An ANP-Multi-Criteria Assessment of Factors Associated with Coastal Sprawling in a Developing Economy

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ABSTRACT

The needs and desires of people around the world are diverse, particularly, with distinguishing characteristics from one economic environment to another, and when it comes to living in and enjoying coastal areas. Moreover, coastal zones are experiencing significant changes over time, including encroachment, changes in land use, and alterations to the physical environment, With consequential environmental issues, social exclusion, and segregation. An example of this coastal urbanization is Banana Island in Ikoyi, Lagos State. However, there are insufficient studies identifying the multi-faced driving factors for the causes of these coastal changes and the best ways to address them, especially in the context of a developing economy. This study aimed at identifying the drivers of coastal sprawling in Banana Island for a sustainable coastal community. The study uses a multi-criteria evaluation (MCE) approach that is based on the Analytic Network Process (ANP) model commonly used in literature. The reviewed factors were further adjudged by relevant stakeholders through three rounds of Delphi process till a consensus was reached. The study found that the environmental factor was the most important, accounting for over 40% of the relative weight of contribution to the coastal sprawling in Banana Island. In comparison, this is followed by engineering (26%), economics (19%), and social factors (16%). The findings of this study can help decision-makers address coastal sprawl and engage with different groups interested in the greater future of Banana Island and other coastal areas.

KEYWORDS: Coastal sprawl; Coastalisation; Analytic Network Process (ANP); Multi-criteria Evaluation; Spatial Analysis; Banana Island.

1. Introduction

The affluent society in Nigeria is characterized by steadily increasing demands for residential and recreation facilities, particularly around the coastal areas. These demands will lead to changes in the coastal zones' land use and cover (LULC). Also, there will be distortions of the physical and spatial configurations, and a decrease in the available land uses, leading to social exclusion, and limited access to better infrastructure. Over time, Nigeria's geographical layout of coastal urbanization has transitioned from low-rise steward's bungalows to tall high-rise apartments, predominantly constructed on ground reclaimed from the sea. These modifications have substantial ecological effects on the coastal area and its adjacent surroundings (Ogungbe & Bello, 2021; Olowoporoku, 2018).

Among the effects of coastal sprawling in coastal metropolitan areas according to Seekamp *et al.* (2019) are continuous expansion that could accommodate the increasing socio-economic

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developments and the growing global demands, as witnessed in Banana Island, and for tourism. As a result, coastal regions experience rapid transformation and unregulated development of natural and agricultural land into urban areas. Negative consequences include the loss of green open spaces, degradation of the coastal ecosystem, increased traffic congestion to and from the coast, and the decline of scenic coastal views.

The transformation of a peaceful coastal area into a bustling urban center has resulted from various factors, leading to environmental challenges related to coastal sprawl. Such expansions have both direct and indirect impacts on the entire coastal ecosystem. This is the current situation in Banana Island, located in Ikoyi, Lagos State, Nigeria. According to Beach (2002), coastal sprawl refers to 'the expansion of low-density residential and commercial development scattered across large coastal land areas'. On the other hand, Theodora and Spanogianni (2022) considered it to be coastal urban sprawl, which is a linear type of urban sprawl along the coastal zone, particularly concerning the effects of climate change on our environment. Moreover, there is ocean sprawl, which is considered to be the proliferation of all human-made structures on the seafloor (Urban Marine Ecology, 2024). The coastal urban growth, according to Mansour et al. (2023), is viewed to be multifaceted with diverse interrelated geospatial events and associated with numerous socioeconomic and environmental criteria affecting the environmental diversity and marine ecosystems. Coastal sprawl refers to an unregulated, sparsely populated, and frequently uncontrolled form of urban expansion that occurs along and behind the shoreline. It is defined by the transformation of land use from natural, agricultural, or recreational regions to residential and commercial use. The consequences of this excessive development are diverse and extensively documented. The impacts encompass a decrease in the aesthetic and leisurely appeal of the coastline, devastation of marine habitats close to the shore, diminished water quality in coastal lagoons and estuaries caused by heightened runoff from paved surfaces, heightened risk of flooding due to disregard for floodplain locations, and the disappearance of distinctive landscapes with diverse biodiversity. Considering the magnitude, velocity, and path of coastal sprawl (excessive growth) and its resulting adverse effects, there is a pressing necessity for suitable coastal management techniques (Amponsah *et al.*, 2022; Oyalowo, 2022).

