark reminder of the urgent need to protect marine and coastal ecosystems. By advocating for a balanced approach to development, she laid the groundwork for actionable solutions to safeguard the environment and the communities that depend on it.

5.2.4 Land Use Land Cover Changes and their Impacts on the Lower Pra River Basin Ecosystem

Plate 25: Presentation on impacts of LULC on the estuarine and coastal ecosystems of the Lower Pra River Basin

Prof. Cynthia Borkai Boye, from the University of Mines and Technology, Ghana, presented her research on the impacts of Land Use and Land Cover (LULC) changes on the estuarine and coastal ecosystems of the Lower Pra River Basin. Conducted in collaboration with Baffoe and Asante, her study explored how human activities and environmental changes are transforming these ecosystems, with significant socio-economic and ecological impacts.

Significance of Coastal Ecosystems

Prof. Boye emphasized the critical role of coastal ecosystems in:

- Regulating Earth's temperature and sequestering carbon.
- Acting as natural buffer zones during tidal waves and heavy precipitation.

However, these ecosystems face global declines in productivity and function due to sea-level rise, land subsidence, and anthropogenic activities.

Drivers of LULC Changes in the Lower Pra River Basin

In Ghana, rapid population growth in coastal areas, coupled with illegal mining activities along the Pra River, has accelerated LULC transformations. These changes:

- Pollute water bodies and increase sediment deposition.
- Drive groundwater extraction, potentially leading to subsidence, as surface water becomes unusable.

Study Objectives

The study aimed to:

1. Detect and quantify LULC changes in the Lower Pra River Basin (2003–2023).

2. Analyze shoreline change trends using the Digital Shoreline Analysis System (DSAS).
3. Assess sea-level rise impacts on shoreline shifts and investigate potential land subsidence.

Methodology

Prof. Boye’s team used remote sensing techniques and multi-spectral satellite images from the USGS Earth Explorer for LULC analysis. Key steps included:

- Supervised classification with a maximum likelihood algorithm to map changes.
- Utilizing ArcGIS and Google Earth for processing.
- Shoreline analysis using DSAS to create a baseline and digitize shoreline data, measuring erosion and accretion trends over time.

Key Findings

1. LULC Transformations:
    - Significant reductions in forest and farmland, converted into settlements at an average rate of 5% per year.
    - Stable water bodies, but with noticeable eastward movement of the Pra River estuary, attributed to increased sediment deposition from upstream illegal mining.
2. Shoreline Change Analysis:
    - Erosion dominated most areas, while sections near the estuary showed stability or slight accretion.
    - Changes in the river's course led to flooding in Anglo township, threatening livelihoods and ecosystems.
3. Socio-Economic Impacts:
    - Farmland losses near the estuary reduced agricultural productivity.
    - Periodic flooding events in Anglo township disrupted local communities.

Recommendations

To address these challenges, Prof. Boye recommended:

1. Dredging the original course of the Pra River estuary to reduce flooding risks in Anglo township.
2. Adopting a balanced approach to regional development, prioritizing economic growth alongside environmental conservation.
3. Conducting further research using Sentinel-1 datasets to monitor coastal land subsidence and assess vulnerability to sea-level rise.

Conclusion

Prof. Boye concluded that the LULC changes in the Lower Pra River Basin pose significant challenges, including the degradation of natural habitats and increased flood risks. She stressed the urgency of implementing sustainable land-use policies and enforcing regulations, particularly against illegal mining, to preserve Ghana's coastal ecosystems and protect local communities from escalating environmental risks.

5.2.5 The Contribution of Coastal Land Subsidence to Potential Sea-Level Rise Impact in Data-Sparse Settings: The Case of Ghana's Volta Delta

Plate 26: Presentation on coastal land subsidence in Ghana´s Volta delta

Dr. Selasi Yao Avornyo, a postdoctoral fellow from the University of Ghana, delivered an insightful presentation on coastal land subsidence in Ghana's Volta Delta, emphasizing its role in amplifying the impacts of sea-level rise (SLR) in data-sparse settings. The presentation addressed key knowledge gaps and explored the relationship between subsidence, coastal hazards, and delta vulnerability.

The Volta Delta: A Dynamic and Vulnerable System

Dr. Avornyo described deltas as dynamic systems shaped by riverine and coastal processes, highlighting the Volta Delta's economic and societal significance:

- Area: Constitutes only 7% of Ghana's landmass.
- Population and Industry: Support over 25% of the population and 70% of industrial activities.

The delta faces severe coastal hazards, including:

- Erosion.
- Flooding.
- Saltwater intrusion.

These hazards are exacerbated by climate change and land subsidence, with historical data from 1974 to 2023 revealing alarming rates of shoreline recession, endangering communities and livelihoods.

Measuring Subsidence in the Volta Delta

Using geodetic techniques like InSAR and GNSS, Dr. Avornyo identified subsidence rates of up to -9.16 mm/year, with over 99% of persistent scatterers indicating subsidence, particularly in floodplains near dominant lagoons.

Key Drivers of Land Subsidence

Dr. Avornyo outlined the primary contributors to subsidence in the Volta Delta:

1. River damming: The Akosombo Hydroelectric Dam has reduced sediment fluxes to the coast by 90%, thus reducing the recompensation of eroded sediment.
2. Groundwater and hydrocarbon extraction: These activities reduce subsurface pore pressure, accelerating subsidence.
3. Land drainage: Removal of water intensifies soil compaction.
4. Overloading by infrastructure: Heavy buildings and structures add pressure to the subsurface.

Integration of Subsidence and Sea-Level Rise

By combining subsidence data with SLR projections, Dr. Avornyo demonstrated:

- Subsidence could increase inundation extents by approximately 10%.
- The impacts are magnified under long-term scenarios and high-emission pathways.

Recommendations and Call to Action

Dr. Avornyo emphasized the urgency of addressing subsidence, proposing several actions:

1. Robust Monitoring Systems:
    - Implement advanced geodetic measurements (e.g., InSAR and GNSS).
    - Develop localized flood risk models.
2. Sustainable Practices:
    - Prioritize sediment management to restore natural sedimentation processes.
    - Reduce reliance on groundwater extraction.
3. Integrating Subsidence into Coastal Planning:
    - Use subsidence data in coastal hazard assessments and infrastructure planning.

Conclusion

Dr. Avornyo highlighted the cascading effects of subsidence on coastal hazards, advocating for:

- Informed policy interventions.
- Interdisciplinary approaches to coastal zone management.

