# Final Evaluation Report

| Your Details | |
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| **Full Name** | Makemie Jumanne Mabula |
| **Project Title** | Identification of suitable cage aquaculture sites amidst the ecologically sensitive areas around the Mwanza Gulf |
| **Application ID** | 35827-1 |
| **Date of this Report** | 25 April 2023 |

**1. Indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.**

| Objective | Not achieved | Partially achieved | Fully achieved | Comments |
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| i) To evaluate the spatial distribution of ecologically sensitive areas in the Mwanza Gulf and identify potential locations for cage aquaculture that minimize negative environmental impacts. | | | | The results indicate that 143.88 $km^2$ (48.25%) of the gulf fell under a constrained area (ecologically sensitive areas) deemed unavailable for cage aquaculture development. Only 29.66 $km^2$ (9.12%) of the gulf area was most suitable for cage aquaculture activities. About 65.79 $km^2$ (20.23%) and 40.68 $km^2$ (12.51%) fell under the "suitable" and "less suitable" category, respectively. The results also reveal that 13 out of 15 cage farms (86.7%) were located in "unsuitable areas," while two cage farms (13.3%) were found in less suitable locations. In contrast, no farm was situated in suitable and most suitable areas. This model spatially reveals important ecologically sensitive areas that need protection and the suitability levels of the remaining space, which can be utilised to promote a sustainable aquaculture industry. |
| ii) To assess the physical suitability of the Mwanza Gulf for cage aquaculture by analysing water depth, and relative exposure to wind-generated waves | | | | The overall physical suitability model shows that approximately 30.06 $km^2$ (9.24%) of the gulf is most suitable, and 43.63 $km^2$ (13.41%) is suitable. These suitable areas are restricted to the mid and innermost northern portion of the Mwanza Gulf. By contrast, the model shows that approximately 120.25 $km^2$ (36.97%) and 131.3 $km^2$ (40.37%) of the Mwanza Gulf are less suitable and unsuitable for cage aquaculture. The unsuitable areas are primarily located in the southern parts of the gulf. The findings also revealed that about 73.33% of the existing fish cage farms are allocated in less suitable areas. These findings provide spatial insight into where cage aquaculture can be |

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| | | | | permitted based on the physical condition of the gulf. The study suggests that production should be avoided in unsuitable areas to ensure the sustainability of cage fish farming in the Mwanza Gulf. |
| iii) To evaluate water quality parameters in the Mwanza Gulf and determine their potential influence on cage aquaculture site suitability | | | | The final map indicated that the most suitable zones are approximately 60.74 $km^2$ or 18.68% of the Mwanza Gulf. The 'suitable zones' occupied an area of about 27.39 $km^2$ (8.42%). On the other hand, the areas considered less suitable and unsuitable covered 101.04 $km^2$ (31.07%) and 136.07 $km^2$ (41.84%), respectively, constituting 240.73 $km^2$ (72.90%) of the Mwanza Gulf. The low suitability of the areas for cage fish farming was attributed to low Secchi depth and elevated chlorophyll-a concentrations. The results indicate that one of the already installed cages was located in an unsuitable area. Seven out of 15 fish cage farms (46.7%) matched the most suitable areas, while three (20%) matched the suitable locations. Four (26.7%) fish cage farms were found within the least suitable zones. The study suggested that production should be avoided in unsuitable areas to ensure the sustainability of cage fish farming in the Mwanza Gulf. |
| iv) To analyse the socio-economic criteria relevant to cage aquaculture in the Mwanza Gulf, such as lake-based activities and accessibility, and assess their influence on site selection. | | | | Although the total available area of the Mwanza Gulf was 325.24 $km^2$, about 160.09 $km^2$ (49.22%) fell under the constrained area. Only a small area of approximately 6.95 $km^2$ (2.14%) was estimated as the most suitable, while 62.68 $km^2$ (19.27%) constituted the suitable area. The remaining site of the gulf (29.37%) was less suitable (84.97 $km^2$ or 26.13%) and unsuitable (10.55 $km^2$ or 3.24%) for cage aquaculture activities. The study also found that five out of 15 fish cage farms were in constrained areas, while seven were in less suitable locations. The results demonstrate the importance of the GIS approach in optimising cage culture |

