

Assessing Spatio -Temporal Dynamics of Vegetation Cover and Urban Expansion in Hambantota Municipal Council (2001–2024) Using Geospatial Techniques

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Abstract: Vegetation plays a vital role in ecosystems by regulating water, carbon, and nitrogen biogeochemical cycles and serving as the foundation of food chains. However, urbanization and infrastructure development often result in significant land cover changes, posing challenges to environmental sustainability. This study investigates land cover dynamics in the Hambantota Municipal Council (MC) area, strategically located near major global shipping routes. Specifically, the study examines changes in vegetation and built-up areas over three time periods: 2001, 2013, and 2024. The objective is to understand the environmental impacts of urbanization driven by projects like the Hambantota Port and City Center development. Using satellite imagery and secondary datasets, the study employed Normalized Difference Vegetation Index (NDVI) and Urban Index (UI) analyses to assess land cover and urbanization trends. Findings reveal significant vegetation loss between 2001 and 2013 due to accelerated development, followed by stabilization from 2013 to 2024, attributed to structured urban planning and conservation efforts. Despite these improvements, wetland areas declined notably by 2024. The study recommends integrating infrastructure development with conservation strategies, including reforestation, habitat protection, community engagement, and adaptive management, to ensure sustainable growth while minimizing environmental degradation.

Keywords: NDVI, UI, Vegetation dynamics, Urbanization, Hambantota port

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Introduction

Vegetation is essential to ecosystems, with the main role of modulating key water, carbon, and nitrogen biogeochemical cycles. By converting solar energy into biomass, vegetation provides the very foundation of all food chains, supporting life from simple unicellular organisms to higher trophic levels (Li et al. 2024). Its influence extends to the balance of energy on earth, both at the surface and within the atmospheric boundary layer, where it moderates local climatic extremes, contributing to a more stable environment. Vegetation also serves as a natural carbon sink, sequestering carbon dioxide and releasing oxygen, thus sustaining life and mitigating climate change (Palazzo Corner et al. 2023).

Vegetation cover in Sri Lanka is vital for biodiversity conservation, climate regulation, and ecosystem services, including carbon sequestration and water management. Despite its importance, the country has experienced significant forest loss, with an 8.6% reduction in areas with over 25% canopy density between 2000 and 2020. Currently, 78% of the land area retains tree cover above 10%, and 64% has over 40%, encompassing both open and dense forests. However, rapid deforestation, particularly in the dry zone, has led to the loss of 246,958.4 hectares over 27 years, driven by agricultural expansion and infrastructure development (Sarithchandra et al. 2021).

The relationship between vegetation cover and development is multifaceted, reflecting both challenges and opportunities in urbanized and restored landscapes. Urbanization often leads to significant vegetation loss, as evidenced by Tehran's decline of over 34,000 hectares of green cover between 1990 and 2020 due to rapid construction and population growth (Zenouzi et al. 2022). This reduction disrupts not only ecological functions but also enhances urban heat island effects, reduces air quality, and diminishes biodiversity (Useni Sikuzani et al. 2024).

On the other hand, restoration in degraded environments like mined areas shows effective recovery if appropriate methods are applied. Techniques like natural regeneration, while cost-effective, require extended periods for meaningful recovery, whereas tree plantations can restore up to 80% of vegetation cover within 15 years (Corrêa et al. 2018). Advanced strategies, including topsoil replacement

and sewage sludge incorporation, have proven particularly effective, achieving 80–95% cover within 2.5 to 5 years. High-resolution fractional vegetation cover assessment along with other monitoring tools may guide urban planning toward striking a balance between development and ecological restoration to ensure long-term sustainability and environmental resilience (Batra, Song & Ramprasad 2020).

The vegetation cover in Sri Lanka has changed significantly due to development pressures, especially through the expansion of agriculture and infrastructure. These changes have brought about significant losses in forested and natural vegetation areas important for biodiversity and the provision of ecosystem services. In Sri Lanka, from 2000 to 2020, there was a decline in tree cover density, with 25% canopy density decreasing from 61.38% to 52.78% (Yang et al. 2022). The dry zone covered 59% of the country's land and contributed to a loss of approximately 246,958.4 hectares of forest between 1992 and 2019, mainly due to infrastructure expansion at an unprecedentedly rapid pace (Ranagalage et al. 2020). The same period saw considerable change in land use, such that 890,003.52 hectares of land (13.5%) were subjected to changes which contributed significantly to the altering of forest reserves (Rathnayake et al., 2020). Despite these challenges, 78% of the country's land still retains a tree cover density exceeding 10%, reflecting the presence of open and sparse forests (Jayasekara & Hmb no date). Urban areas such as Colombo and Gampaha, though limited in forest cover, maintain notable tree density that supports localized ecosystem services. While rapid development has led to widespread vegetation loss, it has also fostered initiatives for reforestation and sustainable land management. These efforts highlight that a balance between development and environmental conservation is possible and provide routes for maintaining biodiversity and ecosystem integrity in the face of ongoing urbanization and land use changes (Wang et al. 2024).

