

Implementation Strategies for Sustainable Irrigation Infrastructures in Nigeria

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Abstract

Irrigation agriculture is critical worldwide, accounting for approximately 70% of total water usage. In Nigeria, implementing effective irrigation strategies is essential to optimize water use and boost agricultural productivity. This paper examines the vital role of civil engineers in developing and applying sustainable irrigation infrastructure strategies in Nigeria. Currently, irrigation systems face significant challenges due to increasing water scarcity and competition. The methodology of this study involves a review of literature and case studies. Various innovative technologies and approaches, such as remote sensing – which includes satellite imagery, aerial photography, and UAVs – were identified for gathering data on crop conditions, soil moisture, and water resources. Findings reveal that establishing sustainable irrigation infrastructure is crucial for advancing Nigeria's agricultural sector, ensuring food security, and supporting economic growth. The significance of sustainable irrigation infrastructure, innovative technologies, and strategies can be employed by civil engineers and other professionals to address these challenges. Civil engineers possess the expertise, knowledge, and skills to design, implement, and manage sustainable irrigation infrastructure projects. Technological innovations, policy and governance, financing and investment, case studies, and community engagement can be used to achieve sustainable irrigation infrastructure.

Keywords: Innovative technologies, implementation strategies, sustainable irrigation infrastructure, civil engineers, policy and governance

INTRODUCTION

Nigeria, a country located in West Africa, faces numerous challenges in its irrigation sector. Insufficient and unsustainable irrigation infrastructure has hindered agricultural productivity, exacerbated food insecurity and hindered rural development. However, civil engineers have a critical role to play in addressing these challenges and implementing sustainable irrigation infrastructure. This introduction provides an overview of the current situation in Nigeria's irrigation sector and sets the stage for subsequent discussions on the implementation strategies. Nigeria has a vast agricultural potential with diverse agroecological zones, but the lack of reliable and efficient irrigation infrastructure has hindered the country's agricultural output [1]. Inadequate access to water for

irrigation purposes, combined with outdated irrigation systems and poor water management practices, has resulted in low crop yields and limited agricultural diversification [2]. Therefore, Nigeria's food security has been compromised, leading to increased dependence on food imports [3].

The implementation of sustainable irrigation infrastructure is of paramount importance for Nigeria's agricultural development, food security, and overall economic growth. Nigeria, as a nation with a rapidly growing population, faces numerous challenges in its irrigation sector, including water

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scarcity, inefficient water management practices, and environmental degradation. However, civil engineers have a crucial role to play in addressing these challenges and spearheading the rescue mission towards sustainable irrigation infrastructure. Implementing sustainable irrigation infrastructure is crucial for addressing these challenges and achieving long-term agricultural and rural development in Nigeria. Sustainable irrigation practices emphasize efficient water use, reduced environmental impact, and improved productivity [4]. By adopting such practices, Nigeria can enhance agricultural productivity, reduce water scarcity, mitigate the impacts of climate change, and improve the livelihoods of rural communities [5].

Civil engineers, with their expertise in infrastructure design and implementation, play a vital role in driving the rescue mission for sustainable irrigation infrastructure in Nigeria. They possess the technical knowledge to develop innovative and efficient irrigation systems that maximize water use and minimize wastage [6]. Civil engineers collaborate with hydrologists, agronomists, and environmental specialists to ensure the integration of diverse perspectives in irrigation projects [7]. Furthermore, their involvement in the planning and implementation stages enables the alignment of infrastructure projects with the needs and aspirations of local communities [8]. Nigeria's irrigation sector is confronted with several pressing challenges. Water scarcity is a significant concern, particularly in arid and semi-arid regions, leading to limited access to water for agricultural purposes. Furthermore, inefficient water management practices, including outdated irrigation methods and insufficient infrastructure, lead to water waste and lower agricultural productivity. Furthermore, unsustainable irrigation methods can lead to environmental degradation, including soil erosion, salinization, and depletion of water resources. These challenges necessitate urgent attention and effective strategies to develop sustainable irrigation infrastructure. The importance of sustainable irrigation infrastructure cannot be overstated. It serves as a cornerstone for agricultural productivity, ensuring increased crop yields and enhanced food security. Sustainable irrigation practices enable efficient water use, minimizing waste and maximizing the availability of water resources. Additionally, establishing sustainable irrigation infrastructure can support rural development, create jobs, and help reduce poverty. By promoting climate change adaptation and resilience, sustainable irrigation practices also play a crucial role in mitigating the impacts of a changing climate on agriculture [9, 10].

Civil engineers possess the expertise, knowledge, and skills necessary to design, implement, and manage sustainable irrigation infrastructure projects. They play a central role in the planning and execution of irrigation projects, collaborating with hydrologists, agronomists, environmental specialists, and other professionals to ensure the optimal use of resources and adherence to sustainability principles. Civil engineers bring a multidisciplinary perspective to irrigation infrastructure projects, considering factors, such as water availability, topography, soil conditions, and environmental impacts. Technological innovations have also revolutionized irrigation infrastructure, offering opportunities for more efficient and sustainable water use. Precision irrigation methods, including drip irrigation and sensor-based systems, enable targeted water application that reduces water loss and meets specific crop needs. Additionally, using renewable energy sources like solar-powered pumps decreases dependence on fossil fuels and improves the sustainability of irrigation practices. Effective policy and governance frameworks are essential to guide and support the successful development of sustainable irrigation infrastructure. Integrated water resources management, effective governance structures, and robust regulatory mechanisms are essential to ensure equitable and sustainable use of water resources. Government agencies, non-governmental organizations (NGOs), and partnerships with the private sector also play pivotal roles in providing the necessary support, funding, and expertise for sustainable irrigation initiatives [11–13].

