

FOSTERING NATURE-ALIGNED ENGINEERING IN COASTAL INFRASTRUCTURE DEVELOPMENTS

DATA AND SKILLS NEEDS ASSESSMENT REPORT

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Executive Summary

Introduction

Kenya's coastal cities, particularly Mombasa and Lamu are critical economic gateways, and are currently experiencing rapid urbanization and significant infrastructure development. However, Reliance on traditional (grey/hard) engineering approaches in coastal infrastructure development has contributed to biodiversity loss, climate vulnerability, and reduced resilience of coastal systems. These negative impacts pose significant safety and sustainability risks to both people and the environment, hence the need to adopt nature-aligned engineering (NAE) approaches when developing coastal infrastructure.

NAE is an approach that integrates natural processes into engineering design, planning and implementation to achieve sustainability, adaptability, and ecological compatibility. Thus, NAE would offer a pathway to foster resilient, cost-effective, and environmentally regenerative infrastructure in Kenya's coastal regions. But implementation of NAE methods would require diverse skillset and essential data alongside community engagement.

This report presents the findings of a study to establish the data and skills needed to support the integration of Nature-Aligned Engineering (NAE) in coastal infrastructure development in Kenya.

Methodology

The study combined a desk review, questionnaires (respondents across three coastal counties of Kenya), and a focus group workshop (participants from academia, industry, government, and community). This triangulated research approach provided insights into current practices, existing capacities, and required skills, data and tools for effective integration of NAE methods into coastal infrastructure projects.

Key Findings

1. **NAE Awareness and Practice:** It was established that while NAE principles are

recognized in Kenya, their consistent application in coastal infrastructure projects remains limited, with only localized efforts at local government level and the Mombasa maritime port. Most organizations in Kenya use NAE methods only occasionally, with significant variation across projects.

2. **Skills:** Essential skills for NAE included coastal engineering, ecological engineering, hydrology, hydrodynamic modelling, materials science, environmental monitoring, circularity, HSE and systems thinking approach. The assessment found strong existing technical capacity in environmental monitoring and impact assessment, largely driven by regulatory frameworks under the National Environmental Management Authority (NEMA). Some universities like Moi, TUM and Kenyatta offer baseline environmental science in engineering curriculum. Nonetheless, specialized expertise in hydrodynamic modelling, ecological design, low-carbon materials, and adaptive management is lacking. Training opportunities are fragmented and inconsistent.

3. **Data:** The available data relevant to NAE includes water quality, land use, and climate projections, but fragmented and held in silos. The critical ecological datasets such as habitat maps, carbon accounting records, ecosystem vulnerability are scarce, undermining NAE planning and decision-making. Data availability has been mainly hindered by lack of standardized data capturing and sharing frameworks, and the absence of decision support systems for data integration.

4. **Tools:** The results indicate that GIS and spreadsheet-based models are the commonly used platforms in Kenya. While useful, they provide limited predictive or valuation power for NAE. Advanced modelling, ecological valuation, and carbon accounting tools are insufficiently adapted to local contexts. Hydrodynamic and ecological modelling software are rarely used due to cost, limited calibration to local contexts, poor interoperability between data and available software tools, and gaps in expertise. Thus, use of

advanced tools remains at basic level, insufficient for holistic NAE integration.

5. Research Priorities: The stakeholders identified the cost-benefit analyses, long-term monitoring frameworks, green and sustainable materials, and performance studies of NAE in varied environments as top research priorities. Research into policy, governance, and social acceptance was also ranked highly.

6. Capacity Building: Stakeholders prefer establishing dedicated graduate programs in NAE and eco-engineering at universities to provide structured capacity, complemented by short-term technical workshops to fill immediate knowledge gaps. This indicates the need for a blended approach involving both long-term academic grounding and immediate practical training.

Conclusions

The study reveals that integrating NAE approaches into coastal infrastructure developments is essential for Kenya's coastal resilience but requires investment in:

- Capacity development through curriculum reform and technical training for NAE-related skills and knowledge
- Open data systems / repositories with standardized local coastal data.
- Context-specific tools/models/software that are affordable, scalable, and adaptable such as low-cost open source modelling tools.
- Research and demonstration projects to build local evidence and trust in NAE approaches.
- Integration of indigenous knowledge and community participation into NAE design and monitoring process.

“
Coastal Engineers must look beyond technical goals to design coastal infrastructure that work in harmony with natural ecosystems to foster safer and more resilient futures for coastal communities
”

Recommendation

The report proposes a collaborative approach by policy makers, government, academic institutions, industry, and communities to close identified gaps. By advancing NAE practices, Kenya can bend the curve away from ecosystem degradation and toward an adaptive and regenerative model of coastal infrastructure development that ensures coastal resilience and environmental sustainability.

1. Introduction

1.1 Background

The Kenya's coastal cities of Mombasa and Lamu are key economic gateways for the country as witnessed by continuous infrastructural developments, especially at the ports. However, the rapid expansion of infrastructure is exerting pressure on limited land, materials and energy resources, creating safety and sustainability challenges for both people and the environment while promoting climate change and biodiversity damage. Yet, a rich biodiversity and stable climate are critical for the well-being of all life. The loss of biodiversity and growing impacts of climate change in the coastal regions presents a need for engineering community to adopt more holistic and nature-aligned engineering approaches when developing coastal infrastructure.

Nature-Aligned Engineering (NAE) is the methodology of designing and implementing engineering solutions that work harmoniously with the natural ecosystem, with emphasis on sustainability, adaptability, and long-term environmental compatibility (Hall, 2024; Kurth et al., 2020). It involves intentional integration of natural processes into engineered solutions to deliver economic and ecological benefits as well as social acceptance (Dolatowski et al., 2024). Within this context, implementation of NAE methods would require diverse and interdisciplinary skills set combining technical expertise with ecological understanding and citizen engagement. The coastal engineers, urban planners, environmental scientists, marine biologists and policy makers should be equipped with the necessary skills, data and tools to effectively participate in planning, design, construction and maintenance of NAE infrastructure systems.

Data is essential to build scientific evidence to support and validate NAE approaches, and thus establish the scientific credibility and practical effectiveness, while specialized tools such as advanced modelling softwares and sensors for monitoring ecosystems are essential for implementation of NAE approaches in coastal infrastructure projects.

This report presents comprehensive analysis of the findings of the skills and data needs assessment from the coastal infrastructure sector in Kenya

1.2 Why NAE Matters

The Kenya's coastal region continues to suffer from flooding, ecosystem degradation, weak infrastructure resilience, and fragmented data ecosystems (Jack et al, 2021; CoM-SSA, 2024). Reimagining our engineering methods to align the development of coastal infrastructure with the health of the surrounding ecosystem can unlock innovation to deliver sustainable, adaptable, resilient and eco-inclusive infrastructure that ensures a safer tomorrow for coastal communities. For instance, designing and constructing coastal infrastructure in ways that preserve natural tides, currents, and sediment flow, supports the conservation of marine biodiversity.

The critical coastal infrastructures include roads, railways, ports, energy systems, sea walls, water supply and drainage systems. Adopting NAE methods for the infrastructure development in the coastal region and in port areas offers a pathway towards lowering negative impacts on coastal and marine ecosystems (Esteban et al, 2023). It ensures harmony between human infrastructure and natural ecosystems, fostering regeneration, resilience and long-term adaptability. Therefore, NAE contributes to bending the curve, reversing negative trends in climate disruptions, biodiversity damage and ecosystem degradation as schematically illustrated by Figure 1.

1.3 Objectives of the Study

Kenya and sub-Saharan Africa in general risk locking into unsustainable (grey and hard-engineered) coastal infrastructure if actions are not taken to invest in NAE skills, data and tools. Therefore, this research aimed to establish the skills, tools and data needed to support integration of NAE methods in coastal infrastructure developments in Kenya, and the existing capacity gaps. This information can unveil valuable insights for the country's coastal urban, marine and maritime sectors.