The Banana Island is a man-made luxury residential and recreational island. Recently, it has undergone significant physical modifications due to unregulated coastal expansion. To ensure sustainable coastal development, it is important to understand the factors driving these developments and to find alternatives that will safeguard the natural environment and allow public access to the coast.

The study of coastal sprawl is becoming important in analyzing the increasing unsustainable development along coastlines. The demand for high-end coastal real estate with leisure facilities has led to a significant rise in property values in coastal areas globally. Many major cities are located along coastlines, driving the trend for coastal urbanization. Over the past twenty years, there has been a substantial increase in high-end real estate projects along coastal areas, attracting affluent individuals. The rising demand for coastal real estate is leading to the depletion of natural coastal features such as wetlands and dunes due to invasion, building, or destruction. Additionally, social exclusion is exacerbating the problem, as less privileged individuals are unable to access publicly owned beaches due to privatization by developers (Antonini, 2002).

Concerning the study area, there are sparse research activities on the sprawling activities (Dadashpoor & Hasankhani, 2022; Crawford, 2007; Obafemi & Soaga 2018). It is essential to create a comprehensive list of variables that explain the observed negative effects in the coastal regions of Nigeria. There is a need therefore to evaluate the factors contributing to these impacts, especially related to land use suitability. One common approach is using multi-criteria evaluation (MCE) in a Geographic Information System (GIS) environment. The Analytical Hierarchy Process (AHP) and the Analytic Network Process (ANP) are both widely used MCE methods that help decision-makers understand and prioritize these factors. The ANP is considered more theoretically and analytically robust because it effectively integrates feedback and interdependence compared to the AHP (Akinci *et al.*, 2013; Bagheri Ghadikolaei *et al.*, 2012; Herzberg *et al.*, 2019).

The purpose of this study is to evaluate the factors contributing to the development of coastal sprawl around Banana Island, Lagos State using the ANP multi-criteria evaluation method. The remaining sections of this paper are organized as follows: Section 2 reviews existing literature on the topic, Section 3 covers the materials and methods, including the study area, data collection, and sources, Section 4 presents the results and discussions, and the conclusion is provided in Section 5.

2. Literature Review

Housing is a basic need for people worldwide, using various materials and architectural styles for construction, reflecting diverse cultural preferences and customs (Ikudayisi & Odeyale, 2019). With urban areas undergoing transformation, there is a growing need for affordable housing situated in or near city centres. As a result, the focus has shifted to developing residential areas in places outside the primary urban centres, often along the coastline or surrounding islands. These areas are naturally beautiful and appealing (D'acci, 2018; Oni-Jimoh & Liyanage, 2018). According to Berkley (2005), urban sprawl is related to the rate of development of urban areas. This is also in line with Ayeni *et* *al.*, (2023); du Toit *et al.* (2018); United Nations (2015) that Africa is urbanizing at an astonishing fast rate globally, with inadequate planning and an increased population. The trends will sooner or later be witnessed around the coastal and marine environment.

Coastal environments are attractive areas for human settlements due to their high aesthetic and recreational values. Coastal regions have seen higher population growth rates compared to inland areas. This growth has been mainly attributed to seasonal and tourist influxes, while development activities impacting the coast have intensified. Today, there is a growing concentration of urban populations on or near the coast. It is projected that by the year 2025, about 75% of the world's population will be located in coastal cities (Hinrichsen, 1998). The increase in the coastal urban population is also attributed to people migrating in search of better job opportunities and an improved quality of life in urban areas (Olayiwola & Igbavboa 2014). Consequently, many of the world's major cities are located on the coast (Oni-Jimoh & Liyanage, 2018). Naturally, people are attracted to the coastal areas due to the regular interplay of interaction of the coastal processes of the tides, currents, waves, and other coastal features (e.g., estuaries, rivers, and beaches), as well as aesthetics and scenery environment. Currently, coastal regions worldwide have experienced significant population growth, leading to extensive urbanization (Neumann *et al.*, 2015). According to Omenai & Ayodele (2014), factors responsible for coastal sprawl could be natural or man-made activities occurring in the coastal regions. Adeleke *et al*., (2016) considered the lack of affordable housing, while Olusina *et al*., (2014) added transportation to be responsible for urban sprawling. Moreover, inadequate coastal planning, ineffective drainage systems, improper waste disposal facilities, land reclamation, over-dredging, and sand mining are among the possible variables for consideration. However, the specific factors driving this coastal urbanization are not well-documented in the existing literature. The study therefore aimed at assessing the drivers of coastal sprawling in a developing economy.