The presentation showed the need to safeguard Ghana’s vulnerable coastal regions, ensuring resilience against the combined impacts of subsidence and sea-level rise.

5.3 INTERACTIVE POSTER SESSION

The networking and poster session took place on the third day of the Coastal Land Subsidence workshop. A total of seven poster presentations were displayed (Plate 27). The session was interactive where participants engaged the various poster presenters on their various research. This session also provided a platform for networking among participants.

Plate 27: Display of some poster presentation on the third day

5.4 ORAL PRESENTATIONS: SESSION 2- MODELLING AND MITIGATION TECHNIQUES

5.4.1 Modelling Land Subsidence Accounting for Uncertainties by Prof. Pietro Teatini

Prof. Pietro Teatini's presentation on the third day was on advanced modelling techniques to address uncertainties in land subsidence analysis. His work focuses on three major case studies that illustrate methods for handling variability in subsidence prediction due to diverse soil compressibility and hydrogeological conditions.

Key Challenges in Subsidence Modelling

Prof. Teatini highlighted that subsidence models face challenges due to:

- Heterogeneous aquifer systems, such as the Keta/Dahomey/Cotier aquifer system near the Gulf of Guinea.
- Limited data for estimating critical parameters like bulk compressibility and aquifer characteristics in regions with sparse datasets.

Case Studies

1. Beijing Aquifer System: Stochastic Simulations

- Method: A facies model approach was used to simulate subsurface properties based on sedimentary structures.
- Model: A 3D groundwater flow and geomechanical model with 100 facies realizations was employed to evaluate displacement fields.
- Findings:
  - Stochastic simulations estimated probabilities of facies transitions in a 3D domain.
  - Variability in sedimentary facies strongly influenced subsidence, especially in areas of extensive groundwater extraction.

2. Arlua Hydrocarbon Reservoir, Northern Adriatic Sea: Data Assimilation

- Method: Integration of real-time GNSS, InSAR, bathymetric, and extensometer data into a geomechanical model.
- Technique: A data assimilation algorithm was used to continuously update model parameters with each new dataset.
- Findings:
  - Continuous updates reduced prediction uncertainties over time.
  - This approach is critical for managing long-term subsidence in hydrocarbon reservoirs to minimize environmental and structural impacts.

3. Alto Guadalentin Aquifer, Spain: Bayesian Inversion

- Method: A Bayesian inversion framework with sparse grids to assess parameter uncertainties.
- Data:
    - Used InSAR measurements and data from 39 observation points to calibrate the model.
- Findings:
    - Achieved robust calibration of the aquifer model.
    - Simulated subsidence rates closely matched observed data, particularly in areas undergoing long-term water extraction.
    - The framework enabled probabilistic subsidence predictions and efficient uncertainty analysis.

Key Insights and Recommendations

1. Soil Compressibility:
    - Identified as a highly uncertain parameter but essential for accurate subsidence modelling.
    - Gradual acquisition of new data can reduce uncertainty and enhance reliability.
2. Complex Numerical Models:
    - By employing advanced modelling techniques, subsidence predictions with quantified uncertainties and standard deviations are achievable.
3. Data Integration:
    - Continuous incorporation of real-time data into models improves predictions and provides actionable insights for subsidence management.

Conclusion

Prof. Teatini emphasized the importance of addressing uncertainties in subsidence modelling through:

- The use of stochastic simulations, data assimilation, and Bayesian inversion frameworks.
- Expanding data collection efforts to refine critical parameters like soil compressibility.
- Gradual reduction of uncertainty as new data is integrated, ensuring more reliable and actionable predictions for land subsidence and its impacts.

5.4.2 *Assessing the Impact of Sea Level Rise, Precipitation, and Subsidence on Flooding Trends in Coastal Communities in Ghana*

Plate 28: Presentation on the compounded effects of SLR, precipitation and land subsidence on flooding trends in Ghana´s coastal communities

Michael Kwame-Biney delivered a detailed presentation on the compounded effects of sea-level rise (SLR), precipitation, and land subsidence on flooding trends in Ghana’s coastal communities. The study focused on two distinct environments:

- Mumford: A low-lying coastal area.
- Atiteti: A rapidly subsiding deltaic zone.

Using geospatial analysis and modelling techniques, the research examined the interplay between shoreline evolution, SLR, relative sea-level rise (RSLR), and precipitation-driven flooding.

Key Insights and Findings

1. Shoreline Evolution

- Atiteti experienced severe erosion, with mid-term rates ranging from -15 m/year to -23 m/year, driven by both natural and anthropogenic activities.
- Drone imagery revealed rapid shoreline changes, highlighting significant land loss over just a few months.

2. Flooding Scenarios Under SLR and RSLR

- Land subsidence rates measured via InSAR were approximately -4.5 mm/year ± 0.4 mm/year.
- Simulations under IPCC SLR scenarios showed:
    - SLR-only inundation: 2%-9% of land.
    - RSLR inundation (including subsidence): 5%-33% of land.

3. Precipitation-Driven Flooding

Using the Malstrøm model, 50 years of rainfall data revealed:

- A declining rainfall trend, yet increased flood risks due to subsidence.
- Community engagement and ground-truthing validated flooding patterns, enhancing model calibration.

4. Applications

- The study highlighted the role of early-warning systems in flood-prone areas.
- Highlighted the use of models like Malstrøm for:
    - Urban planning.
    - Insurance risk assessment.
- Emphasized the need for policymakers to integrate subsidence and flood models into national coastal management strategies.

Recommendations

1. Continuous Monitoring:
    - Establish systems to track coastal dynamics, including subsidence and flooding trends.
2. Enhance Monitoring Systems:
    - Improve tidal and flood monitoring systems to strengthen early-warning capabilities.
3. Promote Nature-Based Solutions:
    - Encourage solutions like sand motors and artificial dunes.
    - Enforce sand mining regulations to reduce environmental degradation.
4. Strengthen ICZM Frameworks:
    - Support integrated coastal zone management (ICZM) for sustainable development.

Conclusion

Michael Kwame-Biney emphasized the urgent need to address the multi-faceted challenges confronting Ghana's coastal communities. The presentation highlighted:

- Robust data collection as a foundation for informed decision-making.
- The use of innovative modelling tools to predict and mitigate flooding.
- The importance of collaborative approaches to address the compounded impacts of climate change and subsidence on vulnerable coastal regions.