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| | | | | areas amidst other existing uses, thus reducing the likelihood of cage fish farmers getting into conflicts with other possible uses of space or other actors. |
| v) To integrate the results of objectives i-iv using a GIS-MCE approach and generate overall suitability maps that identify the most suitable areas for sustainable cage aquaculture production in the Mwanza Gulf. | | | | The results indicate that approximately a large proportion, 188.84 km$^2$ (58.06%) of the gulf, was restrictive to cage aquaculture development. Only 5.10 km$^2$ (1.52%) and 24.20 km$^2$ (7.44%) constituted the most suitable and suitable areas. About 42.63 km$^2$ (13.11%) and 64.47 km$^2$ (19.82%) area of the Mwanza Gulf was considered less suitable and unsuitable, respectively. The findings also reveal that most of the existing cages, 80%, were installed in the constrained area, while 20% of the cage farms were located in less suitable and unsuitable areas. |

**2. Describe the three most important outcomes of your project.**

**a).** First, I have generated maps portraying cage aquaculture suitability amidst important ecologically sensitive areas, lake-based activities, water quality and physical factors. These maps spatially reveal areas where cage aquaculture is constrained and indicate the level of cage aquaculture suitability in the remaining area. These maps can be utilised to promote a sustainable cage aquaculture industry in the area. Before this study, this information did not exist. We now know where fish cages can be installed without conflicting with the biodiversity conservation objectives or other water users.

**b).** Second, I have quantified the space that can be allocated for cage aquaculture development. This information is key to the estimation of the physical carrying capacity of the area, and aquaculture planners can use this information to inform the public and aquaculture investors about the number of fish cage farms that the Mwanza Gulf can accommodate.

**c).** Third, stakeholder engagement and support – In this project, different stakeholders were consulted, and their opinions regarding the relative importance of different factors were incorporated in site suitability analysis. Therefore, the output suitability maps are based on technical requirements for tilapia fish cage farming and consensus among local communities with different interests in the Mwanza Gulf. This increases the credibility and reliability of the study findings.

The successful application of the GIS-MCE approach in this study represents a breakthrough in cage aquaculture site selection in the Tanzanian part of Lake Victoria. Previous approaches relied heavily on conventional field surveys, limiting coverage and point-based maps. With the GIS-MCE approach, this study was able to integrate multiple criteria, including ecological, physical, water quality, and socio-

economic factors, into a comprehensive and transparent method for identifying potential sites for sustainable cage aquaculture.

This achievement provides a more participatory approach to site selection and reduces the potential for conflicts arising from the inclusion of unsuitable sites. The findings of this study provide valuable information for policymakers and investors in the aquaculture industry, as well as for individual fish farmers seeking to comply with licensing requirements. The successful application of the GIS-MCE approach in this study has the potential to serve as a model for other regions seeking to develop sustainable cage aquaculture.

**3. Explain any unforeseen difficulties that arose during the project and how these were tackled.**

Due to the proper guidance from my supervisors, no unforeseen difficulties arose.

**4. Describe the involvement of local communities and how they have benefitted from the project.**

The local communities played an integral role in the project through their active involvement in various workshops and group discussions, where their opinions regarding criteria for cage aquaculture were collected. Additionally, they fully participated in mapping ecologically sensitive areas and locations used for other lake-based activities, such as traditional (artisanal) fishing grounds. This participatory approach ensured that the site selection process was acceptable to the majority and minimised the potential for conflicts arising from including unsuitable sites. The valuable information from the study will benefit individual fish farmers seeking to comply with licensing requirements and provide policymakers and investors in the aquaculture industry with useful insights.

**5. Are there any plans to continue this work?**

There are plans to disseminate the findings to decision makers and community leaders in Tanzania and beyond. This will help inform planning and policy making related to sustainable cage aquaculture. Funding will be sought to support field surveys, spatial analysis, and validation, as well as to provide financial support to riparian local communities around the project area. The ultimate goal is to create a practical tool for sustainable cage aquaculture that enhances the livelihoods of local communities while promoting the conservation of Lake Victoria's biodiversity.