2.1 Multi-Criteria Evaluation (MCE) in Coastal Management

Coastal sprawl or overdevelopment presents a significant challenge to sustainable coastal tourism as it has harmful effects on the local environment, infrastructure, and services. This often leads to unsustainable levels of coastal visitors. Therefore, it is important to develop a model that can assess coastal expansion and forecast its vulnerability to coastal sprawl. Multi-criteria evaluation (MCE) or multi-criteria decision analysis (MCDA) is a highly effective method for assessing coastal and environmental management issues. It involves ranking management solutions based on multiple objective criteria, which often have conflicting priorities. When used correctly, it provides a systematic and clear approach to creating justifiable rankings and making informed choices.

2.2 Analytical Network Process (ANP)

The ANP can model feedback and interdependence in decision-making and can be linked to dynamic systems. It can be used for group decisions and allows the construction of super matrices, moving beyond the limitations of the main AHP. The ANP does not have the AHP's consistency ratio but allows piecewise implementation of a complex program. Since the ANP allows the building of variable dependence networks, it makes it more complicated, both conceptually and in terms of matrix size. Unlike the AHP, it is not easy to integrate the ANP into GIS because of its complex matrix structure. The ANP requires more computationally intensive mathematical calculations (Odunuga *et al.*, 2011; Osei *et al.*, 2006; Saaty, 1996, 2004). The ANP can be seamlessly integrated into Geographic Information Systems (GIS) to model the interdependency among various factors by allowing elements at the same hierarchical level to be networked (Ming-Chang, 2010; Saaty, 1996). The paper examines criteria identified in the literature and incorporates input from field experts. The criteria were determined through multiple rounds of the Delphi method until a consensus was reached. The final model is presented in Figure 1, which displays the main reviewed criteria and sub-criteria based on ANP interdependent and feedback structure to provide a comprehensive understanding of coastal sprawl driving factors. This is followed by alternative considerations for coastal sprawl. The factors for different levels of Figure 1 were as reviewed, their correctness' adjudged by the experts, and thereafter grouped. An example of the review of the four main criteria is shown in Table 1.

Table 1: Reviewed main criteria for coastal sprawl

S/N	CRITERIA	SOURCE
1	ENVIRONMENTAL	Dollard (1999); Ekanade *et al.* (2011); HBSN (2012); Idrus (2009); Komolafe *et al.* (2014); Miskell (2015); Moshen (1999); Nas (2018); Odunuga *et al.* (2014); Omenai and Ayodele (2014); Penrose *et al.* (2005); Van Bentum *et al.* (2012); UNEP (2024)
2	ENGINEERING	Aderiye and Awosemo (2013); Ahmed (2015); Deshpande and Jadhao (2016); Dollard (1999); Macleod and Congalton (1998); Miskell (2015); Oyinloye *et al.* (2016); Shand *et al.* (2015)
3	ECONOMIC	Abiodun *et al.* (2011); Etuonovbe (2007); Eze (2011); Akıncı *et al.* (2013) ; UNEP (2024)
4	SOCIAL	Akinmoladun and Oduwaye (2006); Aledare *et al.* (2014); Montanari *et al.* (2014); Gbadamosi and Ibrahim (2013); Oduwaye (2007); Olayiwola and Igbavboa (2014); UNEP (2024)