5.4.3 Leveraging Nature-Based Solutions to Address Coastal Vulnerabilities in Africa

Plate 29: Presentation on the use of NbS to mitigate the growing vulnerabilities of African coastlines to erosion and flooding

Ms. Chinomnso C. Onwubiko, from the University of Cape Coast, Ghana, presented on the use of Nature-Based Solutions (NbS) to mitigate the growing vulnerabilities of African coastlines to erosion and flooding. Her presentation highlighted the economic, ecological, and societal benefits of sustainable approaches like mangrove restoration to build resilience against coastal subsidence and climate impacts.

Challenges Facing African Coastlines

Ms. Onwubiko outlined the key challenges exacerbating vulnerabilities along Africa's coastlines:

1. Erosion and Flooding:
   - Increasingly driven by environmental degradation and land subsidence, which lower land elevation and intensify risks.
2. Economic Impacts:
   - Coastal damage leads to annual economic losses exceeding $2 billion in some regions, impacting growth and livelihoods.
3. Population Pressures:
   - Rapid urbanization and population growth along coastlines contribute to subsidence and amplify environmental degradation.

Advocacy for Nature-Based Solutions (NbS)

Ms. Onwubiko advocated for NbS as a sustainable, cost-effective alternative to traditional engineering methods like seawalls. Key NbS strategies include:

1. Mangrove Restoration:
   - Mangroves act as natural barriers, reducing wave impacts, stabilizing coastlines, and supporting biodiversity.
   - The Global Mangrove Alliance aims to restore 15 million hectares of mangroves by 2030.
2. Wetlands and Coastal Dunes:
   - These ecosystems serve as buffers against storm surges, erosion, and flooding while supporting biodiversity and livelihoods.

Use of the InVEST Coastal Vulnerability (CV) Model

Ms. Onwubiko introduced the InVEST Coastal Vulnerability (CV) model, developed by Stanford University’s Natural Capital Project. This integrated tool helps visualize disaster risk and prioritize conservation efforts by addressing key questions:

- Where do marine and coastal habitats offer flood protection?
- What level of protection do these habitats provide?
- Which areas are best suited for conservation or restoration?

The model assumes that intact ecosystems offer greater protection than degraded ones and emphasizes the role of fixed habitats like mangroves.

Model Findings and Applications

- The model's outputs compare "exposure-with" and "exposure-without" habitat scenarios, demonstrating that mangroves significantly reduce flood exposure.
- Results showed that mangroves and similar ecosystems are essential in minimizing risk and promoting resilience.

Community Involvement and Awareness

Ms. Onwubiko emphasized that community awareness and positive perceptions of NbS are critical for their success. Local engagement ensures sustainability and fosters a long-term commitment to conservation.

Recommendations

To strengthen the role of NbS in African coastal management, Ms. Onwubiko proposed:

1. Policy Support:
    - Integrate NbS into Disaster Risk Reduction (DRR) strategies.
2. Public Awareness:
    - Promote understanding of ecosystems like mangroves in enhancing coastal resilience.
3. Utilization of Models:
    - Incorporate tools like the InVEST CV model in disaster management for informed and holistic outcomes.

Conclusion

Ms. Onwubiko concluded that NbS offers a pathway to sustainable coastal management in Africa. By integrating these solutions, nations can:

- Protect biodiversity,
- Strengthen adaptive capacities, and
- Support sustainable development in the face of climate and environmental challenges.

5.4.4 Projecting and Mitigating Land Subsidence in Major Deltaic Regions

Dr. Philip Minderhoud discussed the critical issues of projecting and mitigating land subsidence in major deltaic regions worldwide, with a focus on the Mekong Delta. His presentation highlighted how both natural and human-induced subsidence exacerbate relative sea-level rise (RSLR), posing serious risks to densely populated coastal zones.

Subsidence in Deltaic Environments

Dr. Minderhoud described subsidence as an inherent process in deltaic environments influenced by:

- Natural sediment compaction.
- Human-induced activities, such as groundwater extraction, often result in much higher subsidence rates.

He noted that subsidence rates in some deltas can reach up to 200 mm per year, far outpacing global sea-level rise rates of 3-10 mm per year. This significant contribution to RSLR heightens flood risks in coastal regions.

Critical Gaps in Research

Dr. Minderhoud emphasized that only 7% of sea-level rise literature mentions subsidence, and less than 1% quantifies it, leaving a substantial gap in understanding its impact on coastal flood risks. The spatial and temporal variability of subsidence creates a "4D puzzle in the subsurface," making accurate projections challenging.

The Mekong Delta Case Study

The Mekong Delta, home to approximately 18 million people, serves as a prime example of accelerated subsidence driven by groundwater extraction. Key findings included:

- Subsidence rates doubled within a decade:
    - 2006-2010: 2-3 cm per year.
    - 2014-2019: 5-6 cm per year.
- Continued extraction will lead to further subsidence, increasing the region's vulnerability to:
    - Flooding.
    - Saltwater intrusion.

Dr. Minderhoud's team modelled 25 years of groundwater extraction to illustrate the escalating costs of unchecked extraction. His key message was: "Groundwater extraction is not free—you pay with elevation and salinization."

Strategies for Managing Subsidence

Dr. Minderhoud outlined three main strategies for addressing subsidence in deltaic regions:

1. Prevention:
    - Avoid activities that accelerate subsidence, such as:
        - Over-extraction of groundwater.
        - Drainage and sediment starvation.
2. Mitigation:
    - Implement measures like:
        - Smart water management.
        - Maintaining wet soil layers to minimize compaction.
    - Address sediment starvation to promote natural sedimentation.
3. Adaptation:
    - Use infrastructural and nature-based solutions, including:
        - Dykes and flood protection systems.
        - Sedimentation strategies to enhance coastal elevation.

A Success Story: Bangkok, Thailand

Dr. Minderhoud highlighted Bangkok as a model for managing subsidence effectively:

- The introduction of the Groundwater Act (1977) and the Groundwater Tariff and Conservation Fee (1985) significantly reduced groundwater extraction.
- Over three decades, these policies stabilized groundwater levels and subsidence rates, offering lessons for other regions.

Recommendations

Dr. Minderhoud stressed the need for:

1. Incorporating Subsidence into IPCC Assessments:
    - Recognize subsidence alongside sea-level rise in climate models to improve risk assessments.
2. Learning from Effective Policies:
    - Regions like the Mekong Delta can adopt measures similar to those in Bangkok to mitigate future risks.
3. Early Intervention:
    - Proactive management can reduce future costs and environmental degradation in deltaic regions.