The Hambantota District is integral to Sri Lanka's environmental and ecological heritage, renowned for its agricultural practices, water management systems, and cultural traditions. Its legacy in rice cultivation, rooted in the Ruhunu Kingdom era, has ensured economic stability and agricultural biodiversity, fostering resilience during hardships (Vitharana 2015). Advanced irrigation systems, including the Udawalawa initiative and projects linked to Kirama Oya

and Uruboku Oya, have bolstered agricultural productivity and ecological balance. Natural watercourses like the Walawa River and Kirindi Oya sustain biodiversity and provide essential water resources, while the district's coastal ecosystems, including lagoons and marine habitats, support fisheries and biodiversity conservation. Coastal infrastructure, such as mini fishery harbors and salterns, ensures the sustainable use of marine resources, benefiting the local economy (82, Almqvist & Fergéus no date).

Culturally, Hambantota reflects the Ruhunu Kingdom's ethos of sustainable land and water management, with ancient reservoirs and irrigation tanks symbolizing its historical ingenuity and environmental stewardship. However, post-conflict development projects have led to vegetation loss, habitat degradation, and human-wildlife conflicts. The district's ecological and socio-economic health relies on sustainable land management practices. A lack of detailed spatio-temporal analyses of vegetation cover changes hampers effective conservation, posing challenges for biodiversity, disaster risk reduction, and climate regulation in this ecologically vital region (Wickramasooriya & Sugandini 2024).

The Hambantota Municipal Council area is strategically located near major global shipping routes connecting the East and West. Positioned about 12 nautical miles from some of the busiest maritime corridors, the Hambantota Port has been developed as part of an economic transformation initiative. Its prime location enhances its potential to become a key commercial maritime hub, fostering international trade, logistics, and global connectivity (Urban Development Authority 2019). Thus the objective of this study is to analyze the changes in land cover, specifically vegetation, wetland areas, non-vegetated land, and built-up areas, within the Hambantota Municipal Council (MC) area over three distinct time periods (2001, 2013, and 2024). The study aims to understand the impact of urbanization and infrastructure development, particularly the Hambantota Port and City Center development, on the region's land transformation and environmental dynamics. It also seeks to identify patterns in urban growth to provide insights into sustainable urban planning practices that balance economic development with environmental conservation.

2. Materials and Methods

2.1 Study area

The Hambantota Municipal Council (Figure 1) is situated within the Hambantota Divisional Secretariat Division, covering 83 square kilometers and consisting of seven Grama Niladhari Divisions. It lies between latitudes $6^{\circ}7'N$ to $6^{\circ}11'N$ and longitudes $80^{\circ}10'E$ to $81^{\circ}6'E$. This region is strategically located close to major global shipping routes, which has contributed to its recognition as a vital economic hub.