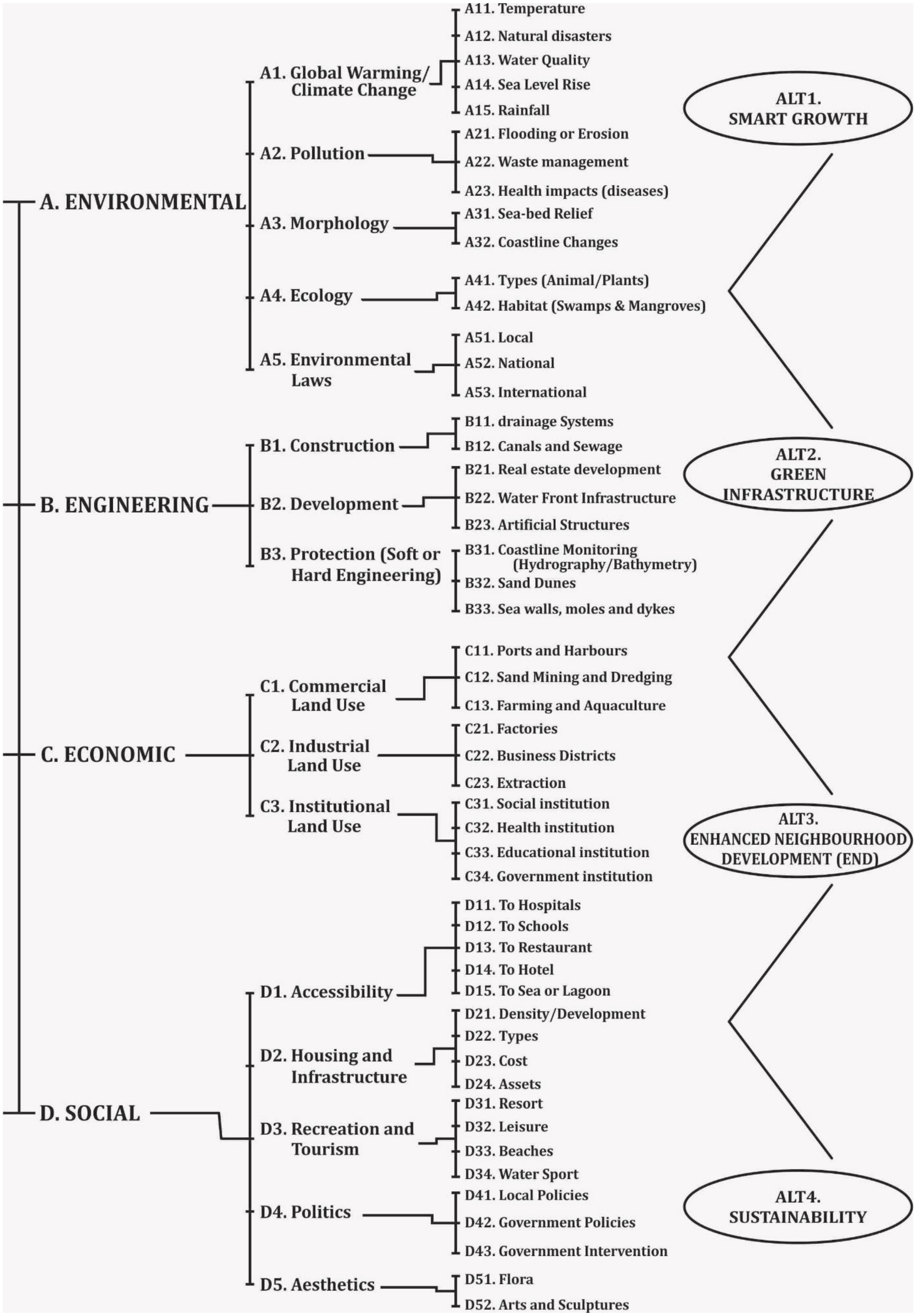


Figure 1: Comprehensive criteria for coastal sprawl

3. Materials and Methodology

3.1 Case Study: Banana Island, Ikoyi

Due to population growth and urbanization, there has always been a significant demand for residential, commercial, and recreational areas. This has led to an increase in the operations of real estate developers and the transformation of coastal areas into artificially created residential islands, such as Banana Island (Awolaja, 2010; Obiefuna, Jerry N *et al.*, 2012; Obiefuna, J. N. *et al.*, 2013). The Banana Island (Figure 2) is an artificial island located along the foreshore of Ikoyi, a suburb of Lagos in Nigeria. It is shaped like a banana, hence its name. The island spans approximately 1.6 million square meters of land and is divided into 536 plots, ranging in size from 1000 to 4000 square meters. These plots are primarily arranged along cul-de-sacs, which were intentionally designed to preserve the residential character of Ikoyi (FairPoint Properties, 2024).

Figure 2: Satellite image of Banana Island and part of Ikoyi Environ (Google, 2023)

The island was developed by the Lebanese-Nigerian Chagoury Group in collaboration with the Federal Ministry of Works and Housing. It is comparable to the Seventh Arrondissement in Paris, La Jolla in San Diego, and the Shibuya and Roppongi neighbourhoods in Tokyo (FairPoint Properties, 2024). The island has its beauty from the helping hands of the island's developer with the creation of lagoons, landscaping, and filling of the lowland beach ridge. The island is noted for its high-profile settlement, high property values, serenity, and security. It is home to several expatriates, top business executives, and government officials. Since the creation of the island, coastal sprawl has been observed with the assemblage of structures on the water's edge diminishing the visual access to the coastline (FairPoint Properties, 2024).

Before the construction of the residential and commercial buildings, the island was a swamp used for fishing activities. Currently, according to Olugbade (2021), the existing amenities on the island include a swimming pool, private elevators, a fitted kitchen, a gymnasium, a reverse osmosis plant, a water treatment plant, a sewage treatment plant, remote-controlled gate, roller shutter, tennis court, a sauna, a mist coolant, video-enabled intercom device, helipad, jetty, basketball court, squash court, and private cinema.

3.2 Data Collection Methods