Conclusion

Dr. Minderhoud concluded that addressing subsidence is essential for safeguarding deltaic regions against flooding, infrastructure damage, and habitat loss. He emphasized that integrating subsidence into climate planning is critical for developing sustainable strategies to manage these risks. Early intervention is key to avoiding the long-term consequences of "sinking deltas.

5.5 QUESTIONS AND ANSWERS SESSION

The Day 3 Q&A session was highly engaging, featuring diverse inquiries that spanned technical, ecological, and policy-focused aspects of land subsidence measurement, modelling, and mitigation strategies. The panellists provided detailed responses, offering valuable insights as shown in Table 2.

Table 2 Q&A session after the presentation for day 3

Question	Response
How can elevation changes along the coast be attributed to subsidence or erosion?	Panelists clarified that inland reference points are used for subsidence measurement to avoid uncertainties caused by coastal erosion, ensuring accurate assessments of subsidence rates.
Mangroves are absent in sandy coastal areas near communities. How effective are they?	While mangroves may not be directly adjacent to sandy coastal communities, panellists emphasized their role in flood mitigation and stressed the importance of community education on mangroves' ecological benefits.
What innovative strategies can manage coastal erosion and flooding in Ghana?	Sand motors and artificial dunes were discussed as potential strategies. Panelists highlighted the need for feasibility studies to assess the effectiveness of these solutions in different coastal zones.
How are population density and migration accounted for in flood modelling?	Panellists shared that they use census data for population projections but acknowledged the importance of incorporating migration dynamics for more accurate flood risk assessments.
How can the risks of subsidence and groundwater over-extraction be effectively communicated to policymakers?	Panelists recommended moving beyond awareness campaigns to quantify the economic impacts of subsidence (e.g., associating monetary value with elevation loss). They cited Jakarta's success as a model for engaging governments.

Broader Discussions

1. Innovative Mitigation Strategies:
    - Sand motors and artificial dunes were highlighted by Michael Kwame-Biney as promising methods for managing coastal risks. However, panellists emphasized the need for region-specific feasibility studies to determine their suitability and effectiveness.
2. Economic Advocacy for Policy Change:

- Panelists stressed the importance of demonstrating the economic costs of subsidence, linking it to infrastructure damage, flood mitigation expenses, and land loss. Quantifying impacts can make the issue more compelling for policymakers.

3. Lessons from Jakarta:
    - Jakarta’s subsidence management efforts, including limiting groundwater extraction and implementing collaborative frameworks with international support, were shared as examples of effective policy-driven solutions.

Conclusion

The session accentuated the importance of integrating technical solutions, community education, and economic advocacy to address land subsidence effectively. Panelists emphasized the need for tailored strategies, enhanced data integration, and collaborative approaches to mitigate the growing challenges posed by subsidence and coastal hazards.

Plate 30: Q&A session after presentation

6.0 DAY 4: POLICY & PLANNING (HIGH PANEL DISCUSSION)

6.1 WELCOME ADDRESS

The welcome address was delivered by Professor Kwasi Appeaning Addo, who warmly acknowledged the contributions of Ms. Clementine Dardy, the Country Director of AFD, to the event. He expressed gratitude for her presence and the critical role she plays in fostering partnerships and advancing sustainable development in the region.

He emphasized the importance of the gathering, noting its unique opportunity to bring together experts, researchers, and stakeholders to address pressing challenges.

Professor Appeaning Addo concluded by expressing his optimism for a productive session and his gratitude to all attendees for their dedication to addressing shared challenges.

6.2 KEYNOTE ADDRESS

Plate 31: Keynote address being delivered by Ms. Clementine Dardy

The keynote address for the session was delivered by Clementine Dardy, who began by acknowledging the invaluable contributions of the ENGULF Programme, funded by the AFD. Ms. Dardy expressed her deep gratitude for their commitment to fostering research and knowledge sharing, which has been instrumental in organizing this event.

In her address, Ms. Dardy underscored the critical importance of the session, describing it as a unique opportunity to unite the scientific community from West Africa and the Gulf of Guinea region to address the pressing issue of coastal subsidence. She highlighted subsidence as a phenomenon with far-reaching economic, social, and environmental consequences, yet one that remains insufficiently understood in the region. This gathering, she emphasized, seeks to enhance collective understanding and foster a much-needed regional approach to tackling this challenge.

Ms. Dardy elaborated on the mission of the AFD, which focuses on promoting fair and sustainable development. AFD achieves this by building strong connections between experts, researchers, and local stakeholders, enabling coordinated and adaptive responses. She noted that AFD's initiatives span essential areas such as sustainable agriculture, environmental protection, infrastructure development, energy, and urban planning, all of which are deeply intertwined with the challenges posed by coastal subsidence.

Furthermore, Ms. Dardy emphasized the significance of collaboration across administrative borders, acknowledging that issues such as subsidence transcend national boundaries. She highlighted the need for collective efforts to not only develop concrete solutions but also to strengthen local capacities to address these challenges effectively.

Ms. Dardy expressed her optimism about the progress made so far, noting that the results presented and the evident interest in the topic reflects a strong commitment to advancing shared goals. However, she acknowledged the ongoing challenge of mobilizing policymakers and practitioners to translate research findings into actionable policies.

In closing, Ms. Dardy expressed her confidence that through sustained collaboration and commitment, the participants would contribute to building a more resilient and sustainable future for the region. She encouraged all attendees to actively participate in the discussions and thanked them for their dedication to addressing this critical issue.

6.3 COASTAL SUBSIDENCE IN WEST AFRICA: KEY INSIGHTS AND CHALLENGES

6.3.1 Understanding Coastal Subsidence: Focus on the Gulf of Guinea

Prof. Pietro Teatini presented an in-depth exploration of coastal subsidence, focusing on its drivers, mechanisms, and impacts, with a specific emphasis on the Gulf of Guinea. His presentation, part of the ENGULF Project, aimed to address knowledge gaps and propose strategies for mitigating subsidence risks in this vulnerable region.

Definition and Global Examples

Prof. Teatini defined land subsidence (LS) as the downward motion of the earth's surface, resulting in a loss of elevation due to processes beneath the surface. Subsidence may be:

- Even or uneven, both forms pose risks to urban infrastructure and coastal ecosystems.

He provided global examples, including Mexico City, Delft, and Jakarta, to illustrate the widespread nature of subsidence and its impacts.

Drivers of Land Subsidence

Prof. Teatini categorized the causes of subsidence into:

1. Natural Drivers:
    - Sediment compaction from overlying pressure.
    - Tectonic activity affecting coastal land stability.
2. Human-Induced Drivers:
    - Groundwater extraction is a major contributor.
    - Mining and hydrocarbon extraction, which reduce pore space and destabilize subsurface layers.