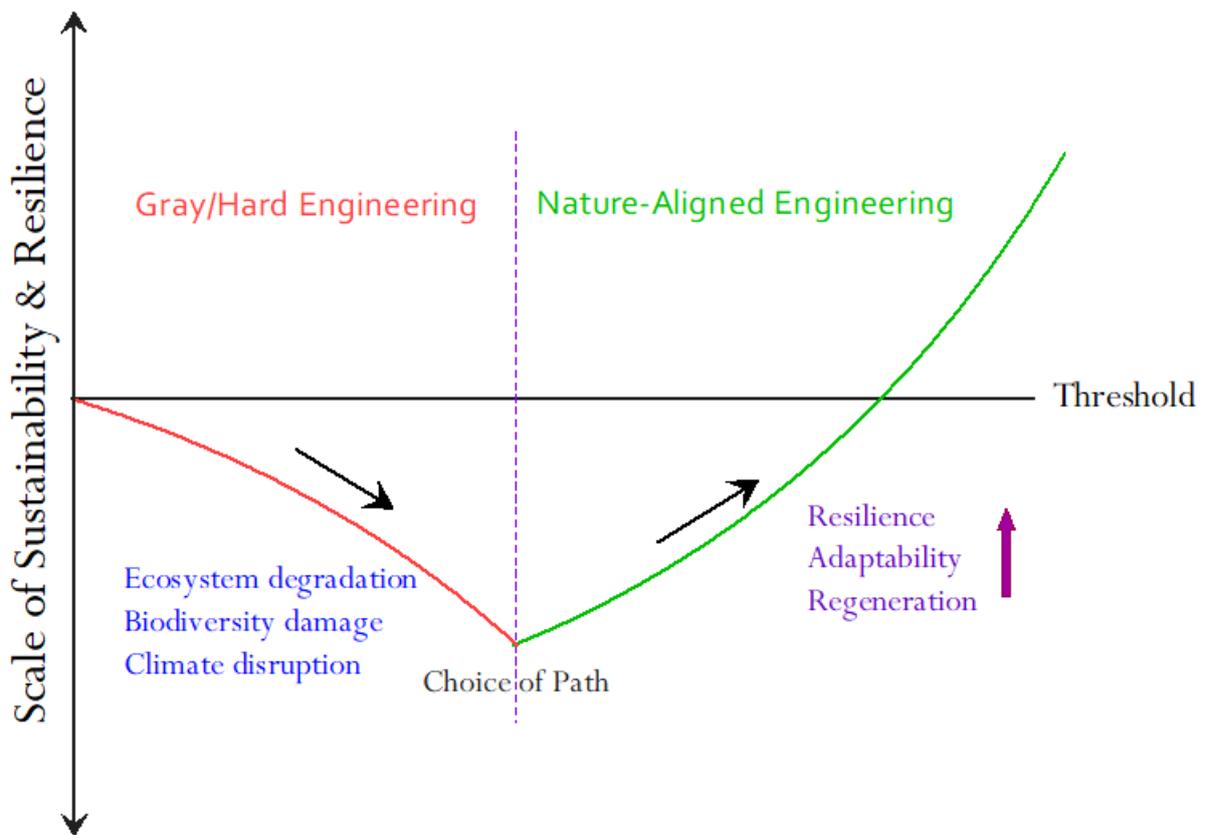


Figure 1. Schematic illustration of bending the curve from Gray Engineering to NAE



2. Methodology

2.1 Desk Review

The study commenced with a systematic literature survey to identify and understand the level of knowledge, skills and practice of Nature-Aligned Engineering in planning, design, construction, operation and maintenance of coastal infrastructure systems. Thus, the desktop review formed the knowledge base of the needs-assessment, enabling the project team to contextualize the data obtained from questionnaires, interviews and workshop. Documents that were reviewed to obtain valuable information include journal papers, technical reports, policy documents and company profiles.

2.2 Questionnaires

Building on the findings of desk review, questionnaires were designed for data collection from the field. The questionnaires were organized into different sections that contained questions related to participants background and characteristics of their organizations, awareness and practice of NAE in their projects, skills and capacity within their organization to implement NAE, data availability and tools usage, research gaps, training needs and opportunities for collaboration on NAE actions. The sample is provided in Appendix A1. Key respondents from each stakeholder category were invited to complete the questionnaires via google forms. These stakeholders were selected based on the stakeholder analysis of their role in the coastal engineering sector. A total of 56 out of 71 participants that were contacted, responded to their respective questionnaires. Data was collected between 18th July and 31st July 2025, in 3 coastal counties of Kenya that boarder the Indian Ocean as illustrated in Figure 2

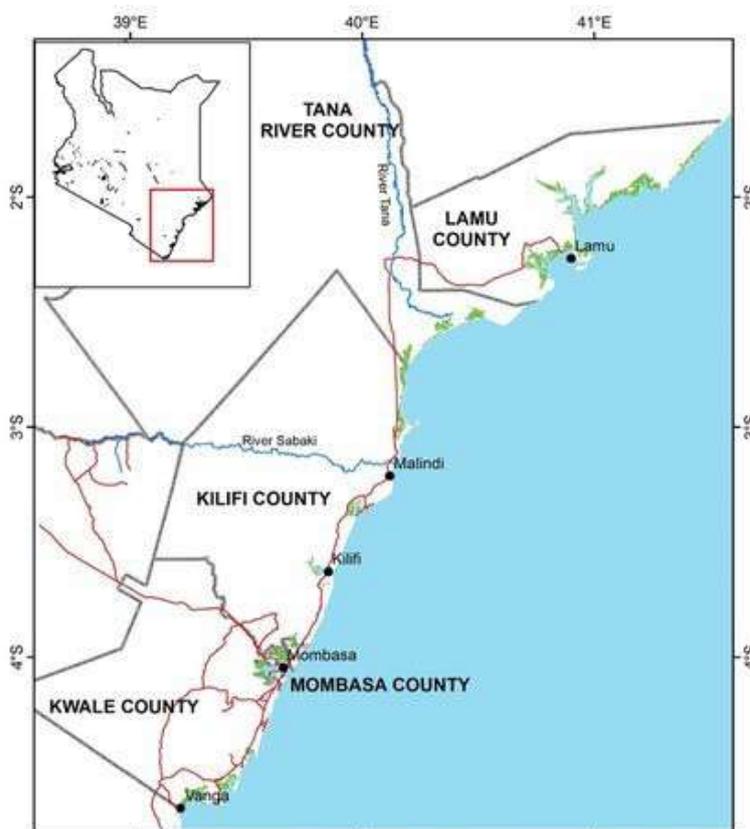


Figure 2. Study area (Kenya coastal Counties of Mombasa, Lamu and Kilifi)

Participants in the survey were selected based on the following criteria:

- Professional experience in coastal engineering, urban planning, sustainability, environmental science, policy or governance
- Experience with NAE and related subjects
- Institutional affiliation (e.g. Works at the Port or County Government department responsible for infrastructure, public works, environment etc)

2.3 Focus Group Workshop

The use of focus groups is recognised as a form of group interview promoting interaction within the group. In this study, a total of 26 participants drawn from various stakeholder categories participated in the workshop, held in Mombasa on 12th September 2025. Initial stakeholders were identified during the project proposal stage and additional experts and stakeholders were identified from the networks of research team members, professional recommendations and through pre-workshop survey. Experts and stakeholders were invited based on their professional background, influence and/or interest in NAE methods.

The workshop was structured around three facilitated sessions that included a general session, breakout group sessions, and a final plenary discussion. The plenary session was used to consolidate findings. An interview guide was designed to support focus group discussions with focus on the following four NAE aspects of infrastructure:

- Adaptive infrastructure
- Ecologically inclusive infrastructure
- Sustainable infrastructure
- Resilient infrastructure

The participants were drawn from different organizations as shown in Table 1

Table 1. List of organizations that participated in the workshop

S.No	Organization	Number of Participants
1	Moi University	4
2	Kenya Ports Authority (KPA)	5
3	Institution of Engineers of Kenya (IEK)	2
4	Lloyd's Register Foundation (LRF)	2
5	Bamburi Cement Ltd	2
6	Technical University of Mombasa	4
7	Maritime Technology Cooperation Centre (MTCC)	1
8	ARUP East Africa	1
9	National Construction Authority (NCA)	1
10	Architectural Association of Kenya (AAK)	1
11	County Government of Mombasa	3
Total		26

The participants were mapped out according to their organization and professional experience, and placed in each thematic group based on their expertise, experience and role in the thematic focus area. The sampling approach was purposive and stratified, augmented by maximum variation strategy in order to capture diversity of experiences and perspectives. The participants were pre-assigned to one of the three thematic groups as indicated in Table 2.

Table 2. Distribution of participants to focus groups

Group	Group Profiles
A	Academics, Engineers, Planners, Local government, Architects
B	Planners, Engineers, researchers, data analysts, Port workers
C	Policy-makers, Engineers, Contractors, Professional bodies, Community

Each group had between 6 and 8 participants to allow for productive discussion. The allocation mix of participants to the focus groups was as shown in Table 3. The distribution deliberately aimed in the most practical way to include the following:

- A mix of junior and senior professionals
- Representation from different sub-sectors of infrastructure development
- Interdisciplinary perspectives (engineers, planners, architects, researchers etc)
- At least 25 % female participants

Table 3. Participants allocation mix in focus groups

Category	Criteria	Target Representation
Expertise domain	Coastal Engineering, Ecology, Nature-based Solutions, Environmental science, Planning.	At least 2 per group
Infrastructure sub-sector representation	Government, Academia, Private Sector (engineering, consultancy, contractors), Community etc.	At least 1–2 per sector per group
Thematic relevance	Assigned to each group	6–8 participants per group
Gender Balance	Gender inclusive participation	2 female participants allocated per group
Experience Level	Senior Experts (10+ years), Young Professionals (<5 years)	Mix of all levels in each group

It was ensured that each group had one key informant to provide the lead during discussions. This was established during the pre-workshop evaluation.