Financing and investment represent significant challenges in implementing sustainable irrigation infrastructure. Adequate funding is required to develop and maintain irrigation systems, overcome financial constraints, and incentivize sustainable practices. Nigeria's irrigation infrastructure faces

challenges, including limited water access, outdated systems, and poor management practices, which hinder efficient water use and agricultural productivity. Water scarcity issues are driven by irregular rainfall, inadequate storage, and inefficient traditional irrigation methods, leading to high water loss. Remote sensing and satellite technologies offer solutions for managing hydrological issues, such as flooding and erosion, in vulnerable regions. Addressing these obstacles through innovative financing, like public-private partnerships (PPPs), and enhanced infrastructure maintenance could support sustainable irrigation, contributing to agricultural growth and food security [14].

Moreover, the environmental impacts of unsustainable irrigation practices pose significant challenges. Excessive water extraction from rivers and aquifers can lead to the depletion of water resources, resulting in long-term negative consequences for both ecosystems and communities [15]. Poor drainage and inadequate wastewater management can also lead to waterlogging, salinization, and soil degradation [16]. Addressing these challenges and transforming Nigeria's irrigation infrastructure into a sustainable and efficient system requires concerted efforts and the adoption of appropriate strategies. By implementing sustainable irrigation practices and modernizing the existing infrastructure, Nigeria can enhance water use efficiency, improve agricultural productivity, and ensure long-term water availability for irrigation purposes.

ROLE OF CIVIL ENGINEERS IN SUSTAINABLE IRRIGATION

Civil engineers are integral to sustainable irrigation in Nigeria, overseeing design, construction, operation, and maintenance. They calculate water requirements, select efficient irrigation methods, and design systems that meet local crop and soil needs [17]. Collaborating with hydrologists, agronomists, and communities, they create systems that reflect water availability, environmental impact, and community needs [18]. Civil engineers ensure regular infrastructure maintenance, optimizing water delivery and prolonging infrastructure lifespan.

Importance of Sustainable Irrigation Infrastructure

Sustainable irrigation is essential for food security, productivity, economic development, and climate resilience in Nigeria. By efficiently managing water, these systems boost crop yields and reduce losses, supporting food security [19]. Sustainable irrigation helps cultivate larger areas and diversify crops, improving farmer income and rural economies. Additionally, it addresses climate variability and reduces water over-extraction, protecting ecosystems and preserving soil health [20].

Technological Innovations in Sustainable Irrigation

Technologies like precision irrigation, drip irrigation, and remote sensing optimize water use. Precision irrigation adjusts water application to crop needs, minimizing waste and boosting yields [21]. Drip irrigation targets root zones, reducing evaporation losses and maximizing efficiency. Remote sensing with satellite data and IoT sensors enhances monitoring, allowing data-driven decisions in water management [22].

Financing and Investment for Sustainable Irrigation

Financing is key to establishing sustainable irrigation, with support from government, development agencies, private investors, and farmer cooperatives. PPPs facilitate cost-sharing and expertise. Public funds, development grants, and private investment, supported by government incentives, collectively strengthen Nigeria's sustainable irrigation initiatives [23]. PPPs can attract private investment, expertise, and efficient management practices while ensuring public oversight and affordability [24]. Other financing options include concessional loans, revolving funds, and crowdfunding initiatives tailored for irrigation infrastructure development [25]. Furthermore, it is crucial to explore innovative financing approaches for sustainable irrigation infrastructure. Climate finance mechanisms, such as the Green Climate Fund, provide opportunities for accessing funding for climate-resilient irrigation projects [26]. Innovative financial instruments, such as green bonds, impact investment funds, and risk-sharing mechanisms, can attract private sector involvement and support the transition to

sustainable irrigation [27]. By leveraging diverse funding sources, engaging multiple stakeholders, and employing innovative financing mechanisms, Nigeria can address the financial challenges associated with sustainable irrigation infrastructure. Ensuring adequate and sustainable financing is key to building and maintaining resilient irrigation systems that contribute to agricultural productivity, rural development, and water resource management.

METHODOLOGY

The methodology includes literature reviews and case studies. Various innovative technologies and implementation strategies were highlighted for sustainable irrigation infrastructure in Nigeria. Case studies of successful sustainable irrigation projects in Nigeria or other relevant regions provide valuable insights and lessons learned. By analyzing these case studies, the best practices can be identified and replicated in future projects. Exchanging knowledge and experience is essential for informed decision-making and encourages collaboration among stakeholders. Community involvement and capacity building are key elements in implementing sustainable irrigation infrastructure. Engaging local communities in the planning, design, and management stages ensures that projects are tailored to their specific needs and goals. Capacity-building programs can empower farmers and stakeholders by equipping them with knowledge, skills, and training in sustainable irrigation practices. Awareness campaigns can emphasize the advantages of sustainable irrigation, promoting a sense of ownership and responsibility within the community.

A lack of collaboration among basin authorities often hampers effective surface and groundwater management on both local and catchment scales.

Policy and Regulatory Framework for Sustainable Irrigation Infrastructure

An effective policy and regulatory framework are crucial for the successful implementation of sustainable irrigation infrastructure in Nigeria. This section discusses the importance of policies, regulations, and institutional arrangements in promoting sustainable irrigation practices and ensuring the long-term viability of irrigation systems. Clear and coherent policies are essential to guide sustainable irrigation development. National policies should prioritize water resource management, agricultural development, and environmental sustainability [28]. Policy frameworks need to address key aspects, such as water allocation, water rights, water pricing, land tenure, and environmental protection. Integrated water resources management (IWRM) approaches can provide a foundation for policy development by considering the interconnections between water, agriculture, and the environment (Figures 1 and 2) [29].