He used the analogy of a deflating ball to explain how reduced pore space from human activities causes the surface to sag.

Comparative Examples

Prof. Teatini compared subsidence rates in cities with varying sediment properties and extraction practices:

- Venice: Loss of 0.14 meters due to controlled groundwater management and low sediment compressibility.
- Jakarta: Loss of 4 meters, driven by extensive sediment compressibility and unregulated groundwater extraction.

Focus on the Gulf of Guinea

The ENGULF Project focuses on filling data gaps and addressing subsidence risks in the Gulf of Guinea. Key objectives include:

1. Understanding subsidence mechanisms along the Gulf of Guinea coast.
2. Forecasting future subsidence under different groundwater management scenarios.
3. Preventing severe subsidence through sustainable groundwater practices.

Preliminary results indicate significant risks in areas like Lagos and the Volta Delta, where data on hydrogeochemical properties and groundwater usage is sparse.

Challenges in Data Collection

Prof. Teatini highlighted several barriers to effective subsidence monitoring:

1. Limited resources for establishing and maintaining monitoring networks.
2. Administrative obstacles and fragmented institutional responsibilities.
3. Data accessibility issues due to lack of open-access policies.

Efforts to collaborate with institutions like the Lagos State Ministry of Environment and Water Resources and Lagos State University have faced challenges in sustaining consistent data-sharing agreements.

Recommendations

Prof Teatini proposed solutions to address data and management challenges:

1. Strengthening Monitoring Networks:
    - Allocate dedicated budgets for subsidence data collection.
2. Enhancing Regional Collaboration:
    - Foster cooperation among governments, research institutions, and international partners.
3. Adopting Open-Access Policies:
    - Ensure data accessibility for non-commercial research purposes.

Conclusion

Dr. Teatini concluded by emphasizing the need for a collaborative approach involving scientists, policymakers, and stakeholders to tackle subsidence risks. He stressed that addressing subsidence in the Gulf of Guinea requires:

- Reliable monitoring systems.
- Sustainable groundwater management.
- Regional cooperation to ensure the long-term resilience of coastal ecosystems and communities.

6.3.2 Coastal Elevation and Relative Sea-Level Rise: Challenges and Uncertainties

Ms. Katharina Seeger delivered a presentation on the challenges and uncertainties associated with coastal elevation data and relative sea-level rise (RSLR) assessments, with a focus on the Gulf of Guinea. Collaborating with researchers like Prof. Pietro Teatini and Dr. Philip Minderhoud, Ms. Seeger emphasized the critical role of accurate elevation data in understanding flood risks and guiding coastal management strategies.

Global Projections and RSLR Challenges

Ms. Seeger referenced the IPCC AR6 report, which projects sea-level rise (SLR) between 0.4 m and 2 m by 2100, with further increases expected by 2300. She explained:

- SLR projections are uncertain due to variables like ice-sheet dynamics.
- Coupled with land subsidence, SLR accelerates RSLR, exacerbating risks in low-lying coastal areas.

Importance of Elevation in RSLR Assessments

Elevation plays a fundamental role in understanding RSLR impacts and flood risk, particularly in densely populated areas like the Niger and Volta Deltas. Ms. Seeger stressed:

- High vertical accuracy in elevation data is essential, as even slight inaccuracies can misrepresent flood exposure and hazards.
- Coastal lowlands often lack access to high-resolution elevation datasets, hindering accurate vulnerability assessments.

Challenges with Global Elevation Datasets

Ms. Seeger outlined common issues with relying on global elevation models:

1. Vertical inaccuracies: Errors can vary by several meters, creating significant uncertainties for low-lying regions.
2. Sensing artefacts: Distortions in satellite data can misrepresent true elevations.
3. Vertical reference datum issues: Global geoid models often misalign with local sea level measurements, compounding errors.

These challenges have critical implications for RSLR impact assessments, particularly in regions without properly contextualized elevation data.

Findings for the Gulf of Guinea

Ms. Seeger's team focused on vulnerable zones, including Accra and the Volta Delta, using models like FABDEM and CoastalDEM v2.1. Key findings:

- Ensemble assessments identified areas below 2 meters of Mean Sea Level (MSL) as high-risk hotspots.
- For the first time, satellite-derived Vertical Land Motion (VLM) estimates were used to measure subsidence rates along the Gulf of Guinea, revealing rates of 1 to 5 mm per year.

These findings provide baseline data critical for assessing future RSLR impacts and developing mitigation strategies.

Recommendations for Enhancing Coastal Management

To improve adaptation and support decision-making, Ms. Seeger announced:

1. Freely available digital elevation models (DEMs): New datasets aligned to local sea levels will enable more accurate RSLR assessments.
2. Stakeholder access: Coastal cities like Accra, Lomé, Lagos, and Douala can use these resources to guide climate adaptation strategies.

Conclusion

Ms. Seeger concluded that improving access to high-resolution elevation data and incorporating subsidence measurements are crucial for understanding and mitigating the risks of RSLR. She emphasized the need for:

- Accurate data resources to support effective coastal management.
- Collaborative efforts to adapt and build resilience in vulnerable coastal regions of the Gulf of Guinea.

6.3.3 Coastal Land Subsidence- The Case of Ghana's Volta Delta

Dr. Selasi Yao Avornyo delivered a second presentation that delved into the relationship between coastal land subsidence and flooding risks in Ghana's Volta Delta, building upon his earlier discussion by incorporating advanced modelling techniques and projections. The presentation demonstrated how subsidence exacerbates flood risk in this vulnerable region.

Key Insights and Findings

1. Historical Evidence of Shoreline Erosion:
    - Using historical imagery from 1974 to 2023, Dr. Avornyo illustrated alarming shoreline erosion rates.
    - A striking example included the loss of a community water source to the ocean, caused by progressive subsidence and erosion.

2. Drivers of Subsidence:
    - Human activities such as sand mining, resource extraction, and river damming (e.g., reduced sediment flow from the Akosombo Dam).
    - These drivers disrupt sediment balances, compounding subsidence rates and intensifying coastal hazards.

Flood Modelling and Projections

A significant portion of the presentation introduced flood modelling tools, like Maestro, to simulate the impacts of relative sea-level rise (RSLR) under subsidence scenarios:

- Dynamic Models vs. Static Models:
    - Dr. Avornyo emphasized the inadequacy of static models for long-term projections, as they fail to account for evolving subsidence rates.
    - Dynamic flood models that integrate subsidence data showed a potential 10% or greater increase in inundated areas under RSLR scenarios.
- Altered Digital Elevation Models (DEMs):
    - Subsiding land changes DEM accuracy, making updated and subsidence-adjusted models critical for reliable flood risk assessments.