2.4 Ethical Considerations

In line with research ethics, all the secondary data was acknowledged by citing the source and referencing it. Also, the information and data provided by the respondents was kept confidential. All respondents filled the questionnaires willingly without any coercion. The identity of the respondents remains anonymous in the report.

3. Results & Discussion

3.1 Findings from Desk Review

The desk review synthesized evidence on NAE from different literature sources to assess the current practices and the required skills and data. It provided a priori knowledge and understanding that guided the interpretation of the data from the questionnaires. To effectively implement NAE methods in coastal infrastructure development, each phase of the infrastructure development cycle requires specific skills and data to ensure achievement of both ecological integrity and engineering efficacy. The evidence from literature (Burt et al, 2019; Correa et al, 2025; Dale et al, 2021; Rickard, 2008; Pioch et al, 2018; Charuka et al, 2023) points to the following needs, summarized in Table 4.

Table 4. Skills, knowledge and data required to implement NAE

{a}	Planning Phase		
	Skills <ul style="list-style-type: none"> Coastal environmental engineering Surveying GIS & remote sensing Geospatial engineering 	Data <ul style="list-style-type: none"> Ecosystem and habitat maps Biodiversity data Climate & Sea-level rise projections Natural hazard & Vulnerability maps Land use/Land cover (LULC) data Socio-economic & demographic profiles 	Training /Knowledge <ul style="list-style-type: none"> EIA (Environmental Impact Assessment) methods and tools GIS & Remote sensing for ecosystem mapping Risk assessment for climate change and coastal hazards Stakeholder engagement & participatory planning Policy and regulatory frameworks Sustainability appraisal
{b}	Design Phase		
	Skills <ul style="list-style-type: none"> Ecological engineering Bioengineering Hydrology Geospatial analysis Civil engineering Coastal engineering Adaptive design 	Data <ul style="list-style-type: none"> Hydrodynamic models Sediment transport and erosion patterns Water quality profiles Social spatial data (e.g. sociographic maps) Citizen science datasets (e.g., biodiversity or pollution reports) Historical climate data Trigger thresholds 	Training /Knowledge <ul style="list-style-type: none"> Engineering with Nature principles of design Eco-engineering Hydrological & hydrodynamic modelling Community co-design approaches Geospatial data integration Sociographic analysis Systems thinking approach
{c}	Construction Phase		
	Skills <ul style="list-style-type: none"> Construction management and sustainability Materials Science e.g. Low carbon materials Health, Safety & Environment 	Data <ul style="list-style-type: none"> Environmental impact and mitigation plans Site-specific ecological sensitivity maps Construction materials life-cycle and carbon footprint data Noise and emission baseline data 	Training /Knowledge <ul style="list-style-type: none"> Low impact, sustainable construction methods Green, modular construction materials Environmental monitoring protocols Carbon counter-measures Waste reduction (4R approach)

Operation & Maintenance		
Skills	Data	Training /Knowledge
<ul style="list-style-type: none"> • Environmental monitoring • Green maintenance • Data analysis for environmental performance metrics • Circular economy • Pollution control • Adaptive management 	<ul style="list-style-type: none"> • Performance indicators (e.g., water/air quality) • Resource consumption data (energy, water etc) • Waste and emissions data • Soil and sediment quality reports • Citizen reported data • Ecological events data • Carbon accounting records 	<ul style="list-style-type: none"> • Environmental performance monitoring (water, air, soil, biodiversity) • Adaptive management • Circularity principles: Reduce, Reuse, Recycle, Recover (4R) • Sustainable operations and green maintenance practices • Carbon and energy accounting • Community based monitoring and response

3.2 Data from Questionnaires

The survey by questionnaires provided valuable insights into the current skills and data needs for advancing NAE practices in the coastal region of Kenya. The findings reveal apparent needs for data, tools, resources, technical expertise and knowledge sharing that are essential to support NAE approaches in coastal infrastructure developments. The results are organized in thematic sections for clarity, logical flow and ease of comparison.

3.2.1 Background of the Respondents

The respondents background data included the organization that the respondent works for, their professional role and the years of experience in coastal infrastructure projects or related. From Figure 3, majority of the respondents (74.1%) were engineers, followed by environmental experts at 11%. Also, among the respondents were Architects, Physical Planners, Green finance experts, policy experts and community leaders that collectively constituted 9.2%. With regards to experience, majority of the respondents (37%) had only between 3 and 5 years of experience in NAE or related practices. The respondents were mainly from National and County Government departments responsible for engineering and infrastructure development, and the private sector. Other respondents were from Non-Governmental Organizations, green financing institutions, research institutions and community leadership groups.

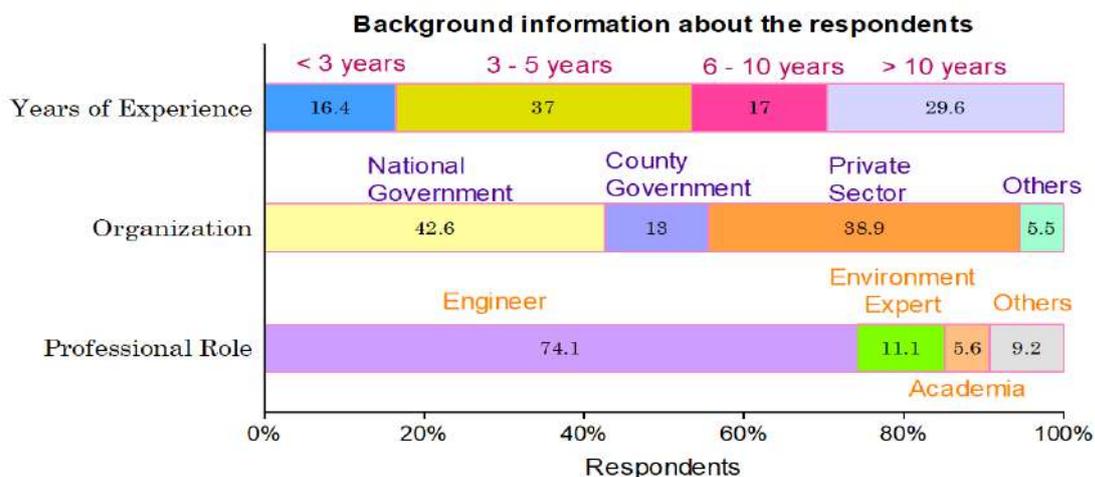


Figure 3. The distribution of respondents based on background information

3.2.2 Awareness and Implementation of NAE Practices

The survey also sought to understand the level of awareness and application of NAE in infrastructural projects at the respondent’s organization or company. From the results presented in Figure 4, most organizations (53.7%) are applying NAE methods only occasionally depending on the project. Only 29.6% of respondents indicated wide application and integration of NAE in their coastal projects, while 1.9% have never used NAE methods.

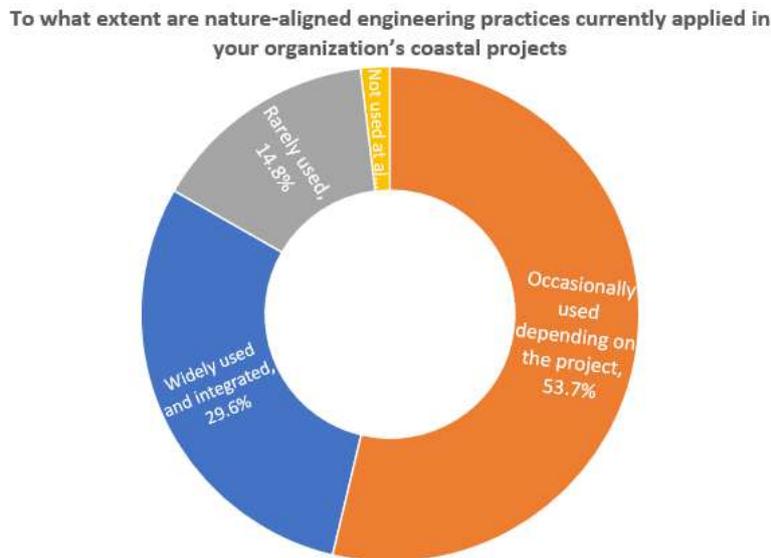


Figure 4. The extent of application of NAE practices in coastal projects across organizations

In Figure 5, the results reveal varying levels of frequency in application of the different NAE methods across coastal projects. The most frequently applied methods (> 50% of respondents) were holistic environmental impact assessment, Sustainable construction methods (Reduce, Reuse, Recycle, Recover), and community participation. These were consistently highlighted by respondents as part of standard procedures in planning and implementation of infrastructure projects. Moderately applied methods included ecosystem mapping & vulnerability analysis, ecological performance monitoring, modular construction techniques, low impact design techniques and hybrid infrastructures. Respondents noted these as emerging approaches that are yet to gain strong traction in coastal infrastructure projects but important for balancing resilience, cost-effectiveness and environmental integrity. Less frequently used practices (reported by less than 25% of respondents) were adaptive coastal protection systems, constructed wetlands, nature compatible upgrades/retrofits, and systems thinking approach. These methods were considered to be context -specific and limited by technical expertise. Overall, the results suggest a gradual integration of NAE methods but at varied degrees.