When studying sprawl/growth, various factors were considered, including environmental and socio-economic impacts, using the ANP model and Supermatrix to effectively identify the sprawling factors for the study area. These factors were reviewed from the literature and the list went through experts' judgment and, thereafter, was structured into a questionnaire based on the ANP model. This was followed by the primary data collection through the fieldwork in the study area. The flowchart explaining the procedure for the study is shown in Figure 3. It consists of three different components: the scope and knowledge base, the review and experts' judgment, evaluation, and analysis that eventually leads to the quantification of the driving factors contributing to coastal sprawling and to the case of the Banana Island. The scope and knowledge base are further divided into problem definition for understanding the issues at hand and the formulation of the research design. Next is the data consideration, sources, types, and data collection strategies: imageries depicting the extent of the study area and ANP structured questionnaire. Thereafter, the Super Decision software consideration follows.

The second phase of this flowchart is the review and experts' judgment for the review of the various factors; their categorizations into clusters/nodes, and the generation of Alternatives (see Figure 1). The experts' judgment about the arrangement of these factors was achieved through the Delphi Process. Thereafter, the Questionnaires were prepared and administered. The Evaluation and Analysis phase involves the assessment of the priorities of the factors and the alternatives that depict the outcomes of the driving factors of coastal sprawling.

3.3 ANP Application Framework - Modelling the Problem

The first step in the Analytic Network Process (ANP) model is the Saaty Nine-scale, which provides a ratio-based measure of strength for decision-making. It is based on humans' ability to judge and express relative importance. Pairwise comparisons are used to assess the strength of each criterion in comparison to the others. Consistency is an important factor in making sound judgments. The judgment matrix should not have more than 0.1 consistency ratio to ensure that the decision-maker can make reliable decisions (Nataraj, 2005; Saaty, 2004; Saaty, Thomas, 2008).

The Analytic Network Process model was used to structure the problem; the problem of interest here is arranged in hierarchies with feedback from the alternatives to the primary factors. The factors are grouped into clusters in the model and each of these primary factors was then decomposed into its sub-factors, sub-sub-factors, and parameters (Table 1 & Figure 1).