Community Impact and Field Data

Dr. Avornyo shared findings from local engagement and field surveys, including:

- UAV imagery fused with population studies, highlighting specific communities at risk.
- First-hand accounts of subsidence impacts on livelihoods, including loss of land, homes, and water sources, underscoring the human cost of these hazards.

Recommendations

Dr. Avornyo concluded with actionable recommendations to mitigate the growing risks:

1. Transition to Dynamic Models:
    - Incorporate subsidence data into flood modelling tools for accurate, long-term projections.
2. Continuous Geodetic Monitoring:
    - Invest in advanced geodetic technologies like InSAR and GNSS to monitor subsidence trends.
3. Enforce Regulations:
    - Strengthen laws and enforcement mechanisms to curb illegal activities that exacerbate subsidence.
4. Invest in Protective Measures:
    - Develop artificial dunes and early-warning systems to safeguard vulnerable populations.

Conclusion

Dr. Avornyo's presentation highlighted the urgent need for proactive measures to address the compounding effects of subsidence and flood risks in the Volta Delta. By integrating advanced models, enforcing protective policies, and engaging local communities, the region can better prepare for the dual threats of sinking land and rising seas.

6.4 POLICY DAY DISCUSSION

The Day 4 panel discussion, moderated by Dr. Philip Minderhoud (Co-chair of the ENGULF Project, Wageningen University and Research, Netherlands), brought together esteemed experts to discuss critical issues surrounding geospatial technology, groundwater extraction, land subsidence, and coastal protection in West Africa. The discussion emphasized the need for regional collaboration, improved data-sharing policies, and the integration of subsidence monitoring into coastal management strategies. The Panel was made up of the following experts:

- **Prof. Kwasi Appeaning Addo** (University of Ghana Principal Investigator —ENGULF Project).
- **Prof. Amos T. Kabo-Bah** (University of Energy and Natural Resources, Ghana).
- **Surv. Stephen Djaba** (Geo-Tech Systems Surveys Ltd, Licensed Surveyors Association of Ghana (LISAG), and Chair, Diversity and Inclusion Task Force, International Federation of Surveyors).
- **Mr. Eric D. Guesta** (Sustainable Development Support Officer, Gulf of Guinea Regional Division, AFD).

Plate 32: Policy Day discussion with a group of experts. R-L: Prof. Kwasi Appeaning Addo, Prof. Amos T. Kabo-Bah, Surv. Stephen Djaba, Mr. Eric D. Guesta and Dr. Philip Minderhoud (Moderator).

1. Geospatial Technology and Coastal Management

The panel began by exploring the role of geospatial technology in managing coastal zones. Key insights included:

- Accurate data acquisition and robust analysis are critical for effective monitoring of coastal changes.
- Panellists emphasized the importance of installing reference points for long-term monitoring and using geospatial data to guide sustainable coastal management practices.
- Advocacy for expanding geodetic infrastructure along the West African coast and adopting modern technologies to improve data reliability.
- Collaboration between surveyors, policymakers, and coastal managers was identified as crucial to ensuring geospatial data effectively supports policy and decision-making.

2. Groundwater Extraction and Land Subsidence

Groundwater extraction was identified as a major driver of land subsidence, with significant implications for West Africa. The discussion highlighted:

- Weak enforcement of groundwater policies in the region increases subsidence risks.
- Prof. Amos T. Kabo-Bah and Mr. Eric D. Guesta noted the lack of comprehensive data on boreholes and water usage, emphasizing the need for:
    1. Better collaboration between countries.
    2. Improved data acquisition systems.
    3. Fostering an open data culture to enhance research and policy development.

3. Proactive Measures to Mitigate Subsidence

Panelists discussed strategies to maintain low subsidence rates in West Africa amidst increasing groundwater extraction. Key recommendations included:

- Integrating subsidence prevention into coastal protection strategies that require:
    1. Stronger policy enforcement.
    2. Combination of technical solutions with community-based interventions.
- Advocacy and public education were highlighted as essential tools to:
    1. Raise awareness about the long-term risks of subsidence.
    2. Encourage sustainable practices, particularly around groundwater management.

4. Building Resilience in Coastal Zones

The discussion concluded with a call for a coordinated, interdisciplinary approach to address the challenges of land subsidence and coastal management. Key takeaways included:

- Strengthening Regional Collaboration:
    1. Connect stakeholders across governments, academia, and the private sector to develop joint solutions.
- Promoting Open-Access Data Policies:
    1. Ensure that geospatial and hydrogeological data are readily accessible to support evidence-based decision-making.
- Prioritizing Long-Term Coastal Resilience:
    1. Combine technical measures (e.g., geospatial monitoring, subsidence

modelling) with community-driven strategies to address future risks effectively.

Conclusion

The panel highlighted the need for collaboration, education, and proactive policy implementation to tackle the dual challenges of land subsidence and coastal management in West Africa. Panellists highlighted that only through integrated efforts can the region build resilient coastal communities and address the mounting threats posed by subsidence and climate change.

6.5 GNSS STATION INSTALLATION LECTURE

As part of the ENGULF Project, a Global Navigation Satellite System (GNSS) station was successfully installed during the ENGULF Workshop to support monitoring coastal land subsidence and relative sea-level rise (RSLR) in the Gulf of Guinea. This installation represents a significant milestone in addressing critical data gaps for subsidence research and regional coastal management.

Workshop Installation Overview

The installation of the GNSS station at the University of Ghana in Accra was an integral activity during the workshop. Participants, including researchers, technicians, and stakeholders, actively engaged in the setup process, gaining hands-on experience in deploying GNSS technology for subsidence monitoring.

- The workshop provided participants with insights into the importance of GNSS technology, focusing on its role in ground-truthing satellite measurements and enhancing the accuracy of subsidence and flood risk models.
- Detailed demonstrations were conducted, covering the technical installation, data calibration procedures, and integration with global reference frames.

Significance of the GNSS Station

The station serves as a permanent reference point to calibrate InSAR-derived vertical land motion (VLM) data, transforming relative subsidence measurements into absolute values. This capability addresses the limitations of satellite-only measurements by providing:

- Reliable ground-truth data for subsidence monitoring.
- Continuous high-accuracy vertical land motion measurements.
- Support for open-access data initiatives to empower research and policymaking.