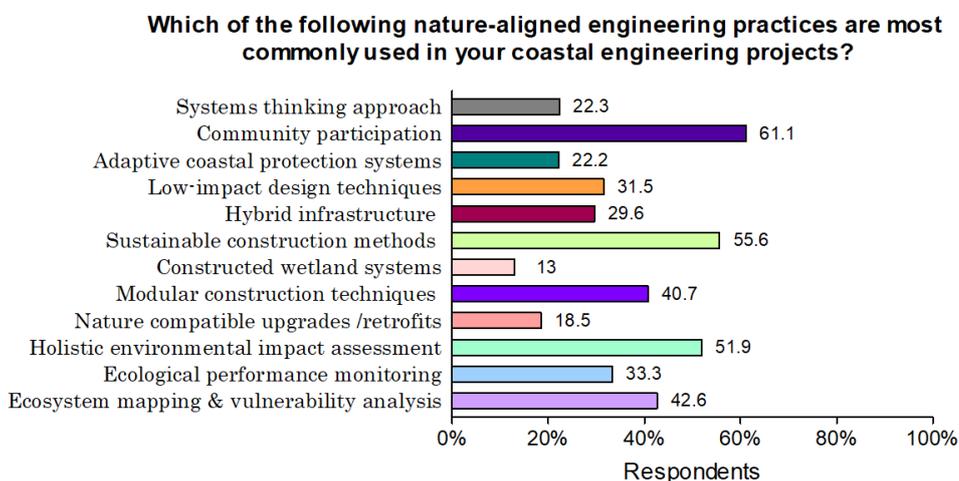


Figure 5. The NAE practices commonly used by the respondent’s organizations

3.2.3 Skills and Capacity to Implement NAE Practices

Adequate professional skills capacity in coastal engineering is essential for achieving infrastructure design solutions that are nature-aligned. For instance, technical expertise enables the creation of designs that balance functionality with ecological integrity. The results in Figure 6 reveal uneven distribution of technical skills within the respondents' organizations. Core environmental expertise was relatively strong, with environmental impact assessment, environmental monitoring, and Health, Safety & Environment (HSE) appearing among the most frequently reported skills capabilities. Stakeholder engagement is also reported consistently indicating recognition of inclusive planning in NAE application. More specialized skills such as hydrodynamic and sediment modelling, GIS and remote sensing, data analysis, and materials science focusing on low-carbon materials were reported moderately, highlighting technical skills gap in advanced modelling and clean materials applications. Similarly, circular economy and waste management, adaptive management, and green maintenance and operations were recorded as not widespread, suggesting emerging but still limited practice in these areas.

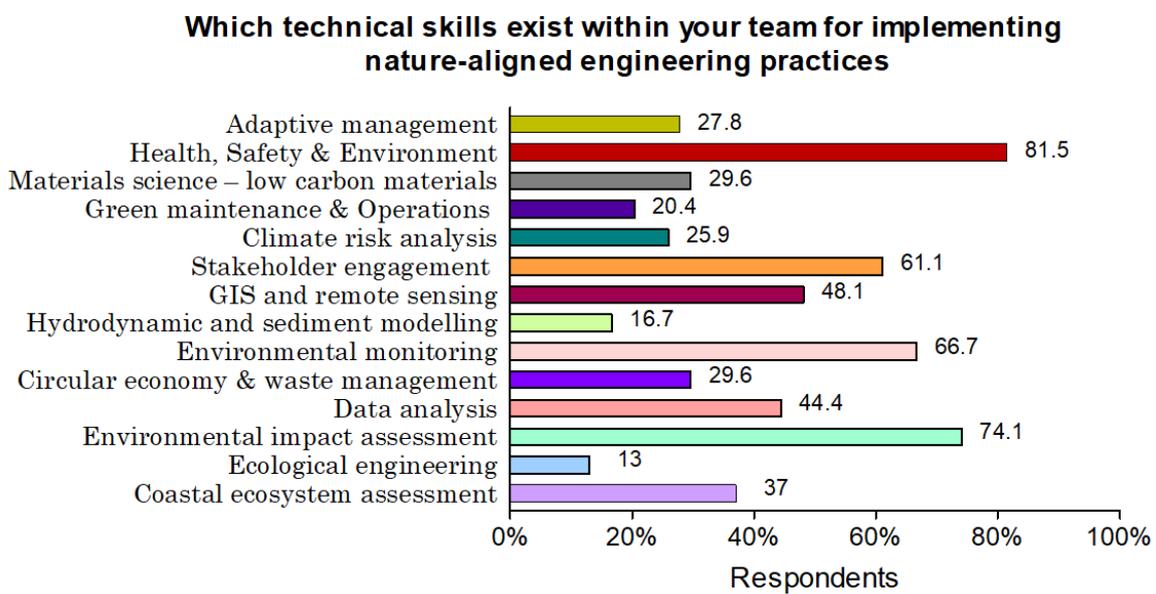


Figure 6. Existing technical skills in the organization to support implementation of NAE practices

Figure 7 depict the skills gaps that require capacity building for effective implementation of NAE methods in coastal infrastructure projects. From the results, specialized technical skills such as hydrological and hydrodynamic modelling, carbon and energy accounting, and ecological design and ecotechnologies have emerged as areas where most organizations require capacity strengthening, indicating challenges in applying advanced analytical tools for coastal sustainability planning. Also, a moderate number of respondents (between 25% and 50%) recorded engineering with nature design principles, adaptive management, green maintenance & operations, data analysis, community co-design approaches, and coastal risk assessment as areas that require skills improvement, pointing to a limited ability to integrate ecological processes and long-term adaptive strategies into infrastructure life-cycle process. Further, skills gap in policy & regulatory understanding, and systems thinking approach have been moderately reported by respondents, which suggest that professionals may lack the policy literacy and system-level thinking required to align engineering practices with broader environmental and governance frameworks. Less than 25% of respondents indicated a need for capacity building in sustainable construction techniques, and sustainability & circularity.

Which skills are lacking and require capacity building

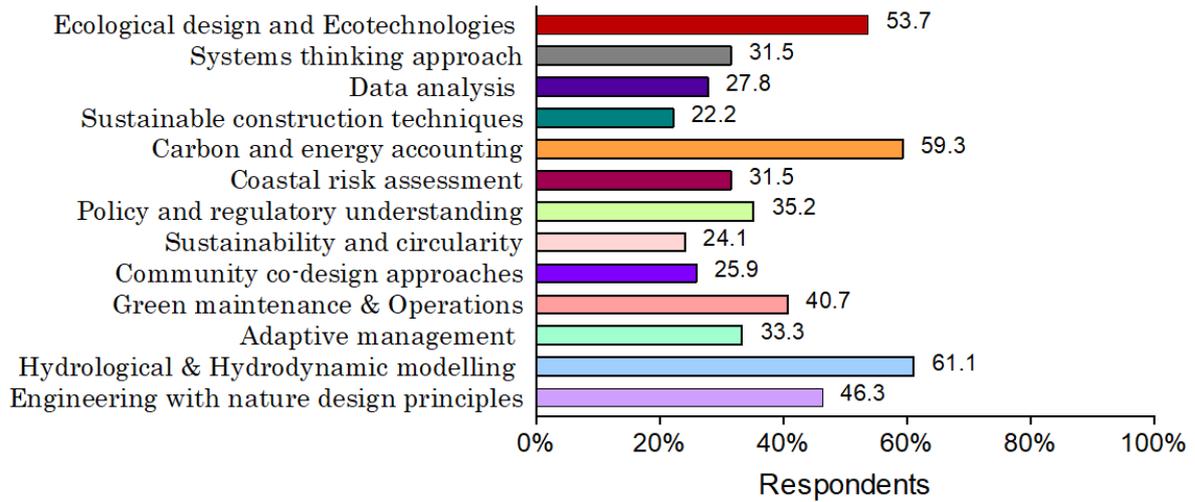


Figure 7. Skills gap that require capacity building

Figure 8 shows the responses on training related to NAE. It is apparent that training on NAE methods is not consistent across institutions. Only a small proportion (14.8%) reported receiving such training regularly, at least once a year. The majority (44.4%) indicated that training occurs only occasionally, sometimes within a year but not consistently. Notably, 27.8% of institutions receive NAE related training rarely, with gaps of more than three years, while 13% have never received any training. Generally, the results suggest that while some training opportunities exist, capacity building in NAE methods remains insufficient, pointing to a clear need for consistent training.