**6. How do you plan to share the results of your work with others?**

I plan to disseminate the results of my work through various channels, including publication in peer-reviewed journals, scientific forums, and symposia. To date, I have already presented my work at the University of Dar es Salaam Research Week and have had two articles accepted for presentation as posters at the Trevor Platts Foundation Symposium, which will be held from August 9-11, 2023, at the Plymouth Marine Laboratory in the UK.

Furthermore, I am delighted to share that my article titled "Application of Machine Learning Algorithms and Sentinel-2 Satellite for Improved Bathymetry Retrieval in Lake Victoria, Tanzania" is currently under review (Manuscript Number: EJRS-D-22-00029) at the prestigious Egyptian Journal of Remote Sensing and Space Sciences. Once published, this article will add to the existing knowledge on using machine learning algorithms and satellite data for improved bathymetry retrieval in Lake Victoria, Tanzania.

In addition to these achievements, I am exploring other avenues for sharing my findings, such as presenting at conferences and workshops and submitting articles to other renowned peer-reviewed journals. I believe that disseminating my research findings is essential to advance knowledge in my field and make a positive impact on the environment and society.

**7. Looking ahead, what do you feel are the important next steps?**

The first stage of this project was to delineate suitable areas to support sustainable cage aquaculture, using Mwanza Gulf of Lake Victoria as a case study. Moving forward, I plan to expand the project's reach to cover the entire Tanzanian part of Lake Victoria. This is of utmost importance because a large part of the lake has yet to be surveyed and mapped, despite ongoing fish cage installations in different areas. Therefore, upscaling the project is highly needed to generate comprehensive information that will support lake wide spatial planning. Funding needs to be secured to support field surveys, spatial analysis, and validation.

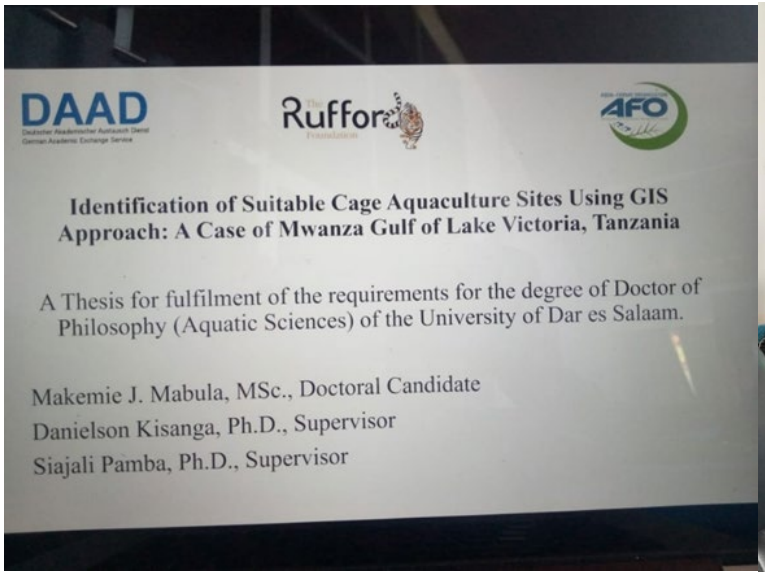
Secondly, it is crucial to financially support local riparian communities around the Mwanza Gulf to initiate pilot fish cage farms in areas identified as most suitable or suitable by this study. This will ensure that the findings of this study become relevant by creating and enhancing the livelihoods of the local people. Such support needs to ensure that the local people are capacitated to create individual or corporate ownership of the farmed stock, plan, and operate aquaculture operations correctly through locally tailored approaches such as citizen science.

Furthermore, the next important step would be disseminating the findings to decision-makers and community leaders in the country and beyond. This study can become a practical tool for sustainable cage aquaculture by informing those responsible for planning and policymaking.

**8. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the Foundation receive any publicity during the course of your work?**

Yes, I used the Rufford Foundation logo materials produced in relation to this project. The logo was used in the following settings:

- Poster and banners showcased during the University of Dar es Salaam Research Week .
- Pre viva voce presentation at the University of Dar es Salaam (photo below) School of Aquatic Sciences and Fisheries Technology.



- I also plan to use the RF log in my articles selected for poster presentation at the Trevor Platts Foundation Symposium, which will be held from August 9-11, 2023, at Plymouth Marine Laboratory in the UK.
- Besides, I acknowledged the financial support provided by RF when submitting my manuscript for publication in journals.