Context and Objectives

The Volta Delta and other areas along the Gulf of Guinea face increasing risks from subsidence, sea-level rise, and flooding, yet data availability in the region remains sparse. The ENGULF Project's GNSS initiative aims to:

- Establish a robust geodetic monitoring network for the region.
- Integrate subsidence measurements with dynamic flood models to improve projections of inundation risks.
- Provide accessible data to regional and global researchers, supporting evidence-based

coastal management strategies.

Next Steps and Long-Term Goals

Following the installation in Accra, the ENGULF Project plans to establish a second GNSS station in the Volta Delta, a critical area for subsidence monitoring. These installations will:

- Enhance regional capacity for subsidence and RSLR assessment.
- Facilitate collaboration among stakeholders to address coastal hazards.
- Inform policy decisions and support sustainable development goals for vulnerable coastal communities.

Conclusion

The successful installation of the GNSS station during the workshop symbolizes the ENGULF Project's commitment to building geospatial monitoring capacity in West Africa. This achievement not only addresses immediate data needs but also lays the foundation for long-term coastal resilience by combining technology, education, and collaboration to mitigate the impacts of land subsidence and climate change.

6.6 GNSS STATION LAUNCH CEREMONY

The launch ceremony for the newly installed GNSS station was a significant milestone in advancing geospatial research and coastal monitoring within the framework of the ENGULF Project. The event showcased the station's potential to address critical environmental challenges in the Gulf of Guinea, particularly land subsidence and relative sea-level rise (RSLR).

Plate 33: GNSS launch ceremony in the Department of Marine and Fisheries Sciences

6.6.1 Welcome Remark

The ceremony began with a warm welcome address by the head of the host department (Marine and Fisheries Department), Dr. Benjamin Osei Botwe. He indicated that the GNSS station will not only elevate the research capabilities of the department but will also play an essential role in monitoring coastal land subsidence and geophysical changes. By providing precise geospatial data, the GNSS station will help address pressing issues such as land subsidence and sea-level rise—challenges that are increasingly relevant to coastal regions. The data will be crucial for developing sustainable coastal management strategies and supporting both local and international research aimed at protecting vulnerable coastal communities. The initiative was lauded as a step forward in addressing data gaps and fostering regional collaboration in coastal resilience.

6.6.2 GNSS Station: Component and Operational Description

A technical presentation followed, detailing the station's components and operational capabilities:

- The station utilizes satellite signals to deliver highly accurate geospatial data, including real-time monitoring of vertical land motion.
- Experts showed the integration into the global geodetic network, demonstrating its capacity to contribute to both regional and international research.
- The presentation provided insights into data collection, processing, and the station's role in validating InSAR-derived subsidence data.

6.6.3 Ribbon Cutting and Inspection of GNSS Station

The ribbon-cutting ceremony, performed by dignitaries, symbolized the official launch of the GNSS station. Attendees were then guided on a site inspection, where a live demonstration was showcased:

- Data collection processes.
- A brief analysis of the station's outputs, illustrating its ability to monitor critical environmental parameters such as vertical land motion and RSLR.

6.6.4 Closing Remarks

The event concluded with a heartfelt speech from the organizing committee, expressing gratitude to the stakeholders, partners, and sponsors whose contributions made the project possible. The speaker emphasized:

- The significance of the GNSS station in enhancing coastal resilience.
- The importance of leveraging the station’s capabilities for research, policy development, and sustainable environmental management.

6.6.5 Closing Ceremony

The closing ceremony marked the culmination of a successful workshop. Prof. Kwasi Appeaning Addo delivered a reflective speech, emphasizing:

- The importance of collaborative efforts in tackling coastal and environmental challenges.

- The achievements of the workshop which included knowledge sharing, capacity building, and practical steps toward resilience.

In his final closing remark, Prof. Appeaning Addo expressed gratitude to all participants, facilitators, and stakeholders. While acknowledging the ENGULF Programme team, he accentuated the success of the workshop and seized the opportunity to thank the workshop funder, AFD for its unwavering support. In a gesture of appreciation, the funders and team members were honoured with traditional Kente sashes, symbolizing respect, gratitude, and cultural pride. The event concluded with participants reaffirming their commitment to utilizing the GNSS station as a tool for advancing scientific understanding and driving coastal management solutions in the region. The workshop successfully highlighted the urgent need for integrated approaches to address coastal subsidence, combining scientific research, policy interventions, and community engagement.

7.0 DAY 5: FIELD VISIT

The fifth day of the workshop involved a field trip to the Volta Region, offering participants an opportunity to observe the impacts of land subsidence, saltwater intrusion, and coastal challenges firsthand. The trip included visits to Adina Township, Keta Township, and the Forestry Commission, where the group explored the environmental and socio-economic issues faced by local communities and attended a presentation on mangrove restoration efforts as a nature-based solution to coastal hazards in the region.

7.1 COURTESY CALL ON THE CHIEF OF ADINA

The day began with a courtesy visit to the Chief of Adina, a gesture underscoring the importance of engaging traditional leadership in environmental initiatives.

- Gifts of goodwill were presented to the Chief, symbolizing appreciation for the community's warm reception.
- The Chief welcomed the workshop participants and acknowledged the relevance of addressing coastal and environmental challenges, expressing his support for collaborative efforts to promote sustainability.

7.2 TOUR OF ADINA TOWNSHIP: IMPACTS OF SALTWATER INTRUSION AND LAND SUBSIDENCE

The visit to Adina Township provided participants with insight into the community's struggles with saltwater intrusion and land subsidence, exacerbated by groundwater extraction and salt mining activities.

- Community Discussion led by Mr. Francis Agabu Abundi. The discussion revealed:
  - The community's initial support for using seawater in salt mining.
  - A shift to groundwater extraction by the salt company has caused:
    - Structural damage to homes and gates misaligning due to subsidence.
    - Saline intrusion into wells which has reduced access to potable water.
    - Lowered groundwater levels disrupt traditional salt production, a major livelihood.
- Field Observations:
  - Widespread cracks in buildings and altered landscapes were visible signs of the damage.
  - Residents expressed frustration over unfulfilled promises from the company and insufficient governmental support, calling for immediate interventions to address their challenges.

7.3 TOUR OF KETA TOWNSHIP: IMPACTS OF LAND SUBSIDENCE AND FLOODING

The group continued to Keta Township, a region deeply affected by subsidence and flooding in the Volta Delta.