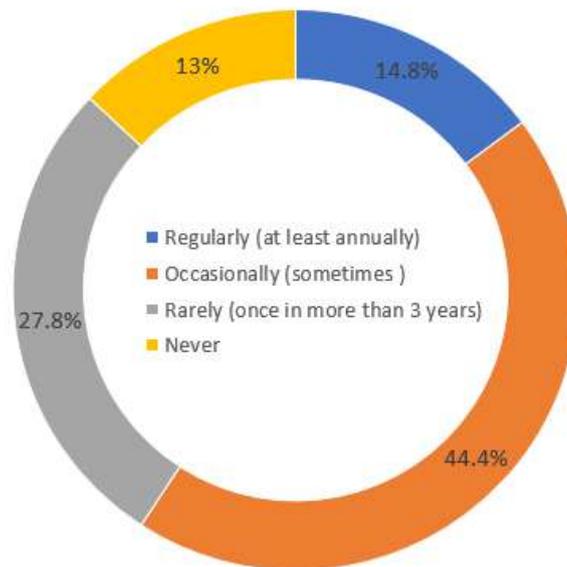


Figure 8. Trainings related to NAE

3.2.4 Availability of Data and Tools Usage

Data is essential to build scientific evidence to support and validate NAE approaches. The results in Figure 9 reveal a variation in the availability of data to support NAE methods. The most commonly available data is for water quality profiles (55.6%), climate and sea level rise projections (51.9%), and land use (50%),

indicating relatively wide usage of data relating to environment and planning. Waste and emissions data (42.6%) and noise and emissions baselines (38.9%) are also fairly accessible, suggesting attention to environmental impact monitoring. Contrary, there is limited availability of several types of data that are essential for ecosystem-based design with only 27.8% of respondents having access to ecosystem and habitat maps, with the same proportion for resource consumption data, while site-specific ecological sensitivity maps (18.5%) and carbon accounting records (11.1%) remain scarce. This points to significant data gaps in ecological and carbon-related assessments that are central to advancing NAE approaches. Data on socioeconomic and demographic profiles (33.3%) and citizen science datasets (24.1%) is available but to a moderate degree. It is noteworthy that 14.8% of respondents indicated very limited or no relevant data availability, underscoring persistent challenges in data availability/management or access.

Overall, the findings suggest that while climate, water quality, and land use data are relatively well-developed, ecological sensitivity and carbon footprint information remain insufficiently available. This situation could constrain the ability of engineers and planners to fully integrate NAE approaches in coastal infrastructure projects. Strengthening ecological and carbon-related datasets, alongside better use of community and citizen-science data, will be essential for more holistic and effective NAE practices.

What types of data are available to support nature-aligned engineering design and planning?

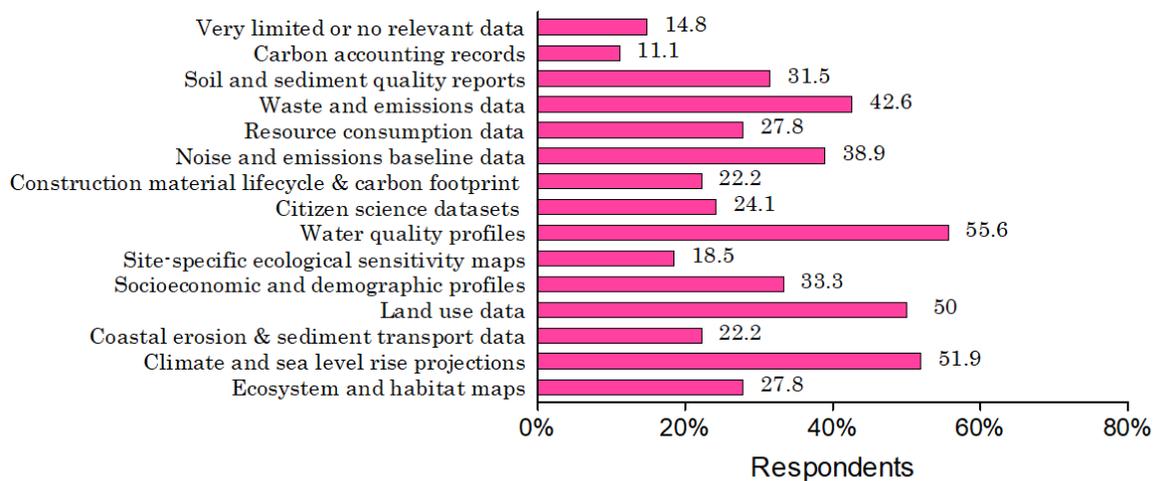


Figure 9. Types of data available to support NAE planning and design

Besides data, access to specialized tools for monitoring coastal ecosystems is also essential for implementation of NAE approaches in coastal infrastructure projects. Figure 10 shows the tools used are the tools used for coastal infrastructure planning and design in Kenya, while Figure 11 presents the level of sufficiency of the tools to support integration of NAE methods in coastal infrastructure planning and design. From the results in Figure 10, it is notable that most organizations/institutions use GIS platforms and custom spreadsheet tools. Advanced tools for hydrodynamic modelling, ecological evaluation, decision support and carbon accounting are lacking.

The results in Figure 11 indicate that the current tools available for project planning are only partially sufficient in addressing NAE considerations. This suggests that while some tools and methods exist, they may need to be adapted to the country settings to fully support ecosystem-based approaches. They pointed out some limitations that include systemic gaps such as inadequate data integration, limited modelling capacity, and the lack of context-specific applications in Kenya. A moderate proportion (25.6%) of respondents indicated that no major limitations exist. Notably, only 5.5% of respondents consider the tools to be fully sufficient. Meanwhile, 13% were not sure, which may reflect either limited awareness of the tools available or uncertainty about their application in coastal projects.

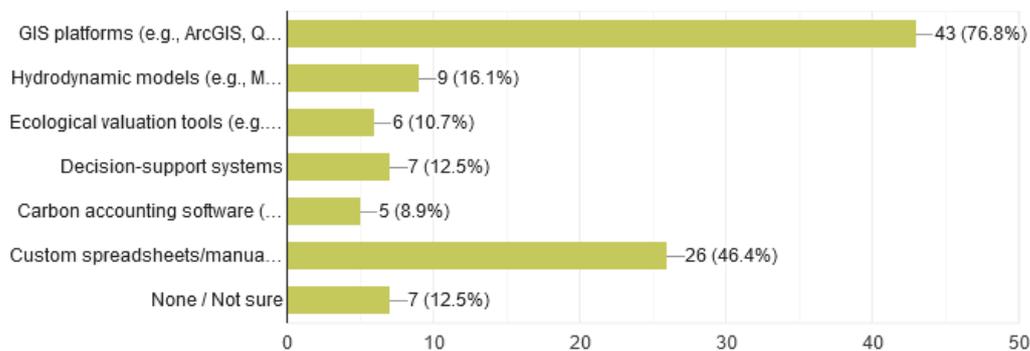


Figure 10. Tools usage for infrastructure design and planning

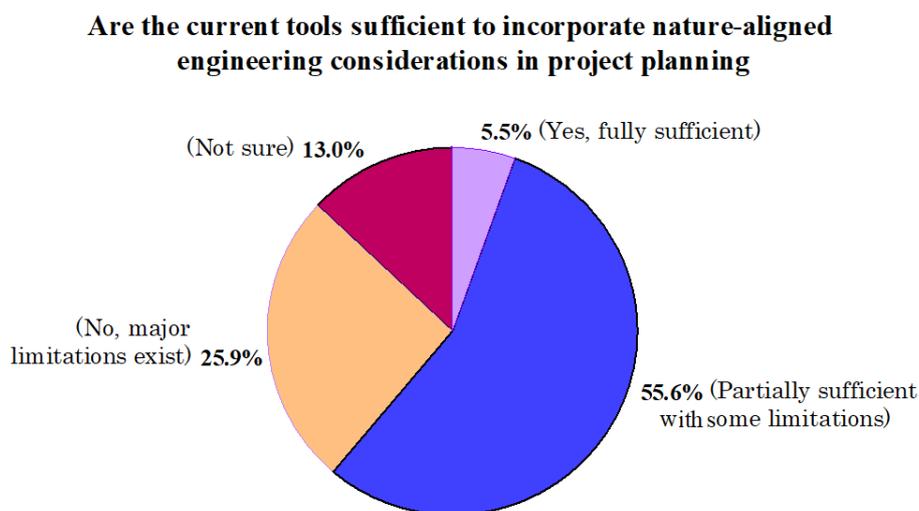


Figure 11. Sufficiency of available tools for NAE planning

The results in general point to a need for diverse tools and their adaptation to different coastal contexts. This could involve developing more accessible tools and expanding the training for practitioners to maximize the potential for tools usage.