**9. Provide a full list of all the members of your team and their role in the project.**

**Dr Siajali Pamba** is a lecturer at the University of Dar es Salaam, Department of Aquatic Sciences and Fisheries Technology. Dr Pamba provided technical guidance while modelling ecologically sensitive areas in the study area.

**Dr Danielson KIsanga** is a Senior Lecturer from the University of Dar es Salaam, Department of Geography. He is in Geographic Information Systems and Remote Sensing. In this study, Dr. Kisanga provided technical guidance while coding Google Earth Engine scripts to pre-process remote sensing data and retrieve water quality parameters.

**Ezekiel Charles Nyarongo** is a researcher (ecologist) from the Tanzania Fisheries Research Institute (Mwanza centre). In this study, Mr. Ezekiel was expected to contribute his experience during assessing ecologically sensitive areas and associated species diversity and abundance.

**Charles Mashafi** is a researcher from the Tanzania Fisheries Research Institute (Mwanza centre). In this study, Mr. Mashafi assisted in mapping and collecting in-situ water quality parameters for validation purposes.

**Matias Lugeye** is a driver. He was responsible for carrying out all logistical arrangements during the field survey.

## 10. Any other comments?

I acknowledge The Rufford Foundation's and AquaFarm Organisation (AFO) financial support for this research. The Germany Academic Exchange Services (DAAD) also provided support (tuition fee) through the In-Country/In-Region Programme in Developing Countries-2017 academic scholarship no 91671687. I also thank Dr Danielson Kisanga and Dr Siajali Pamba for their scholarly supervision, guidance, constructive criticism, and unconditional support throughout my research journey. I also acknowledge the anonymous government officials, local community members in Mwanza, aquaculture and ecology experts who provided valuable opinions on cage development around the Mwanza Gulf. I also appreciate the GEE initiative, which provided free access to cloud computation of Sentinel 2 images.

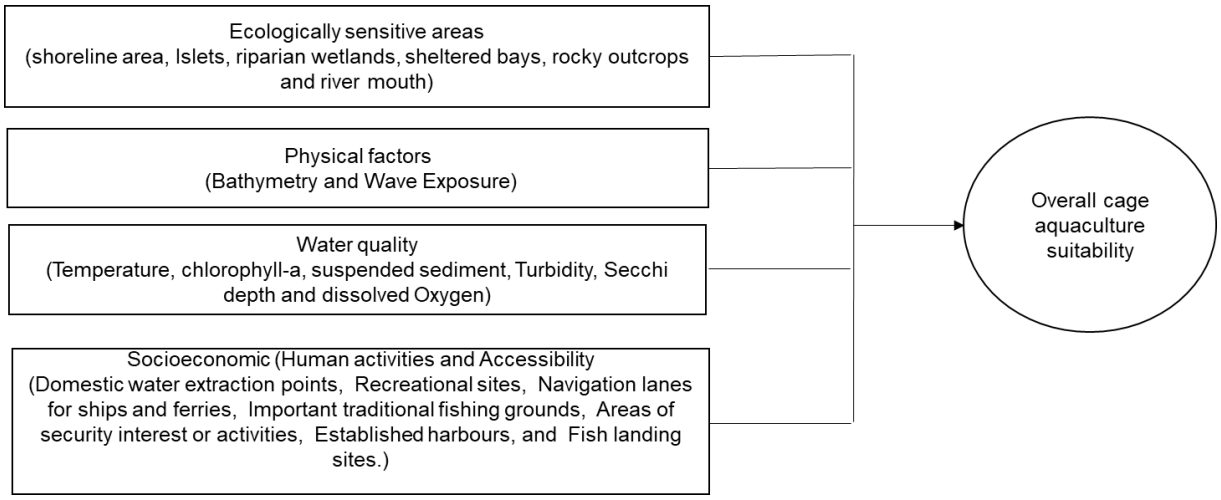



**FIGURE 1**: A GIS-MCE process for determining suitable areas for potential cage fish culture within the Mwanza Gulf

**FIGURE 2**: Map of Tanzania showing the Mwanza Gulf of Lake Victoria, where this project was conducted. (Data Source: Tanzania Bureau of Statistics online GIS Database, https://www.nbs.go.tz).