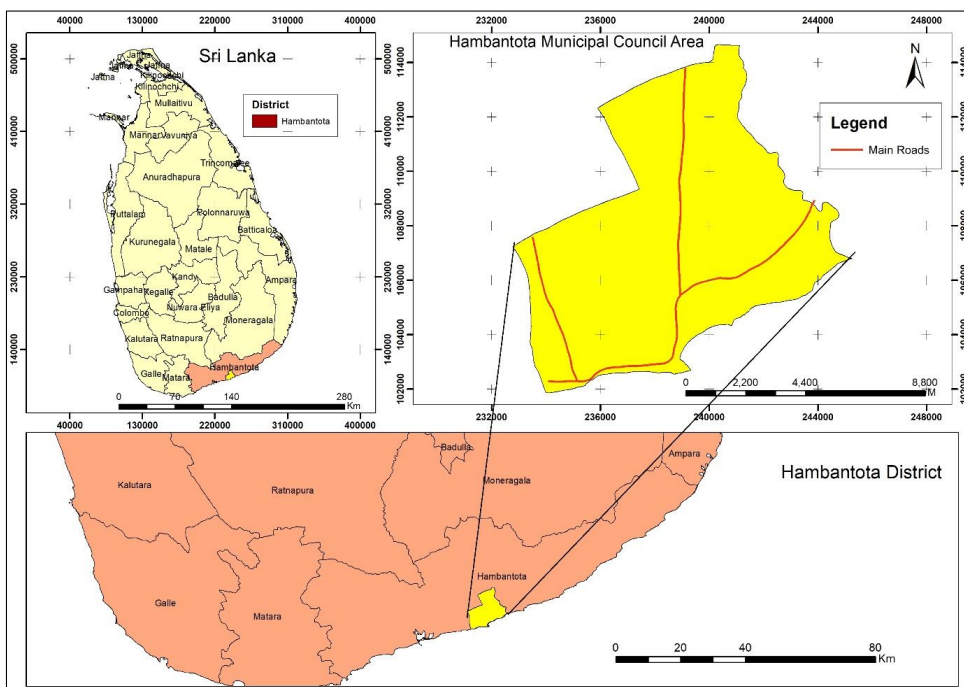


Figure 1: Hambantota Municipal Council

Population growth in the Hambantota area has been steady, reflecting the ongoing development efforts in the region. In 2015, the population of the Hambantota Municipal Council area was recorded at 25,560, while the Hambantota District's population reached approximately 736,500 by 2017. The present population of the area is approximately 27, 465. Projections show continued growth, with the municipal population estimated to reach 30,365 by 2025, and potentially as high as 141,366 by 2030, driven by both natural growth and significant migration. This

rapid increase will likely result in a higher population density (Anputhas, Jayakody & Weligamage 2005; Liyanage no date).

The climate of the Hambantota Municipal Council area is defined by its location in Sri Lanka's semi-arid zone, which presents distinct challenges and opportunities. The region experiences an average annual rainfall of less than 1,265 mm, primarily during the northeastern monsoon season from October to December. This period brings the highest rainfall, while the rest of the year, particularly from January to September, is marked by long, dry spells and limited precipitation, contributing to frequent drought conditions. The average annual temperature ranges from 30°C to 33°C, with the hottest months typically occurring in February, March, April, and June. These climatic conditions make water resources and agricultural sustainability significant concerns for the region, requiring adaptive strategies for managing scarce water and ensuring food security (Madhavi Abeysinghe & Lanka 2019; Liyanage no date).

2.2 Data Collection and Analysis

This study employed two key analyses: Normalized Difference Vegetation Index (NDVI) and Urban Index (UI), to assess changes in land cover and urbanization in the Hambantota Municipal Council area. The methodology involved the use of both secondary data sources, including satellite imagery and ancillary datasets.

2.2.1 Satellite Imagery Analysis

Multi-temporal satellite datasets were utilized for the years 2001, 2013, and 2024. These datasets provided essential inputs for calculating NDVI and UI values (Hartoyo et al. 2021; Muhaimin et al. 2022).

Table 01: Details of Satellite Dataset

Satellite Name	Path/Row	Date Acquired	Bands Used (NDVI)	Bands Used (UI)
Landsat-7 ETM+	141/056	2001/02/10	Band 3 (Red), Band 4 (NIR)	Band 5(SWIR1) - Band 7(SWIR2)
Landsat-8 OLI/TIRS	141/056	2103/12/20	Band 4 (Red), Band 5 (NIR)	Band 6(SWIR1) - Band 5(SWIR2)
Landsat-8 OLI/TIRS	141/056	2024/02/18	Band 4 (Red), Band 5 (NIR)	Band 6(SWIR1) - Band 5(SWIR2)

The NDVI analysis was performed using the following formula, implemented within the ArcMap 10.8 software to process and analyze the satellite imagery (Hu et al. 2023).

$$\text{NDVI} = \frac{((\text{NIR} - \text{Red}))}{((\text{NIR} + \text{Red}))}$$

Likewise, the Urban Index (UI) analysis was performed using the following formula (Khan, Ullah & Chen 2021; Waleed et al. 2023).

$$\text{UI} = \frac{((\text{SWIR } 1))}{((\text{SWIR1} + \text{SWIR2}))}$$

2.2.2. Ancillary Data Collection

Secondary data were collected to complement and validate the satellite-based analysis. These included: Hambantota Divisional Secretariat Reports, Statistical Reports, Project Reports, and Development Plans sourced from the Urban Development Authority (UDA)

These documents provided contextual insights into the region's development initiatives, socio-economic conditions, and land-use planning strategies, enriching the interpretation of the NDVI and UI results.