3.2.5 Research Needs

Part of the study objectives was to understand the top research priorities for critical data to support implementation of NAE methods in coastal projects. It is evident from the results displayed in Figure 12 that the top priorities for research to support implementation of NAE in coastal projects are: cost-benefit analysis (68%), long-term monitoring frameworks (63%), and performance of NAE approaches in different environments (59.3%). The high priority given to cost-benefit analysis underscores the demand for robust economic comparisons to justify adoption of NAE approaches versus traditional infrastructure. Similarly, the high priority on long-term monitoring and performance studies indicates a need for empirical data and evidence to build confidence in how these approaches function across diverse environmental settings.

Policy and governance studies (55.5%) and social acceptance and behavioural research (46.3%) came out as moderate priority research areas, while ecosystem services valuation (35.2%) and scaling up pilot projects (35.2%) were voted as lower priority, though still comparatively significant. The significant research interest in policy and governance studies reflects recognition that institutional and regulatory frameworks are key to effective implementation of NAE practices. Meanwhile, social acceptance and behavioural research highlight the importance of community buy-in and local indigenous knowledge for success.

Lower rankings for ecosystem services valuation and scaling up pilot projects may not mean they are unimportant, but rather owed to lack contextual example in local context.

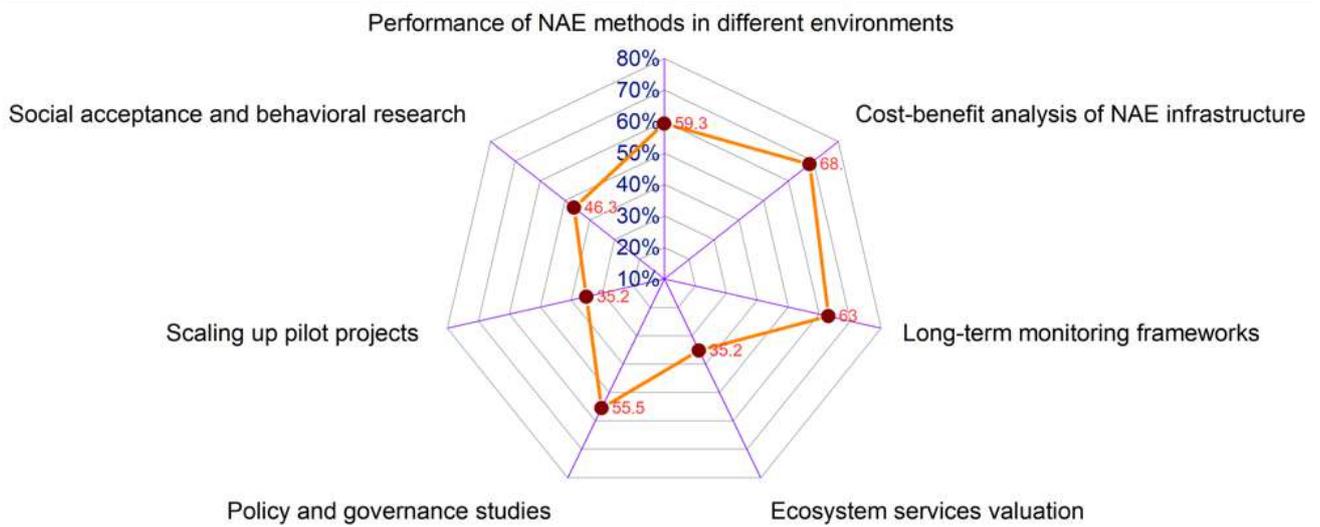


Figure 12. Research priorities for data to support NAE implementation

3.2.6 Enablers for Implementation of NAE

Figure 13 presents results on the kind of support that would help institutions/organizations better implement NAE practices. Training and capacity recorded the strongest response (83%), followed by access to funding and resources (65%) and technical assistance (60%) that were also rated highly. Surprisingly, partnerships with other institutions received the lowest selection, but the fact that 40% of respondents still selected it suggests that collaboration is viewed as beneficial but perhaps secondary to more immediate needs such as skills, funding, and technical support.

These results point to a strong recognition that capacity building is foundational for advancing NAE practices. However, that alone are not sufficient. The relatively high demand for funding and resources reflects the reality that many NAE solutions require investment in new materials, technologies, or pilot projects.

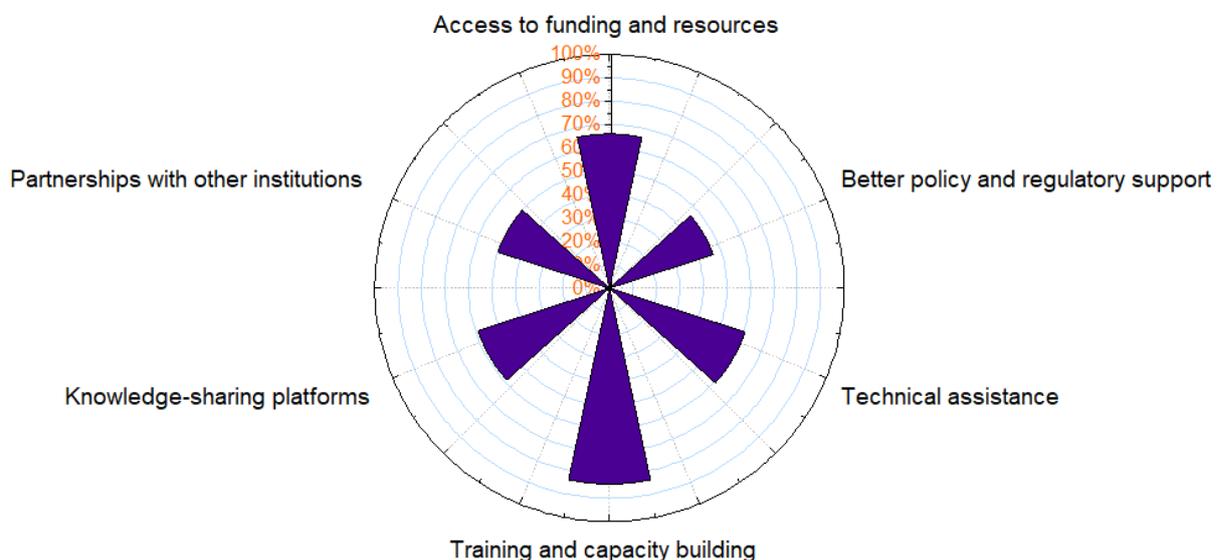


Figure 13. Enablers for implementation of NAE

The need for technical assistance and knowledge-sharing platforms shows that organizations / institutions are seeking both practical guidance and collaborative learning spaces to accelerate adoption. The emphasis on policy and regulatory support indicates that structural barriers remain, with organizations/institutions needing guidelines, incentives, and regulatory frameworks to mainstream NAE approaches.