Water productivity (WP) is a measure that compares the net benefits obtained from crops and agricultural systems to the water used in production. This can be represented by the ratio of the harvested crop's weight or the monetary value of output to the volume of water consumed. In Nigeria, irrigation schemes like the Kano River Irrigation Project (KRIP) and the Hadejia Valley Irrigation Project (HVIP) demonstrate variations in WP. WP may differ across spatial scales due to factors, such as crop selection, climate conditions, irrigation methods, field water management, and other inputs like labor, fertilizer, and machinery. Effective regulations are necessary to enforce compliance with sustainable irrigation practices. Regulations can cover aspects, such as water use efficiency, water quality standards, land use planning, and the use of advanced irrigation technologies [30]. They also play a role in managing conflicts and balancing competing water demands among different sectors, including agriculture, industry, and domestic use [31]. Regulatory frameworks should be transparent, consistent, and enforceable to ensure equitable access to water resources and promote responsible irrigation practices. Institutional arrangements and capacity building are critical for the implementation of irrigation policies and regulations. Effective governance structures should be in place to coordinate and oversee irrigation activities [32]. This includes establishing institutions responsible for water resources management, agricultural extension services, and irrigation infrastructure operation and maintenance. Institutional collaboration and coordination among relevant

government agencies, local communities, farmers' associations, and research institutions are essential for the effective implementation of sustainable irrigation practices [33].

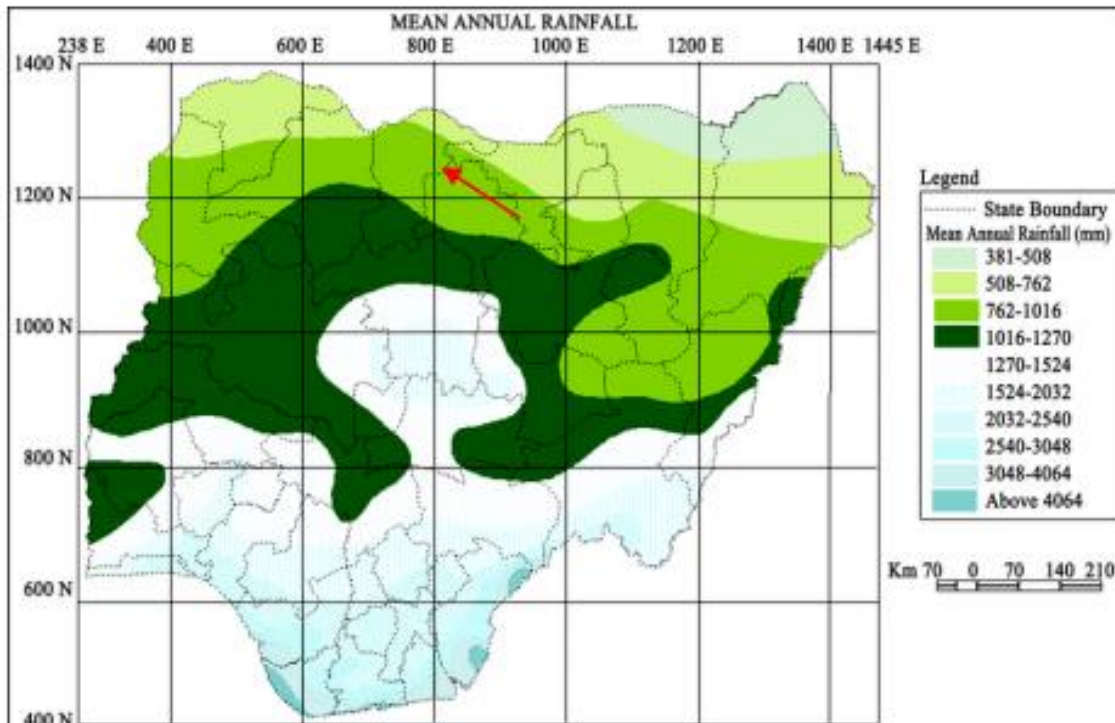


Figure 1. Map of Nigeria showing mean annual rainfall patterns.