- Field Observations:
  - Participants observed submerged buildings, stark reminders of the advancing waters caused by subsidence and erosion.
  - Community members described how these processes have displaced families, threatened infrastructure, and affected agricultural productivity, which is vital for their livelihoods.
- Challenges:
  The encroaching water continues to reshape the region, intensifying the need for resilient coastal management strategies.

7.4 PRESENTATION: MANGROVE RESTORATION EFFORTS – A NATURE-BASED APPROACH TO COASTAL HAZARDS

The field trip concluded with a visit to the Forestry Commission, where participants attended a presentation on mangrove conservation and restoration efforts. This session offered in-depth insights into the ecological importance of mangroves, restoration achievements, challenges faced in their conservation, and plans for the future.

Ecological Importance

The presentation began by underscoring the vital role of mangroves as dynamic ecosystems that provide numerous environmental and socio-economic benefits:

- **Erosion Control and Soil Stabilization**: Mangroves act as natural barriers, reducing the speed of water flow and encouraging sediment deposition. This prevents soil erosion and reinforces the shoreline.
- **Habitats for Biodiversity**: They serve as critical habitats for diverse marine and terrestrial species, including fish nurseries that support over 60% of ocean fish populations.
- **Mitigating Climate Change**: Mangroves are efficient carbon sinks, sequestering carbon and mitigating greenhouse gas emissions.
- **Water Regulation**: The prop root system of species such as Rhizophora (red mangroves) aids in maintaining the balance between fresh and saltwater in the coastal environment.

Restoration Achievements

Over the past three years, notable strides have been made in mangrove restoration:

- **Reforestation Initiatives**: Restoration of over 210 hectares of degraded mangrove areas has been completed.
- **Community Woodlots**: Establishment of 55 hectares of community woodlots to reduce dependency on mangroves for firewood, with species like Acacia planted to serve as alternatives.
- **Community Engagement**: Training Programmes have empowered communities to establish nurseries and restore degraded mangrove ecosystems independently.

Challenges

The presentation also highlighted significant barriers to effective mangrove conservation:

- **Weak Legal Protections**: The absence of laws specifically protecting mangroves, such as the insufficient LI 1652, leaves them vulnerable to exploitation.
- **Political Interference**: Conservation efforts are often hindered by external political pressures that override community-driven initiatives.
- **Hydrological Constraints**: Blocked creeks and canals within Ramsar sites impede water movement, creating high salinity levels detrimental to mangrove growth.

Future Plans

The session detailed ambitious plans to address these challenges and enhance mangrove conservation:

- **The WACA Blue Carbon Project**: This initiative aims to incentivize communities to conserve mangroves through carbon credit Programmes, providing financial rewards for sustainable practices.
- **Hybrid Solutions**: Combining green and grey infrastructure, such as mangrove restoration alongside sea defences, to combat flooding and erosion. The example of Atorkor's sinking sea defence highlighted the need for integrated approaches.
- **Addressing Water Movement**: Mobilizing communities to manually unblock creeks and canals, ensuring adequate water flow for optimal mangrove regeneration.
- **Research and Monitoring**: Expansion of hydrological studies to identify optimal restoration techniques and ensure the long-term sustainability of interventions.

Additional Insights

- **Species Diversity**: The landscape supports three dominant mangrove species:
    - *Rhizophora mangle* (red mangrove), is known for its above-ground prop root system.
    - *Avicennia germinans* (white mangrove), prevalent but less dominant.
    - *Laguncularia racemosa* (black mangrove), which is relatively sparse.
- **Local Applications**: Mangroves' ability to regulate soil moisture and prevent soil compaction makes them critical for reducing tidal flow erosion and mitigating land subsidence.
- **Community Challenges**: Participants learned about areas like Gamenu and Anloga, where land subsidence has led to significant coastal changes, including the loss of multiple communities.

Conclusion

The presentation concluded with a call for strengthened collaboration between local communities, government agencies, and international stakeholders to prioritize mangrove conservation. Investing in nature-based solutions such as mangrove restoration offers a cost-effective, sustainable path to mitigating coastal hazards and fostering resilient ecosystems. This session reinforced the importance of integrating local knowledge with scientific expertise to ensure that mangrove ecosystems are preserved for generations to come.

Plate 34: Interaction with key stakeholders in the Adina Community

Plate 35: Interaction with the *Forestry* Commission

8.0 CRITICAL REFLECTIONS AND FUTURE DIRECTIONS

8.1 KEY CHALLENGES IDENTIFIED

1. **Data Scarcity**:
    - Despite advancements in remote sensing (e.g., InSAR, GNSS), regions like the **Volta Delta** and **Niger Delta** lack high-resolution elevation data and long-term monitoring infrastructure. This limits accurate flood risk assessments and policy formulation.
    - *Recommendation*: Expand geodetic networks and prioritize open-access data policies to support regional research.
2. **Policy-Research Disconnect**:
    - Discussions revealed weak enforcement of groundwater extraction policies and fragmented institutional responsibilities. For example, in **Accra**, **Lagos** and **Douala**, rapid urbanization often overrides environmental regulations.
    - *Recommendation*: Establish transboundary frameworks for groundwater management and strengthen partnerships between scientists and policymakers.
3. **Community Vulnerability**:
    - Field visits to **Adina** and **Keta** highlighted how subsidence disproportionately impacts marginalized communities reliant on fishing and agriculture. Saltwater intrusion and land loss threaten livelihoods, yet local voices are often excluded from decision-making.
    - *Recommendation*: Integrate community-based adaptation strategies, such as mangrove restoration and participatory monitoring, into national policies.

8.2 FUTURE RESEARCH PRIORITIES

1. **Dynamic Modelling**:
    - Current flood models often assume static subsidence rates. Future studies should incorporate temporal variability in subsidence (e.g., seasonal groundwater extraction patterns) to improve projections.
2. **Nature-Based Solutions (NbS)**:
    - Mangrove restoration and artificial dunes (e.g., the **Atorkor pilot project**) show promise but require long-term viability studies. Research should quantify NbS' economic and ecological benefits compared to traditional engineering solutions.
3. **Regional Collaboration**:
    - The **Gulf of Guinea** lacks a unified platform for sharing subsidence data. A regional observatory could harmonize monitoring efforts and facilitate joint adaptation strategies.

8.3 CALL TO ACTION

The workshop underscored that addressing coastal subsidence in West Africa demands **urgent, coordinated action**. Priorities include:

- Scaling up investments in monitoring infrastructure (e.g., GNSS stations).
- Mainstreaming subsidence into national climate adaptation plans.
- Empowering communities through education and participatory governance.