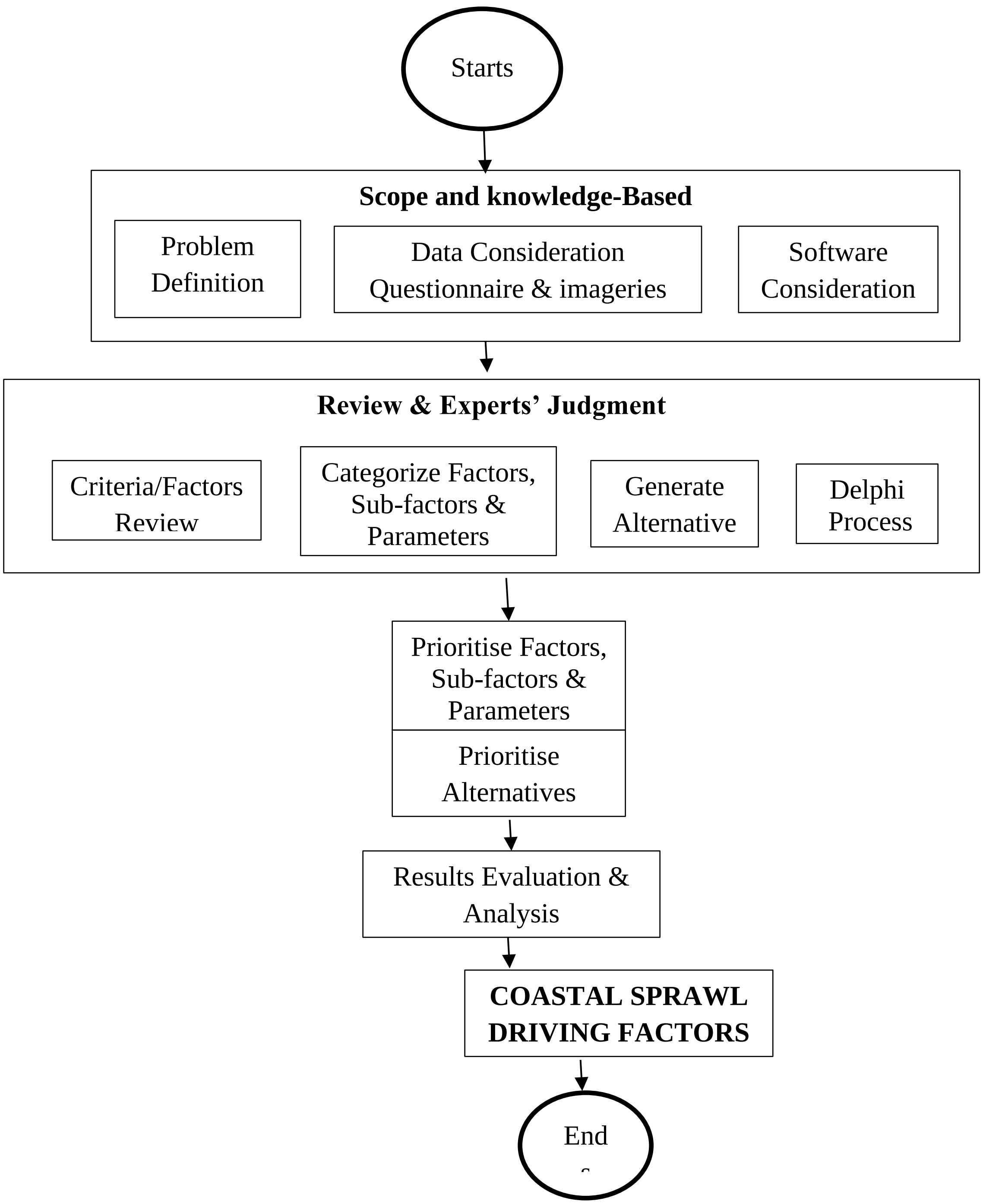
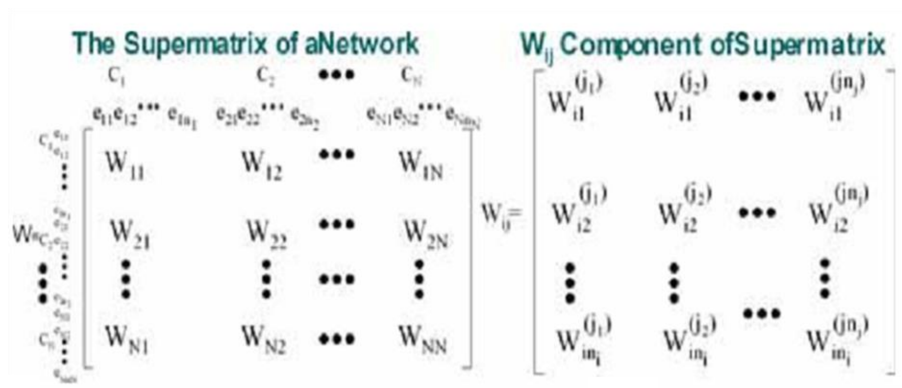