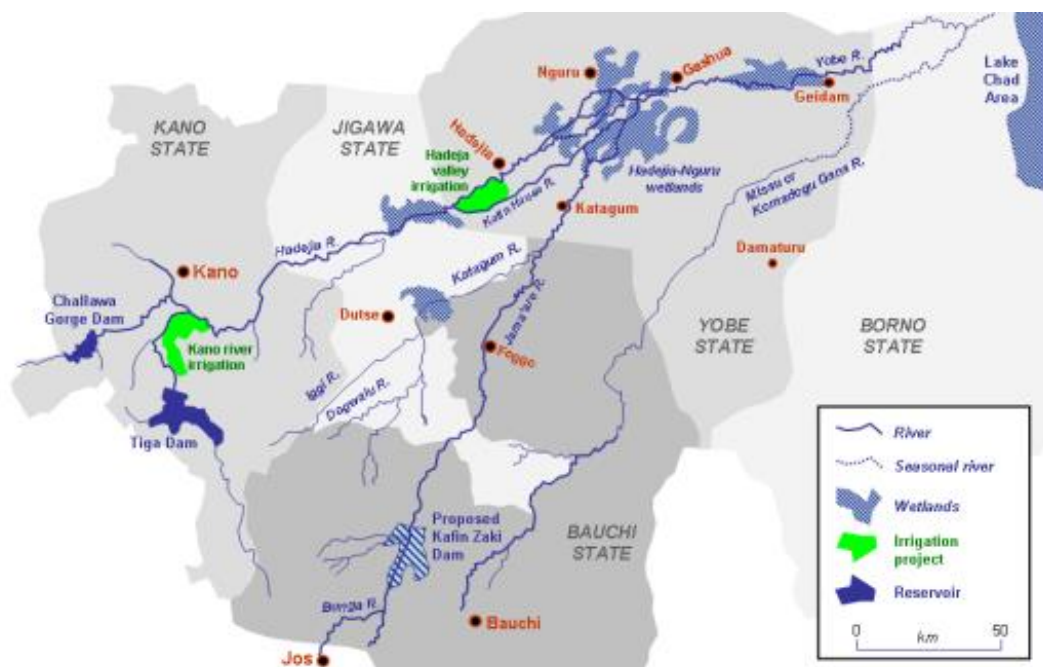


Figure 2. Map showing the large irrigation schemes in the project area and the hydrology pattern of the basin.

Furthermore, active stakeholder engagement and participation are vital components of a comprehensive policy and regulatory framework. Engaging farmers, local communities, and other relevant stakeholders helps ensure that policies and regulations are responsive to the needs, priorities,

and specific conditions of the irrigation sector [34]. By incorporating participatory methods, stakeholders can share valuable insights, perspectives, and experiences, leading to more inclusive and effective policies and regulations. Creating an environment with comprehensive policies, a strong regulatory framework, and appropriate institutional structures will enable Nigeria to support sustainable irrigation infrastructure. This supportive environment can promote efficient water use, increase agricultural productivity, protect the environment, and enable sustainable water management.

Capacity Building and Knowledge Transfer for Sustainable Irrigation Infrastructure

To achieve sustainable irrigation infrastructure in Nigeria, building capacity and facilitating knowledge transfer are crucial. This section highlights the importance of strengthening technical and institutional capacity, fostering knowledge sharing, and promoting innovation within the irrigation sector.

Technical Capacity Building

Developing technical capacity is essential for the planning, design, construction, operation, and maintenance of sustainable irrigation systems. Professionals within the irrigation sector – such as civil engineers, agricultural experts, and water managers – require specialized skills and knowledge to maximize irrigation systems' effectiveness. Training programs and workshops are key to building this expertise, covering topics like water management, efficient irrigation system design, advanced irrigation technology use, water conservation strategies, and maintenance practices [35]. Continuous professional development is also essential to keep practitioners updated on recent advancements and best practices in sustainable irrigation.

Collaborations with educational and research institutions can support the transfer of technical knowledge and expertise. Collaborative projects, exchange programs, and joint training initiatives can enhance knowledge exchange between academic institutions and professionals in the field. These partnerships can contribute to the development of locally relevant and context-specific solutions, considering the specific challenges and opportunities of the Nigerian irrigation sector.

Institutional Capacity Building

In addition to technical capacity, building institutional capacity is essential for the effective governance and management of sustainable irrigation infrastructure. This involves strengthening the capacity of government agencies, irrigation management institutions, and farm organizations responsible for the planning, regulation, and operation of irrigation systems. Capacity-building programs can focus on improving governance structures, policy formulation, regulatory developing enforcement, and coordination mechanisms among diverse stakeholders is vital for effective irrigation management. These mechanisms benefit from monitoring and evaluation frameworks to assess irrigation projects' performance and impact. By building institutional capacity, Nigeria can enhance the enforcement of policies and promote sustainable practices across the irrigation sector.

Knowledge Transfer and Innovation

Promoting knowledge transfer and fostering innovation are essential for the continuous advancement of sustainable irrigation infrastructure. Farmers, local communities, and irrigation practitioners hold valuable expertise that can contribute to refining irrigation techniques. Knowledge-sharing platforms, including workshops, field demonstrations, and farmer-to-farmer exchanges, provide spaces to share best practices, experiences, and locally developed innovations. These initiatives allow for the exchange of challenges and success stories, encouraging peer learning and collaboration. Additionally, fostering the adoption of new technologies and supporting innovation in irrigation is critical for sustainability. Research institutions can significantly contribute by developing solutions tailored to Nigeria's unique needs, such as climate-resilient irrigation methods, water-saving technologies, and digital tools for effective irrigation management. Innovation hubs, incubators, and funding models can also support the dissemination of these solutions. By focusing on capacity

building, knowledge transfer, and innovation, Nigeria can fortify its irrigation sector's capacity to sustain and expand sustainable irrigation practices.

Stakeholder Engagement and Community Participation in Sustainable Irrigation Infrastructure

Stakeholder engagement and community participation are essential for the successful implementation of sustainable irrigation projects in Nigeria. This section examines the importance of involving all stakeholders and local communities in decision-making, promoting participatory methods, and building accountability.

Stakeholder Engagement

Inclusive stakeholder engagement ensures that diverse perspectives and interests are represented throughout irrigation project planning, implementation, and management. Relevant stakeholders in the irrigation sector include government agencies, local communities, farmers' associations, civil society organizations, private sector entities, and research institutions. Engagement processes should be transparent, inclusive, and participatory, allowing stakeholders to share their insights and actively contribute to decision-making. Involving stakeholders from the early stages helps foster trust, facilitate knowledge exchange, and build collaboration across different groups. Multi-stakeholder forums, working groups, and consultations provide platforms for open dialogue, negotiation, and consensus-building enabling local knowledge and cultural practices to be integrated into irrigation planning and design. Effective engagement processes help identify potential conflicts, support social equity, and increase the acceptability and sustainability of irrigation projects.