**TABLE 1:** Group stakeholders consulted during the project.

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| 1. Local Fishers |
| 2. Fish cage farmers |
| 3. Aquaculture and ecology experts (from TAFIRI) |
| 4. environmental experts from Lake Victoria Environmental Management Program (LVEMP) |
| 5. Fisheries officers from District Councils |
| 6. wildlife conservationists from Saanane National Park |
| 7. Environmental specialists from the Tanzanian Lake Victoria Basin Water Board (LVBWB) |
| 8. Ferry operators and Tanzania Ports Authority (TPA)-Mwanza Office |
| 9. Police and Military officers |
| 10. Water quality technicians from Mwanza Urban Water Supply and Sanitation Authority (MWAUWASA) and Kahama-Shinyanga Water Supply and Sewerage Authority (KASHWASA). |

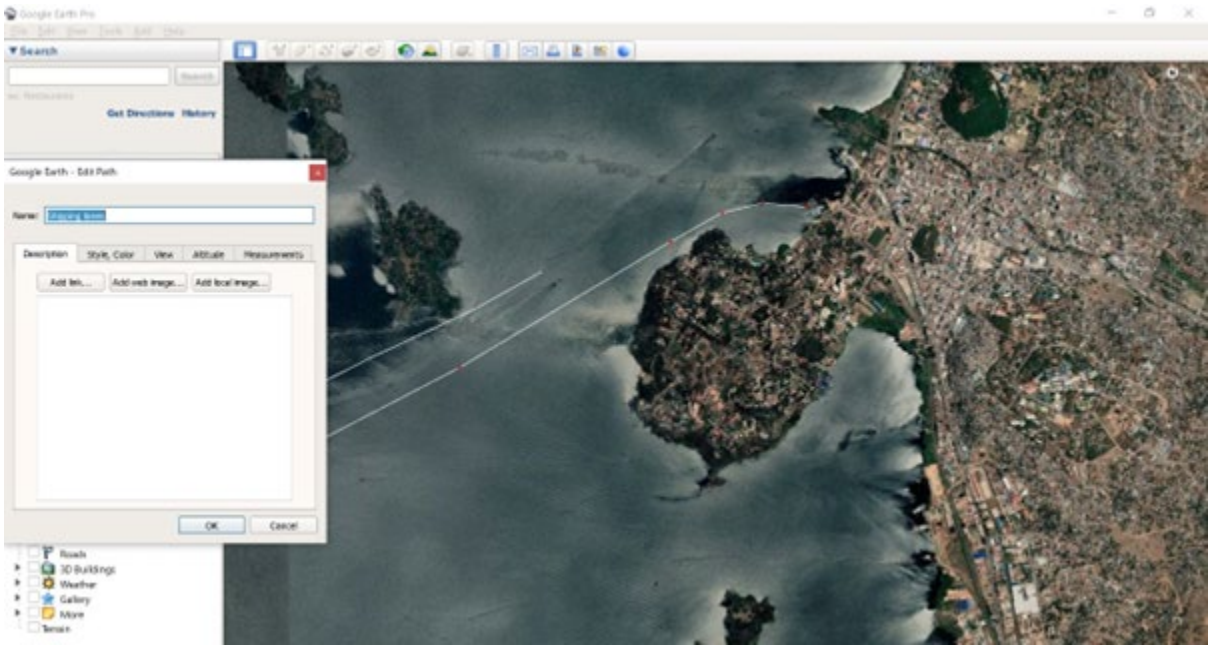

**FIGURE 3:** Local consultation (a) and mapping areas used for lake base activities in Google Earth (© Anthony Magessa).

**TABLE 2:** MCE weightings for the four sub models (ecologically sensitive areas, physical environment, water quality and socio-economic) used to derive the final cage aquaculture suitability model for the Mwanza Gulf.

| Criteria | Weight |
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| Ecologically sensitive areas | 0.42 |
| Physical environment | 0.26 |
| Water quality | 0.12 |
| Socio-economic variables | 0.20 |
| Total | 1 |

Stakeholders' consensus= 94.8%

**TABLE 3:** Summary statistics for different suitability levels in the overall model

| Suitability | Area (km2) | Percentage |
|---|---|---|
| Constrained area | 188.84 | 58.06 |
| Unsuitable | 42.63 | 13.11 |
| Less Suitable | 64.47 | 19.82 |
| Suitable | 24.20 | 7.44 |
| Most Suitable | 5.10 | 1.57 |
| Total | 325.24 | 100.00 |