3.2.7 Training and Collaboration

The results obtained from the survey (Figure 14) show that the most preferred training formats are graduate education programs (75%) and short-term technical workshops (71.4%). The findings indicate a dual demand for formal, in-depth education alongside practical, skills-focused short courses. The strong interest in graduate education programs suggests that many stakeholders value structured, long-term academic pathways to build specialized expertise in NAE. At the same time, the high preference for short-term workshops reflects a need for immediate, targeted skills development that can be directly applied in ongoing projects

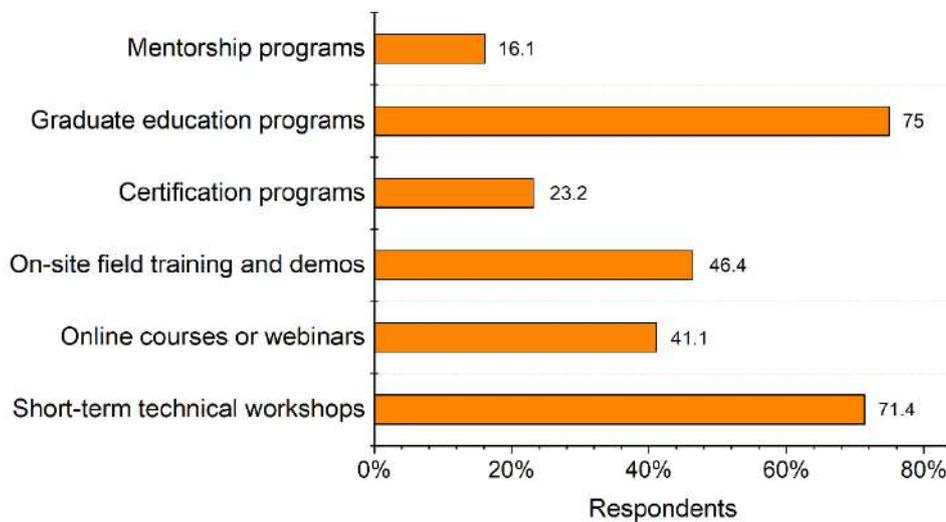


Figure 14. Preferred mode of training for capacity building

On-site field training and demonstrations (46.4%) and online courses or webinars (41.1%) also received notable support, though to a lesser extent. Meanwhile, certification programs (23.2%) and mentorship or twinning programs (16.1%) were the least prioritized training formats. The moderate support for on-site field training and online formats points to an interest in flexible and applied learning approaches, but perhaps as complementary options rather than primary methods. The relatively low preference for certification programs and mentorship schemes suggests that they are not currently viewed as the most effective or urgent methods for capacity building in this context.

Overall, the results imply that a blended training strategy combining academic programs with short, intensive technical workshops would be the most effective way to strengthen capacity for implementing NAE practices.

3.3 Findings from Focus Group Workshop

The focus group workshop was convened to explore the practical skillsets, data and tools needed for integrating NAE approaches into coastal infrastructure projects, in contexts characterized by climate vulnerability and limited resources. Participants identified relevant skills, data and tools required to support NAE in coastal infrastructures.



Figure 15. Participants in a focus group discussion

3.3.1 Skills & Capacity

The skills needed to support nature-aligned engineering (NAE) were classified along the four facets of NAE- skills to support sustainability and circularity, ecological inclusivity, resilience and adaptability of the infrastructure.

Table 5. Skills needs and existing gaps

Skills Needed	Existing Gaps
1) Expertise in ecology, coastal geomorphology and hydrodynamics to design with natural systems in mind.	1) Engineering curricula remain dominated by conventional design approaches with limited exposure to NAE case studies
2) Ecological performance monitoring, adaptive management, and use of local biodiversity indicators	2) Lack of a methodology for integration local/indigenous ecological knowledge
3) Systems thinking – ability to integrate engineering with ecology, indigenous knowledge and economics	3) Training and professional development opportunities are not coordinated but fragmented, and often short-term /project-driven
4) Expertise in hybrid design: knowledge of grey-green infrastructure	4) Weak regulatory support for training and capacity building
5) Circularity: materials reuse, low-carbon design and life-cycle costing	5) Shortage of NAE experienced trainers
6) Community engagement and participatory planning	
7) Expertise in GIS and environmental modelling.	

3.3.2 Data & Tools

Effective implementation of NAE methods in coastal infrastructure projects requires availability of quality essential data as well as practical tools for systems modelling, design and monitoring. The discussions revealed the critical data and tools needed and the existing gaps that must be addressed to advance NAE in the Kenyan coastal context

Table 6. Data and Tools needed for NAE

Data /Tools Needed	Existing Gaps
1) Ecosystem inventories	1) Weak capacity in hydro-metrological and nature-based modeling tools
2) Long-term hydro-meteorological data	2) Fragmented and siloed holding of data
3) Carbon assessment tools	3) Lack of standardized data capturing and sharing frameworks
4) GIS Platforms and AI tools / Software	4) Lack of decision support systems for data integration
5) Life-Cycle Assessment tools for infrastructure projects eg. SIMA	5) Lack of design guidelines for NAE
6) Climate change projections for Kenya’s coastline	6) Poor interoperability between data and available software systems
7) Socio-economic data - community land-use and vulnerability mapping	
8) Data on circular infrastructure practices	
9) Nature-based modelling tools such as ECORESIL	

3.3.3 Research Areas

The workshop highlighted key research gaps that need to be addressed to build clear understanding and generate evidence of the efficacy of NA engineering methods. Bridging these gaps is essential to foster adoption and mainstreaming of NAE approaches. The priority research focus areas identified include:

1. Life-cycle and cost-benefit analysis of NAE solutions to quantify environmental, social and economic performance of NAE options versus the conventional solutions. The expected research outputs would be the locally-relevant life-cycle analysis decision support tools (e.g. models, web applications) for NAE in the coastal region of Kenya
2. Characterization and testing of locally available sustainable building materials and technologies for NAE applications in Kenyan coastal zones. The expected outputs of the research would include construction manuals or technical guides for contractors.
3. Long-term monitoring of local ecosystems to collect data for validation of predictive models used in NAE planning and design. The expected outputs may include validated parameter sets for the Kenyan coastal contexts.
4. Policy research to provide evidence-based guidelines for integration of NAE approaches into existing national and coastal infrastructure regulations and safety risk management strategies.
5. Development of suitable participatory models that enable effective local community engagement in both design and maintenance processes of NAE infrastructure projects. Such models should integrate local and indigenous knowledge to enhance the durability and performance of NAE infrastructure projects. The expected research outputs may include community engagement tool-kits and co-design templates.

4. Conclusion & Recommendations

4.1 Summary of the Findings

Kenya's coastal region is an economic lifeline, but the region remains vulnerable to sustainability and resilience challenges due to reliance on grey and hard engineering methods in infrastructure developments. Adopting nature-aligned engineering (NAE) methods that blend engineering design with ecological processes offers a pathway towards sustainability and resilience. However, the NAE approach requires specialized skills, data and tools for effective implementation.

This research aimed to identify the data and skills needed to implement NAE methods in Kenya's coastal infrastructure and to establish research gaps that should be addressed to demonstrate performance and support wider adoption. The methodology utilized in the study involved desk review, questionnaire interviews and a focus group workshop. Based on the study objectives and findings, the following conclusions are drawn:

A. *Current knowledge and application of NAE*

The assessment shows that NAE principles are moderately understood across Kenya's coastal engineering sector and that their practical application remains inconsistent and largely limited to specific projects. Also, integration into planning, design, construction and maintenance cycles is weak. Current practice is dominated by grey/hard engineering, with NAE methods applied occasionally and often in isolated contexts. The variation in use across organizations reflects uneven exposure, limited technical expertise, and inadequate institutional frameworks to mainstream NAE.

B. *Data and Skills Gaps*

The study identifies significant gaps in both skills and data required for effective and scalable NAE implementation. Most organizations possess general environmental competencies such as environmental impact assessment and monitoring, but lack specialized skills crucial for NAE, including hydrodynamic modelling, ecological design, adaptive management, and carbon/energy accounting. Training is fragmented, and not institutionalized.

Data availability is equally constrained: while climate, water quality and land-use data are relatively accessible, critical ecological datasets are scarce or siloed. Tools for advanced modelling, valuation, and decision support are not widely available or are insufficiently adapted to the Kenyan coastal context.

C. *Trends and Opportunities for scaling NAE*

The findings reveal strong opportunities for integrating NAE within coastal infrastructure development in Kenya. There is growing interest among practitioners in hybrid infrastructure, ecological performance monitoring, and circular construction methods. Institutions also express strong demand for structured graduate programs, targeted technical training, and interdisciplinary collaboration, indicating readiness for capacity development

4.2 Strategic Actions to Accelerate NAE Integration

The synthesized insights point to several strategic priorities that will accelerate integration of NAE approaches:

- I. Capacity development for NAE-related skills should be pursued as a long-term effort through curriculum reforms in universities and colleges in Kenya and specialized training modules.
- II. Building integrated and open coastal data systems, focusing on ecological, hydrological, socioeconomic, and carbon datasets that are standardized, interoperable, and routinely updated.

- 
- III. **Developing context-specific tools and models which are affordable, scalable and calibrated for Kenya's coastline. This may include low-cost open-source modelling and GIS tools**
 - IV. Advancing research and demonstration projects to generate local evidence, validate modelling assumptions, and improve confidence among engineers and policy-makers.
 - V. Embedding community and indigenous knowledge in NAE design and monitoring, supported by co-design approaches, participatory mapping, and citizen science.
 - VI. Enhancing institutional coordination and policy support to standardize NAE practices within infrastructure planning and regulatory systems.

4.3 Overall Conclusion

The study concludes that NAE offers a viable pathway for Kenya's coastal infrastructure transition toward resilience, ecological integrity and sustainability. However, realizing this potential requires investments in human capacity, data ecosystems, modelling tools, research, and community engagement. With targeted action across institutions, Kenya can shift from predominantly grey engineering to integrating nature-aligned infrastructure development model that safeguards livelihoods, biodiversity, and coastal economies.