Community Participation

Active community participation is essential for ensuring the long-term success and sustainability of irrigation projects. Local communities, who are directly impacted by these developments, possess valuable knowledge about regional conditions, water resources, and agricultural practices. Involving communities in decision-making builds ownership, empowerment, and accountability. Participatory approaches, such as participatory planning, budgeting, and community-based management encourage community involvement in irrigation design, implementation, and monitoring. Community engagement should be meaningful, incorporating capacity building and the recognition of local expertise. This input is valuable for shaping project design and implementation. Capacity building within communities for irrigation management, efficient water use, and sustainable farming practices empowers them to manage and maintain irrigation systems over time.

Community-led initiatives, including farmer cooperatives, water user associations, and self-help groups, play a key role in sustainable irrigation governance (Kouziokas et al., 2019). These initiatives foster collective action, promote social cohesion, and ensure that benefits are equitably shared among community members. By prioritizing stakeholder engagement and community participation, Nigeria can ensure that the design, implementation, and management of sustainable irrigation infrastructure align with the needs and aspirations of local communities, promoting social inclusiveness, equity, and long-term sustainability.

FINANCING AND INVESTMENT STRATEGIES FOR SUSTAINABLE IRRIGATION INFRASTRUCTURE

Financing and investment are essential for developing sustainable irrigation infrastructure in Nigeria. This section highlights the importance of securing adequate funds, exploring innovative financing methods, and attracting investment to support the establishment and upkeep of irrigation systems.

Adequate Funding

Developing sustainable irrigation systems requires significant financial resources for planning, design, construction, and ongoing maintenance. Ensuring sufficient funding is critical to providing the

infrastructure, equipment, and resources needed for efficient irrigation practices. Government funding serves as a primary source of support for these projects, with budget allocations dedicated to irrigation development and the potential establishment of special funds or programs to promote sustainability. Additionally, international support – such as grants and loans from multilateral organizations and bilateral partnerships – can further contribute to financing irrigation projects.

Governments need to prioritize irrigation by allocating sufficient financial resources to the sector, given its impact on agricultural growth, food security, and rural livelihoods. Effective financial management and strategic budget planning are also essential for the transparent and efficient use of funds in irrigation projects.

Innovative Financing Mechanisms

Innovative financing strategies can supplement traditional funding sources and attract additional investments for sustainable irrigation. These strategies may involve private-sector investments, PPPs, and alternative funding approaches. PPPs are particularly valuable, as they combine private-sector expertise and resources with government regulatory and policy support. Through models, such as concession agreements, build-operate-transfer (BOT) arrangements, and performance-based contracts, PPPs can facilitate the funding, construction, and management of irrigation infrastructure, with private partners sharing both risks and responsibilities. Microfinance and rural credit schemes can provide financial support to smallholder farmers and local communities for the adoption of sustainable irrigation practices. These schemes offer affordable loans, credit facilities, and savings mechanisms tailored to the needs of farmers. They can contribute to increasing farmers' access to irrigation technologies, improving productivity, and enhancing income generation.

Attracting Investment

Attracting investments from domestic and international sources is crucial for the long-term sustainability of irrigation infrastructure. Investments can support the expansion of irrigation systems, the adoption of advanced technologies, and the implementation of water-saving practices. Creating an enabling environment for investment requires favorable policies, legal frameworks, and incentives. Governments can provide tax incentives, land tenure security, and streamlined administrative procedures to attract private investments in irrigation infrastructure. They can also facilitate PPPs and investor-friendly regulations to encourage investment flows. Engaging with development finance institutions, impact investors, and commercial banks can help mobilize financial resources for irrigation projects. These institutions often provide technical assistance, loans, equity investments, and risk mitigation instruments to support sustainable infrastructure development. By adopting innovative financing mechanisms, attracting investments, and ensuring adequate funding, Nigeria can secure the financial resources needed for the sustainable development and maintenance of irrigation infrastructure.

Case Studies and Best Practices

Examining successful sustainable irrigation projects in Nigeria and relevant regions provides valuable insights into the lessons learned and best practices that can guide future projects. The following case studies highlight notable examples and transferable strategies in the context of sustainable irrigation infrastructure.

Kano River Irrigation Project, Nigeria

The KRIP in Nigeria has been a successful endeavor in sustainable irrigation development. It focuses on improving water management practices, promoting water-efficient technologies, and strengthening the capacity of local communities. The project leverages modern irrigation techniques, like drip and sprinkler systems, to enhance water efficiency and boost agricultural productivity. Key insights include the importance of engaging communities, stakeholders, and adopting climate-smart technologies.

Small-Scale Irrigation in Ethiopia

A study in Ethiopia showed that small-scale irrigation greatly increased household income and food security for smallholder farmers. Success factors included access to water, farmer training, and market connections, underscoring the value of integrating small-scale irrigation into larger agricultural strategies.

Remote Sensing and Geospatial Information Systems

Remote sensing and GIS have advanced precision irrigation by enabling accurate water management and monitoring at large scales. A case study focusing on the application of these technologies highlighted their effectiveness in improving water-use efficiency, crop health monitoring, and decision-making in irrigation management. The integration of remote sensing data with crop water requirement models enables precise irrigation scheduling, reducing water waste and enhancing crop productivity. This case study emphasizes the potential of incorporating technology-driven approaches in sustainable irrigation projects.