3. Results and Discussion

The study has analyzed changes in vegetation cover, wetland areas, non-vegetated land, and the Built built-up area in the Hambantota Municipal Council (MC) area over the years 2001, 2013, and 2024.

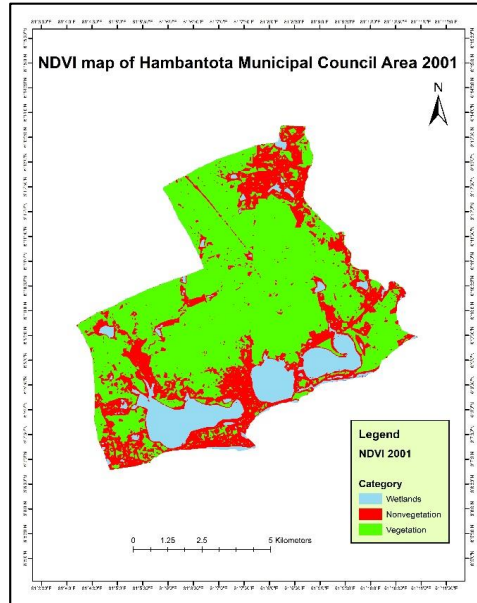


Figure 2: NDVI density maps of Hambantota MC in 2001

Figure 2 shows the NDVI density map of Hambantota Municipal Council in 2001, as per this, the land cover within the Hambantota Municipal Council area was predominantly characterized by vegetation, which accounted for 51.80 sq.km or a significant portion of the total area. Non-vegetation areas, including built-up and bare lands, covered 20.93 sq.km, indicating limited urban development during this period. Wetlands, comprising natural water bodies such as lakes, reservoirs, saltwater bodies, and marshes, occupied 9.98 sq.km, highlighting their presence as an essential ecological feature. This distribution reflects the largely rural and natural landscape of the region in 2001, with vegetation being the dominant land cover type.

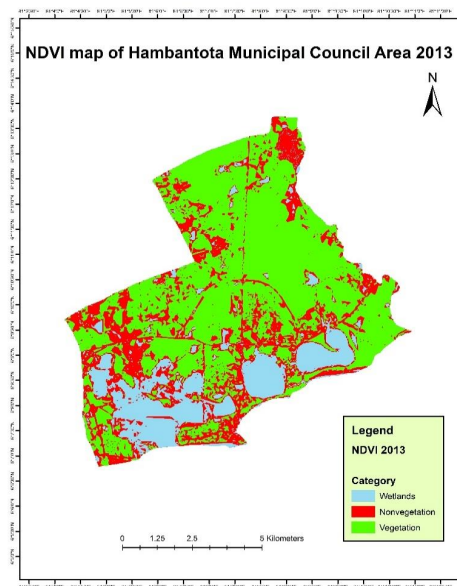


Figure 3: NDVI density maps of Hambantota MC in 2013

The 2013 NDVI map (Figure 3) of the Hambantota Municipal Council area reveals notable changes in land cover compared to 2001. Vegetation cover declined to 48.66 sq.km, reflecting a reduction due to ongoing development activities in the region. Conversely, wetland areas increased significantly to 14.05 sq.km, because the seaport development of the saltwater body was expanded in this period. Non-vegetation areas, which include built-up and bare lands, slightly decreased to 20.00 sq.km, suggesting that while urban development occurred, certain non-vegetated areas may have transitioned into wetlands or vegetation cover. This period marks a shift influenced by significant development initiatives, aligning with Hambantota's emergence as a strategic urban center under national economic development plans.