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Appendices

Appendix A1: Questionnaire

FOSTERING NATURE-ALIGNED ENGINEERING METHODS IN COASTAL INFRASTRUCTURE DEVELOPMENT - DATA & SKILLS NEEDS ASSESSMENT

This questionnaire is designed to help gather relevant insights and information for identification of critical skills needs and data gaps for Nature-Aligned Engineering (Sustainable, Adaptive, and Ecologically Conscious Engineering) practices in coastal infrastructure development. Your responses will inform the development of skilling and research programs to support implementation and mainstreaming of Nature-Aligned Engineering methods. *Nature-Aligned Engineering (NAE) is the practice of designing and implementing engineering solutions with emphasis on sustainability, adaptability, resilience and long-term environmental compatibility*

Section A: Participant Background

1. What is your professional role?

- Engineer (Civil, Environmental, Coastal, Biosystems)
- Planner /Project Manager
- Policy Maker /Regulator
- Researcher / Academic
- Environmental Expert
- Other

2. What type of organization do you work for?

- National government agency /Department
- County government
- Academic /Research institution
- Private sector /Consultancy
- NGO/ Civil society
- Donor Organization
- Other

3. Years of experience in coastal infrastructure or related projects

- Less than 3 years
- 3 – 5 years
- 6 – 10 years
- More than 10 years

Section B: Awareness & Implementation of Nature-Aligned Engineering Practices

4. How familiar are you with nature-aligned (Sustainable, Adaptive, and Ecologically Conscious) engineering approaches/methods?

- Very familiar and currently applying them
 Somewhat familiar, occasional application
 Aware, but not applying
 Not familiar at all

5. To what extent are nature-aligned engineering practices currently applied in your organization's coastal projects?

- Widely used and integrated
 Occasionally used depending on the project
 Rarely used
 Not used at all

6. Which of the following nature-aligned engineering practices are most commonly used in your coastal engineering projects? (Select all that apply)

- Ecosystem mapping & vulnerability analysis
 Ecological performance monitoring
 Holistic environmental impact assessment
 Nature compatible upgrades /retrofits
 Modular construction techniques /precast construction
 Constructed wetland systems
 Sustainable construction methods e.g. Reduce, Reuse, Recycle, Recover
 Hybrid infrastructure (combination of grey and green infrastructure)
 Low-impact design techniques
 Adaptive coastal protection systems
 Community participation (indigenous/traditional knowledge)
 Systems thinking approach
 Other (List)

Section C: Skills & Capacity

7. Which technical skills exist within your team for implementing nature-aligned engineering practices? (Select all that apply)

- Coastal ecosystem assessment
 Ecological engineering
 Environmental impact assessment
 Data analysis
 Circular economy & waste management
 Environmental monitoring
 Hydrodynamic and sediment modelling
 GIS and remote sensing
 Stakeholder engagement and participatory planning
 Climate risk analysis
 Green maintenance & Operations
 Materials science – low carbon materials
 Health, Safety & Environment
 Adaptive management
 None / Minimal skills available

8. Which skills are lacking and require capacity building? *(Select all that apply)*

- Engineering with nature design principles
- Hydrological & Hydrodynamic modelling tools
- Adaptive management and feed-back based protocols
- Green maintenance & Operations
- Community co-design approaches
- Sustainability and circularity
- Policy and regulatory understanding
- Coastal risk assessment
- Carbon and energy accounting
- Sustainable construction techniques
- Data analysis
- Systems thinking approach
- Ecological design and Ecotechnologies
- Other

9. How often does your team receive training related to nature-aligned engineering methods?

- Regularly (at least annually)
- Occasionally (sometimes once in a year but not every year)
- Rarely (once in more than 3 years)
- Never

Section D: Data availability and tools usage

10. What types of data are available to support nature-aligned engineering design and planning? *(Select all that apply)*

- Ecosystem and habitat maps
- Climate and sea level rise projections
- Coastal erosion and sediment transport data
- Land use data
- Socioeconomic and demographic profiles
- Site-specific ecological sensitivity maps
- Water quality profiles
- Citizen science datasets (e.g. pollution reports)
- Construction material lifecycle and carbon footprint data
- Noise and emissions baseline data
- Resource consumption data (energy, water, materials)
- Waste and emissions data
- Soil and sediment quality reports
- Carbon accounting records
- Very limited or no relevant data
- Other

11. What are the main barriers to accessing or using environmental and ecological data? *(Select all that apply)*

- Lack of centralized databases

- Outdated data
- Inconsistent data formats
- High cost of data acquisition
- Lack of technical capacity to process/use data
- Data is not collected at all
- Other

12. Which tools are currently used for coastal infrastructure planning and design? *(Select all that apply)*

- GIS platforms (e.g., ArcGIS, QGIS)
- Hydrodynamic models (e.g., MIKE, Delft3D)
- Ecological valuation tools (e.g., InVEST, ARIES)
- Decision-support systems
- Carbon accounting software (e.g., MS Sustainability cloud)
- Custom spreadsheets/manual analysis
- None / Not sure
- Other

13. Are the current tools sufficient to incorporate nature-aligned engineering considerations in project planning?

- Yes, fully sufficient
- Partially sufficient, with some limitations
- No, major limitations exist
- Not sure

Section E: Gaps, Barriers & Research Needs

14. What are the biggest barriers to implementing nature-aligned engineering practices? *(Select top 3)*

- Lack of awareness or understanding
- Technical skill gaps
- Inadequate data availability
- Financial constraints
- Lack of supportive policies/regulations
- Resistance to change or risk aversion
- Poor coordination among stakeholders

15. What are the top priorities for research to support implementation of nature-aligned engineering in your projects? *(Select all that apply)*

- Performance of nature-aligned engineering approaches in different environments
- Cost-benefit analysis of nature-aligned infrastructure vs traditional infrastructure
- Long-term monitoring frameworks
- Ecosystem services valuation
- Policy and governance studies
- Scaling up pilot projects
- Social acceptance and behavioral research
- Other

Section F: Training & Collaboration

16. Which types of training formats would be most useful for your team? *(Select up to 3)*

- Short-term technical workshops
- Online courses or webinars
- On-site field training and demonstrations
- Certification programs
- Graduate education programs
- Mentorship or twinning programs
- Other

17. Is your organization currently collaborating with any research or academic institution on sustainable infrastructure or coastal engineering topics?

- Yes
- No
- Considering to collaborate
- Not sure

Section G: Final Reflections

18. What kind of support would help your organization better implement NAE practices? *(Select all that apply)*

- Access to funding and resources
- Better policy and regulatory support
- Technical assistance
- Training and capacity building
- Knowledge-sharing platforms
- Partnerships with other institutions
- Other

19. Would your organization be willing to participate in research, training, or pilot initiatives related to nature-aligned engineering?

- Yes
- No
- Maybe / Need more information



Appendix A2: Focus Group Workshop Recordings

[Link 1: https://tinyurl.com/44vhf88x](https://tinyurl.com/44vhf88x)

[Link2:https://drive.google.com/drive/folders/1bLBwtPqmNnCVwLCt2Sjevd_NlRu5vVH6?usp=sharing](https://drive.google.com/drive/folders/1bLBwtPqmNnCVwLCt2Sjevd_NlRu5vVH6?usp=sharing)

Project Core Team



Project Lead: Augustine Makokha is a Professor of Mechanical Engineering at Moi University, Kenya. He obtained MSc and PhD in Engineering (Cum Laude) from University of the Witwatersrand, South Africa. He is a Certified Energy Manager, and a Certified Renewable Energy Professional by the Association of Energy Engineers (AEE). He is currently serving as Dean of School of Engineering at Moi University. He is a chair and grant holder for various research projects with research interests in the broad areas of renewable energy systems, safety and sustainability engineering



IEK Partner: Eng. Ekakoro Elizabeth is a professional Civil Engineer, and member of IEK. She is committed to advancing sustainable infrastructure and is working to bridge engineering practice with research. Her major interests include sustainable mobility, low-carbon systems, Nature based solutions and engineering safety. She is dedicated to supporting initiatives that promote socially inclusive development, increase equal opportunities, and strengthen community resilience.



KPA Partner: Eng. Nixon Oloo is an experienced Planning & Maintenance Engineer at KPA with demonstrated history of working in the marine transportation sector. He is a registered professional engineer with Engineers Board of Kenya and a certified maritime safety trainer.



Research Assistant: Lawrence Omai Muku is a Civil Engineer with research interest in geosynthetics man-made slopes, pavement engineering and optimization of urban reticulation systems. He aims to advance infrastructure development through approaches that combine ecological responsibility with engineering innovation.