Innovative Technologies for Sustainable Irrigation

Irrigation system optimization techniques based on technology exist. For Nigerian farmers, solar irrigation has proven to be a game-changer, especially during the dry season. To assess whether the landscape needs watering, smart uses data on soil moisture or weather. These products, which preserve plant health and quality while cutting down on water waste, optimize irrigation efficiency. Key principles for efficient water use in agriculture include adopting systems like drip irrigation and rainwater harvesting, optimizing irrigation schedules, and choosing crops suited to the local climate and water availability. These methods aim to maximize yields with minimal water use while protecting the environment. Shifting from fuel-powered to solar-powered irrigation systems has transformed water accessibility, boosting agricultural productivity in several regions. In Nigeria, various technological innovations can help address food insecurity. Effective approaches to enhance food production and conserve water include optimizing irrigation. Traditional methods like flooding or undirected irrigation are often inefficient and do not minimize water use effectively. By implementing innovative methods like drip irrigation and effective sprinkler systems, adjusting watering schedules to correspond with plant needs, and creating new crop varieties that require less water, freshwater consumption for irrigation can be maximized. By reducing runoff and managing the salinization process, this can lower water pollution and improve crop yields and irrigation efficiency.

Harnessing Optimal Seasonal Humidity

Expanding crop production during the cold season, when evaporation is lower, is another strategy to maximize water use for sustainable food production. A study conducted on a project in Malaysia revealed that utilizing a “dry seeding” strategy used 25% less water for rice cultivation than the conventional method, which called for pre-transplant flooding of the rice paddy.

- i. *Adopting improved irrigation schedules:* A review in Ghana demonstrated that improved irrigation schedules for dry season tomato cultivation saved between 130 and 1325 mm of water compared to traditional methods, boosting tomato yields by 4–14%. In maize production, water requirements varied from 107–126 mm during low rainfall and frequent dry spells to 88–105 mm during high rainfall with fewer dry spells. Such water management strategies could support year-round crop production by saving water during dry seasons for use in supplementing crops like maize during the rainy season.
- ii. *Tailoring water quality for crop types:* Crop water requirements can be met more sustainably by matching water quality to specific crop tolerances. For instance, salty drainage water from one crop can be redirected to salt-tolerant crops like cotton. In turn, the highly saline drainage from cotton could be used for halophytes, plants with high salt tolerance.
- iii. *Increasing water storage capacity:* Effective water storage, including surface (reservoirs, wetlands) and subsurface (groundwater, soil storage) solutions, is essential. These methods capture excess water during wet periods for use in dry spells. This approach is particularly

- useful in Nigeria's northern regions with limited rainfall.
- iv. *Implementing micro-irrigation technologies*: Technologies like sprinklers and drip systems have been successful in smallholder farms across regions like India and Nepal, increasing yields, conserving water, and improving household food security. Adopting these systems on Nigerian plantations could substantially boost food production across both northern and southern regions.
 - v. *Utilizing ICT for water management*: Tools, such as Geographic Information Systems (GIS) can effectively map watersheds and gather essential geographic and hydrologic data, supporting optimized water supply strategies. ICT enables precise water resource management, ensuring that plants receive only the water they need, and minimizing wastage.
 - vi. *Enhancing wastewater treatment*: Advanced wastewater treatment in water-scarce areas can support year-round crop production and resource optimization. In Mexico, 25% of municipal wastewater irrigates 300,000 hectares of land. Tailored wastewater treatments (biological, physical, chemical) adapted to Nigeria's diverse regions can help improve water quality and availability. In off-grid areas, onsite wastewater treatment using biological filtration, membrane technology, and disinfection provides treated water for irrigation, a model widely adopted in Israel.
 - vii. *Soil and water conservation techniques*: Techniques like terracing, contour bunding, infiltration pits, conservation tillage, tree integration, and green manuring improve rainfall capture, infiltration, and soil water storage. These methods are cost-effective and require minimal land reshaping.

Lessons Learned and Transferable Strategies

- These case studies highlight practical insights that can inform future sustainable irrigation projects:
- i. *Community engagement*: Involving local communities in planning and decision-making ensures that irrigation projects meet the needs and expectations of beneficiaries, improving project success and sustainability.
 - ii. *Adoption of climate-smart technologies*: Implementing water-efficient technologies and climate-resilient irrigation practices can improve water-use efficiency, boost productivity, and strengthen resilience against climate variability.
 - iii. *Capacity building and training*: Training programs for farmers, technicians, and communities promote best practices, build technical skills, and encourage sustainable water use.
 - iv. *Integrated water resource management*: Using an integrated approach to water resource management that considers ecosystems, water allocation, and sustainability helps optimize water use while protecting the environment.
 - v. *Monitoring and evaluation*: Developing robust monitoring and evaluation systems to regularly assess project performance, environmental impacts, and socio-economic outcomes is crucial for adaptive management and continuous improvement.
 - vi. *Technology integration*: Leveraging remote sensing, geospatial information systems, and other technology-driven tools can optimize irrigation scheduling, enhance precision, and improve decision-making in water management.

By incorporating these lessons and transferable strategies into future projects, stakeholders can promote sustainable irrigation infrastructure development, improve water resource management, and enhance agricultural productivity in Nigeria and other regions.

CONCLUSIONS

In conclusion, the implementation of sustainable irrigation infrastructure in Nigeria is crucial for addressing the challenges of water scarcity, food security, and rural development. This paper has discussed various key aspects related to the topic, highlighting the importance of implementation strategies and the role of civil engineers in leading the rescue mission. Throughout the discussion, several key points have emerged. Firstly, sustainable irrigation infrastructure requires a holistic

approach that encompasses technical, environmental, social, and economic considerations. It involves the adoption of water-efficient technologies, stakeholder engagement, community participation, policy and regulatory frameworks, adequate funding, and effective governance.