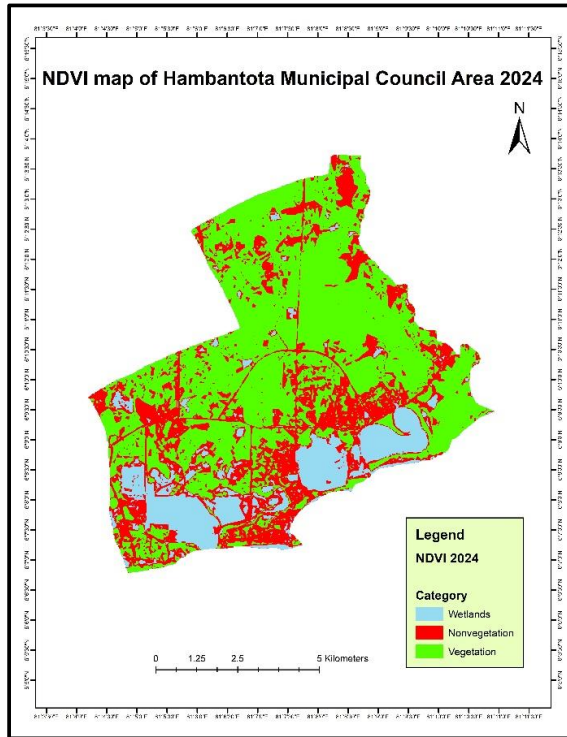


Figure 04: NDVI density maps of Hambantota MC in 2024

The 2024 NDVI map of the Hambantota Municipal Council (Figure 4) area highlights further transformations in land cover driven by rapid urbanization and infrastructure development. Vegetation cover has remained relatively stable compared to 2013, covering 48.68 sq.km, indicating minimal recovery or further decline. However, wetlands have decreased to 11.25 sq.km, marking a significant reduction from 2013, likely due to the conversion of wetland areas for development purposes. Non-vegetation areas, including built-up and bare lands, increased to 22.78 sq.km, reflecting continued urban expansion and infrastructure projects. This trend is indicative of the region's accelerated growth as a key urban center in the Southern Economic Zone, influenced by large-scale projects such as the Hambantota seaport, City development, and related road networks. The decline in wetlands and the increase in non-vegetated areas underscore the environmental trade-offs associated with rapid development.

Table 02: Extend of the NDVI classification

Category	2001(sq.km)	%	2013 (sq.km)	%	2024(sq.km)	%
Wetlands	9.98	12.07	14.05	16.38	11.25	13.6
Non-vegetation	20.93	25.3	20.00	25.39	22.78	27.54
Vegetation	51.80	62.63	48.66	58.23	48.68	58.86

The analysis of the NDVI classification results (Table 02) for 2001, 2013, and 2024 highlights significant changes in vegetation, wetlands, and non-vegetation areas in the Hambantota Municipal Council area over the study period. In 2001, vegetation covered 62.63% of the area, which decreased to 58.23% in 2013, indicating a 4.4% decline due to greater Hambantota development projects, including the construction of the Hambantota Port and city center. By 2024, vegetation cover remained relatively stable at 58.86%, showing only a 0.63% increase compared to 2013.

These trends suggest that while vegetation loss was prominent between 2001 and 2013, primarily driven by infrastructure development projects, the period from 2013 to 2024 saw minimal change due to the implementation of planned development strategies and conservation initiatives. The overall analysis emphasizes the importance of sustainable development practices to balance urban growth and environmental preservation in the region.

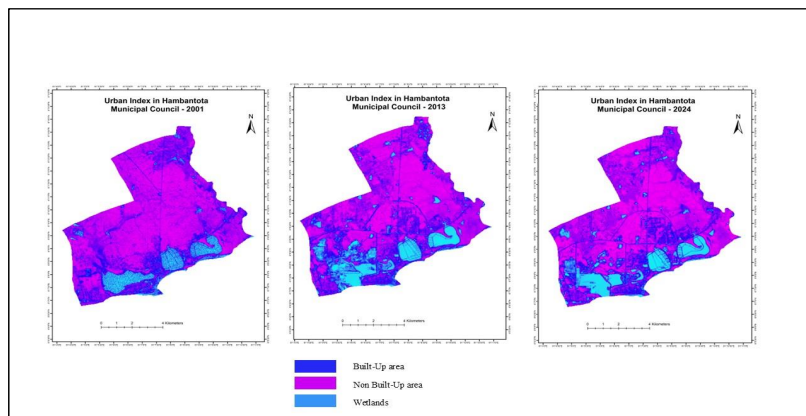


Figure: 05: Urban Growth and Land Transformation

The analysis of the urban index in the Hambantota Municipal Council area for the years 2001, 2013, and 2024 reveals significant trends in urban growth and land use transformation (figure 05). In 2001, built-up areas were relatively small and scattered, with the majority of the land comprising non-built-up areas and notable patches of wetlands. By 2013, built-up areas had expanded, particularly in the central and southern regions, while wetlands remained intact but showed slight signs of reduction. The projections for 2024 indicate a substantial increase in built-up areas, which now dominate much of the central, southern, and southeastern parts of the region, leading to a noticeable decline in non-built-up areas. Wetlands, although still present, appear increasingly under pressure from urban expansion. These trends highlight the rapid urbanization in Hambantota, driven by infrastructure development and economic initiatives, which have resulted in a transition from non-built-up to urbanized land. This growth underscores the need for sustainable urban planning to mitigate the environmental and socio-economic impacts of such rapid development.