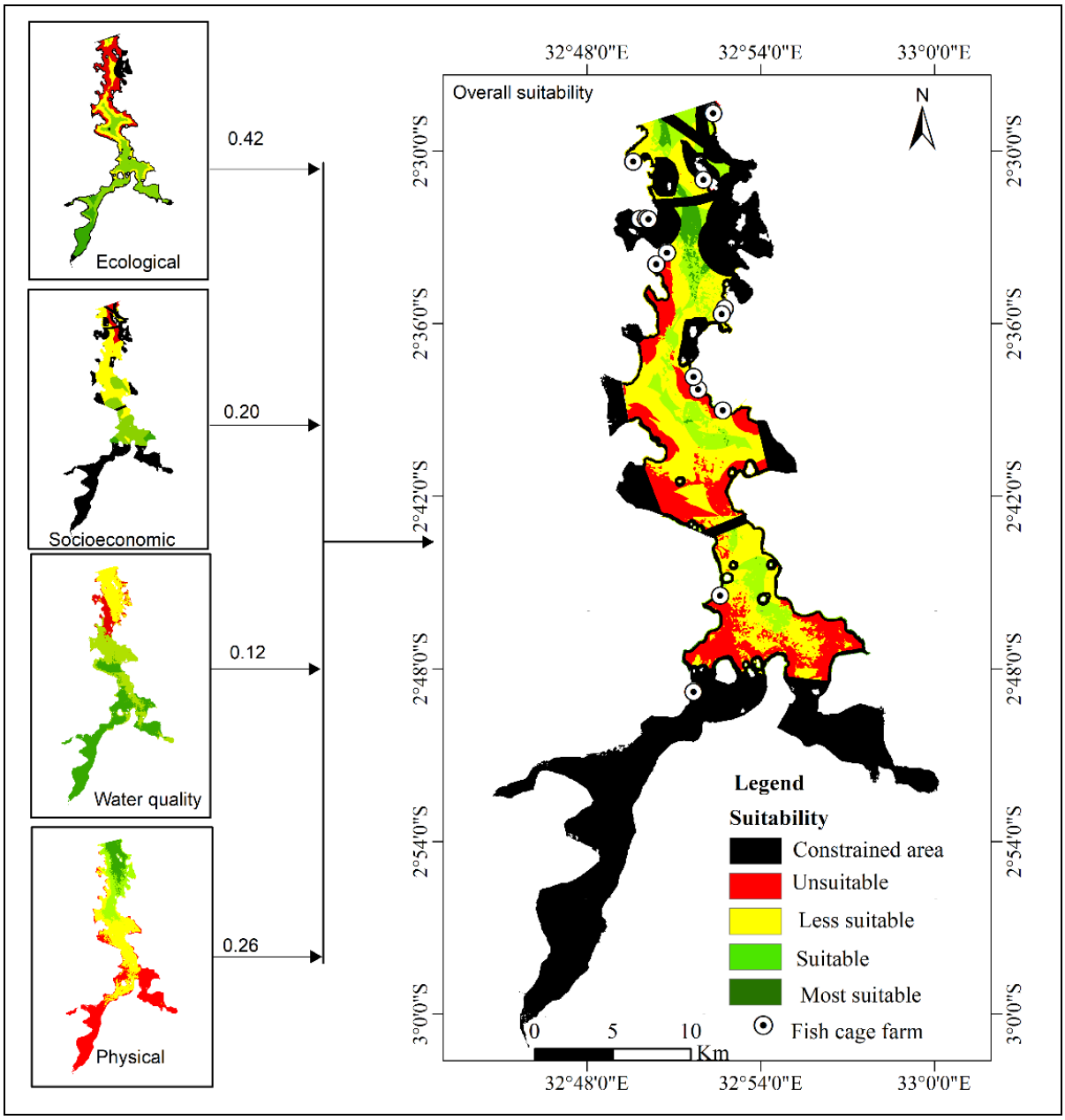


**FIGURE 4**: The site suitability model for cage aquaculture in the Mwanza Gulf.