The potential impact of implementing sustainable irrigation infrastructure in Nigeria is significant. It can enhance agricultural productivity, improve water resource management, reduce water losses, mitigate the impacts of climate change, alleviate poverty, and promote rural development. Sustainable irrigation practices can increase crop yields, improve food security, create employment opportunities, and enhance the resilience of communities to environmental challenges. To drive the rescue mission for sustainable irrigation infrastructure, civil engineers and stakeholders have a crucial role to play. Civil engineers possess technical expertise to design, construct, and manage irrigation systems that are efficient, resilient, and environmentally friendly. They need to take a proactive approach in promoting sustainable practices, advocating for policy reforms, and applying innovative solutions to overcome the existing challenges. Stakeholders, including government agencies, local communities, farmers' associations, research institutions, and the private sector, must collaborate and actively participate in decision-making processes. They should prioritize sustainable water management, support capacity-building initiatives, allocate sufficient funding, and create an enabling environment for investment in irrigation infrastructure.

In conclusion, the successful implementation of sustainable irrigation infrastructure in Nigeria requires a collective effort and commitment from civil engineers, stakeholders, and policymakers. By embracing sustainable practices, engaging communities, adopting innovative technologies, and strengthening governance structures, Nigeria can achieve its goals of enhanced agricultural productivity, improved water management, and sustainable rural development. The rescue mission for sustainable irrigation infrastructure in Nigeria is a call to action for all stakeholders to work together towards a more prosperous and sustainable future.

Recommendations

Based on the discussion of the various aspects of implementation strategies for sustainable irrigation infrastructure in Nigeria, the following recommendations are proposed:

1. *Strengthen collaboration and partnerships:* Foster collaboration among government agencies, civil engineers, researchers, local communities, and other stakeholders involved in irrigation infrastructure development. Establish partnerships with international organizations, development finance institutions, and private sector entities to leverage expertise, funding, and technical support.
2. *Prioritize sustainable technologies:* Promote the adoption of climate-smart and water-efficient technologies in irrigation practices. Encourage the use of precision agriculture, drip irrigation, and other innovative techniques to optimize water use, reduce water loss, and enhance crop productivity.
3. *Enhance stakeholder engagement:* Implement inclusive and participatory decision-making processes that involve local communities, farmers' associations, and civil society organizations. Seek input and feedback from stakeholders at all stages of irrigation infrastructure development to ensure that projects align with their needs, aspirations, and cultural practices.
4. *Invest in capacity building:* Provide training and capacity-building programs for civil engineers, irrigation technicians, and local communities. Build their technical skills in irrigation design, operation, and maintenance, as well as their understanding of sustainable water management and farming practices.
5. *Develop robust M and evaluation systems:* Establish comprehensive monitoring and evaluation mechanisms to assess the performance and impact of irrigation infrastructure projects. Regularly monitor water use, crop yields, environmental indicators, and socio-economic outcomes to identify areas for improvement and make evidence-based decisions.
6. *Create enabling policy and regulatory environment:* Develop and enforce policies and

- regulations that promote sustainable irrigation practices, equitable water allocation, and environmental protection. Enhance the regulatory framework to ensure compliance, transparency, and accountability in the operation and management of irrigation systems.
7. *Mobilize financial resources:* Strengthen government funding for irrigation infrastructure projects and explore innovative financing mechanisms. Seek partnerships with private sector entities, development finance institutions, and impact investors to attract investments and mobilize additional financial resources.
 8. *Foster knowledge exchange and research:* Promote knowledge sharing, research collaboration, and technology transfer among stakeholders in the irrigation sector. Encourage the dissemination of best practices, lessons learned, and research findings to inform policy and decision-making processes.
 9. *Consider climate change adaptation:* Integrate climate change adaptation strategies into the design and management of irrigation infrastructure. Assess the vulnerability of irrigation systems to climate risks and develop measures to enhance resilience, such as water storage facilities and drought-tolerant crop varieties.
 10. *Monitor social impacts:* Pay attention to social impacts and ensure that the benefits of irrigation infrastructure projects are equitably distributed. Address gender disparities, empower marginalized groups, and promote social inclusiveness in decision-making and project implementation.
 11. Nigeria can boost agricultural output, manage water resources more effectively, construct sustainable irrigation infrastructure, and progress the nation's socioeconomic growth by putting these suggestions into practice.
 12. Coordinated evaluations of the viability of implementing various water management strategies at the irrigation district level should be funded by government bodies.
 13. To develop policies that would encourage the adoption of sustainable water management technology in agriculture, state ministries of agriculture and water resources must work together.
 14. Farmers who grow lowland (paddy) rice can minimize their water usage in irrigated fields by implementing Alternate Wetting and Drying (AWD). One of the most popular water-saving irrigation techniques is AWD.
 15. Harnessing smart irrigation technologies, hydrological data for optimized water resource allocation, soil and water conservation techniques as well as proper education/sensitization of all agricultural stakeholders (farmers, extension workers, policy makers among others) in Nigeria will go a long way to ensuring food security and the achievement of all the sustainable development goals dependent on water.