According to the analysis, there has been no significant loss of vegetation within the Hambantota Municipal Council area. However, the region has witnessed substantial developmental activities under the Greater Hambantota Development Project proposed in 2010. Two major large-scale developments highlighted in the proposal include the Hambantota Port and the City Center Development. The Hambantota Port, envisioned as a service and industrial port, was designed to drive economic growth and alleviate unemployment in the region. Despite its potential economic benefits, the project has caused notable disruptions, such as the closure of the CGMT Highway, which adversely impacted local access and commerce. It is a foundation of development in the Hambantota region, was executed in multiple phases with significant financial investments. Phase I of the project was funded through a \$307 million loan from the Export-Import Bank of China at an interest rate of 6.3%, while Phase II received an additional \$809.35 million loan from the same source, bringing the total cost for the first two phases to approximately \$1.116 billion. The total cost for the Hambantota Port project was approximately \$1.5 billion. This project was heavily criticized as a "white elephant" due to its high costs and underutilization (Ratnayake et al. 2012; Mariyathas, Perera & Yehiya 2016).

Similarly, the City Center Development in Siribopura was envisioned as a transformative step towards a prosperous future for Hambantota. While it was portrayed as a cornerstone for urban development, the initiative faced challenges in effectively addressing the diverse needs of the local population, raising questions about its ability to meet public expectations. These developments underscore the complexity of balancing economic ambitions with community and environmental considerations in large-scale urban projects. For the City Center Development in Siribopura, the specific total cost is not explicitly mentioned in the provided text. However, it is part of the Greater Hambantota Development Plan 2030, which encompasses various infrastructure projects aimed at revitalizing the area (Kumara 2014; Madarasinghe et al. 2023).

Conclusion

The examination of land cover changes in the Hambantota Municipal Council area over the years 2001, 2013, and 2024 demonstrates the substantial impacts of accelerated urbanization and extensive infrastructure development on the region's environmental landscape. The research shows a considerable decline in vegetation cover between 2001 and 2013, resulting mainly from developmental projects such as the Hambantota International Port and City Center Development. However, the period from 2013 to 2024 suggests a stabilization in vegetation cover, illustrating the effectiveness of structured urban development strategies and conservation initiatives. Despite these efforts, wetland areas have experienced fluctuations, with a marked decline by 2024.

The findings emphasize the critical balance required between economic growth and environmental preservation. While the development projects have positioned Hambantota as a strategic urban and economic hub within the Southern Economic Zone, they also highlight the environmental trade-offs and socio-economic challenges faced by local communities. To ensure sustainable growth, future urban planning initiatives must prioritize integrated approaches that combine infrastructure development with conservation efforts. Strategic land management, community engagement, and effective policy implementation will be essential in mitigating environmental degradation while fostering long-term economic prosperity for the region.

Recommendation

It is crucial to carefully balance the goals of development with the protection of the environment and vegetation cover before implementing a development project, especially in developing countries. To ensure the project's success and long-term sustainability, several factors must be considered. First, a clear definition of the project's scope, objectives, and alignment with sustainable development goals is essential. All gaps present would be identified through a wide-scale needs analysis, and clear definition of the beneficiaries based on the project, showing equal distribution of benefits accruable from the project. Secondly, financial: the total project development costs, expected incomes, and profitability. Last but not least, socio-economic, ecological impact assessment, highlighting whether a project has positive or adverse implications regarding society, economy, culture, and the environment. These will include the development of effective mitigation strategies for all identified negative impacts, with specified actions, timeframe, and cost implications. There is also a need for community participation through feedback by local stakeholders and the general public to ascertain whether the project would meet their needs. There should be environmental conservation methodologies that may include reforestation and habitat protection. The conserved areas should be identified and protected. The legal framework should be strictly observed in the enforcement of environmental regulations against violations. Future predictions over the course of time to come, including the potential positive and negative roles of this project, should inform adaptive management strategies. Adaptive management requires continuous monitoring of the project's progress, outcome evaluation, and adjustment of strategies to handle unforeseen challenges or opportunities for perpetuating the project amidst change. These will help the project spur positive impacts on the economy, society, culture, and environmental aspects, besides minimizing risk and ensuring sustainable development.

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