REFERENCES

1. Adekunle VA, Chukwuma CB, Adekunle OP. Agricultural water management in Nigeria: Challenges and the way forward. In: Pachauri RK, et al., editors. Handbook of Climate Change and India: Development, Politics and Governance. Springer; 2021. p. 275–287.
2. Adelodun B, Choi KS. A review of evaluation of irrigation practice in Nigeria: Past, present and future prospects. *Afr J Agric Res.* 2018;13(40):2087–2097. doi: 10.5897/AJAR2018.13403.
3. Adhikary P, Choudhary M, Babel MS. Review of water management models in irrigation planning and management: Perspectives and challenges. *Agric Water Manag.* 2020;228:105879.
4. Baroni L, Cenci L, Tettamanti M, Berati M. Evaluating the environmental impact of various dietary patterns combined with different food production systems. *Eur J Clin Nutr.* 2007;61(2):279–286. doi: 10.1038/sj.ejcn.1602522.
5. Bennett NJ, Blythe J, Cisneros-Montemayor AM, Singh GG, Sumaila UR, Turner NJ. Towards a sustainable and equitable blue economy. *Nat Sustain.* 2019;2(11):991–993. doi: 10.1038/s41893-019-0404-1.
6. Biswas AK. Integrated water resources management: Is it working in practice? *Int J Water Resour Dev.* 2017;33(4):502–517. doi: 10.1080/07900620701871718.

7. Bucknall J. Public-private partnerships for sustainable development. Oxford Research Encyclopedia of Economics and Finance. 2019.
8. Dong C, Jiang G, Ge Y. Application of remote sensing in monitoring and evaluation of agricultural water use efficiency. *Remote Sens.* 2019;11(18):2097.
9. Egeru A, Okiror JJ, Nkonya E. Gendered participation in sustainable land management: A review of constraints and opportunities. *Sustainability.* 2018;10(2):462.
10. FAO. Investment in agricultural water for poverty reduction and economic growth in sub-Saharan Africa. 2016.
11. Gebremedhin B, Jaleta M, Hoekstra D, Tefera G. Financing sustainable irrigation: A review. *Water.* 2018;10(6):708.
12. Hassan R, Osman MY, Alobaad A. Financing water and sanitation infrastructure in low-income countries: Challenges and opportunities. *Eng Constr Archit Manag.* 2018;25(6):750–769.
13. Huang G, Wu C, Shao H, Ye X, Xu X. The role of precision agriculture in sustainable irrigation. *Sustainability.* 2020;12(11):4674.
14. Kalogerakis N, Psarras G, Kosmas C. Evaluating the efficiency and sustainability of irrigation techniques in Mediterranean crops. *Sustainability.* 2020;12(6):2389.
15. Katuramu JM, Isabirye M, Kaggwa RC. Application of geographical information systems for decision support in irrigation infrastructure management in Uganda. *J Water Resour Plan Manag.* 2017;143(7):04017029.
16. Kazbekov J, Cader C, Hussain M, Ahmed H, Desai K. Public-private partnerships in irrigation: Lessons from international experience for Nigeria. 2020.
17. Kumar S, Srivastava SK, Vashistha P. Water resources management in sustainable development: A review of literature. *Water Sci Technol: Water Supply.* 2020;20(5):2045–2062.
18. Li Y, Lai G, Liu S, Zhang W, Fu Y. Multi-objective optimization of irrigation infrastructure planning considering ecosystem services: A case study in a semiarid region of China. *Sci Total Environ.* 2021;754:142193.
19. Nasir MA, Bhat NA, Wang X, Pandit AK. Sustainable irrigation practices in agriculture: A review. *Sustainability.* 2019;11(20):5762.
20. Ogden F, Lankford B, Freitas M. What works, where, for whom, and at what cost? A closer look at capacity development for agricultural water management in large-scale public irrigation schemes in sub-Saharan Africa. 2020.
21. Oladunjoye OA, Olaleye AO, Odedina SA. Assessing the performance of irrigation schemes in enhancing food security in Ogun-Osun River Basin, Nigeria. *Food Secur.* 2020;12(3):711–724.
22. Olayide SO. Factors influencing the choice of irrigation system among smallholder farmers in Nigeria. *Land.* 2019;8(3):48.
23. Oyeboode OJ. Strategy for tackling flood and water scarcity for adequate water supply and public health in Nigeria. *EJAET.* 2018;5(8):656–664.
24. Oyeboode OJ, Paul F. Flood mitigation and pollution abatement in Kaduna metropolis through engineering assessment and analytical hierarchy process design. *Nat Environ Pollut Technol.* 2023;22(2):789–801. doi:10.46488/NEPT.2023.v22i02.021.
25. Oyeboode OJ, Oyerinde AO, Oyeboode FA. Engineering hydrology for flood control, adequate water resources, and sustainable environment in Nigeria. *JoWREM.* 2023;10(2):1–10.
26. Oyeboode OJ. Sustainable waste management towards circular economy in Nigerian context: challenges, prospects, and way forward. In: Ayeni O, Oladokun O, Orodu OD, editors. *Advanced Manufacturing in Biological, Petroleum, and Nanotechnology Processing.* Cham: Springer; 2022. p. 237–248.
27. Pandey R, Shrestha S, Sur RK. Stakeholder engagement for integrated water resource management in transboundary river basins: A systematic review. *Environmental Development.* 2020;36:100532.
28. Pazoki A, Wang D, Haghverdi A, El-Shafie A. Advances in precision irrigation using remote sensing and geospatial information systems. *Water.* 2018;10(5):567.
29. Raleigh M, Barrios E, Grum M. Financing infrastructure in developing countries: An overview. World Bank Group. 2018.

30. Seyoum A, Biazin B, Hailelassie A. Impact of small-scale irrigation on household income: Evidence from Ethiopia. *Water*. 2020;12(9):2491.
31. Sharma B. Water governance in South Asia: A review of policies and practices. *Water*. 2020;12(8):2104.
32. United Nations. Financing for sustainable development: Addis Ababa action agenda. 2015.
33. World Bank. Nigeria: Investing in irrigation for sustained growth and resilience. 2017.
34. World Bank. Nigeria—Agricultural resilience project. 2017.
35. World Bank. Financing irrigation: Policy options for sustainable water management in agriculture. 2019.