Figure 3: Research Flowchart

According to Saaty and Vargas (2006), the influence of elements in the network on others can be represented as the Supermatrix (Figure 4a), where each W_{ij} is called a block of the matrix as shown in Figure 4b. The details and mathematical proofing of AHP/ANP and its associated processes are further elaborated and well-documented in the literature (Hamid-Mosaku, 2044; Saaty, 2005, 2006, 2008; Saaty and Sodenkamp, 2008).



a b

Figure 4a and 4b: The Supermatrix of a Network and a block of the matrix Saaty and Vargas (2006)

There are two methods of computing the priority vector: eigenvectors eigenvalues and "column sum, row sum normalization". The second approach was used in this research while Saaty and Vargas (2006); Saaty (2005), the Sylvester theorem (used for the first method) is stated as follows: "When the multiplicity of each eigenvalue of a matrix W is equal to one, an entire function f(x) (power series expansion of f(x) converges for all finite values of x with x replaced by" W, is given by :

$$f(W) = \sum_{i=1}^{n} f(\lambda_i) Z(\lambda_i), \qquad 1$$

where

$$Z(\lambda_i) = \frac{\prod_{j\neq i}(\lambda_j I - A)}{\prod_{j\neq i}(\lambda_j - \lambda_i)}, \qquad 2$$

The $Z(\lambda_i)$ can be shown to be complete orthogonal idempotent matrices of W; that is they have the properties:

$$\sum_{i=1}^{n} Z(\lambda_i) = 1, Z(\lambda_i)Z(\lambda_j) = 0, \; Z^2(\lambda_i) = Z(\lambda_i), \qquad 3$$

where I and 0 are the identity and null matrices respectively.

Once the factors, sub-factors, sub-subfactors, and alternatives were identified, the final ANP model was designed using the Super Decision software, as illustrated in Figure 5. The ANP Model is a network of factors, sub-factors, sub-subfactors, alternatives, and their respective interdependencies. The priorities obtained from each pairwise comparison matrix are fed into the unweighted Supermatrix in the appropriate location in the Super Decision software. The Supermatrix is utilized to calculate the overall priorities of all the factors in the model.

Decision-making is all about setting priorities. The Analytic Hierarchical Process (AHP) and the Analytic Network Process (ANP) are the most powerful synthesis methodologies for combining judgment and data to effectively rank options and predict outcomes. They make it possible to include intangibles in decision-making. The Super Decisions is decision support software (DSS) that implements the AHP and ANP (Super Decisons CDF, 2024).

Saaty's Fundamental Scale of Judgment (1 – 9) was used in in assessing the views of the respondents to the Questionnaire administered to them that is based on the ANP structure and various factors from Figure 1. Details of the procedures are readily available (Saaty, 2008; Saaty and Vargas, 2006). Next, all elements in Figure 1 were carefully designed in the Super Decisions software. Each node constitutes a cluster that was used to form the Decision matrix (D), an example of it is shown in Figure 4 with the outcome shown in Figure 5. Thereafter, the numeric values from the respondents were entered into the software for further processing. The outcomes were the priorities, such as those in Table 5 and Figure 6. They were used to draw the inferences and conclusions for this study, as presented in Sections 4 and 5.

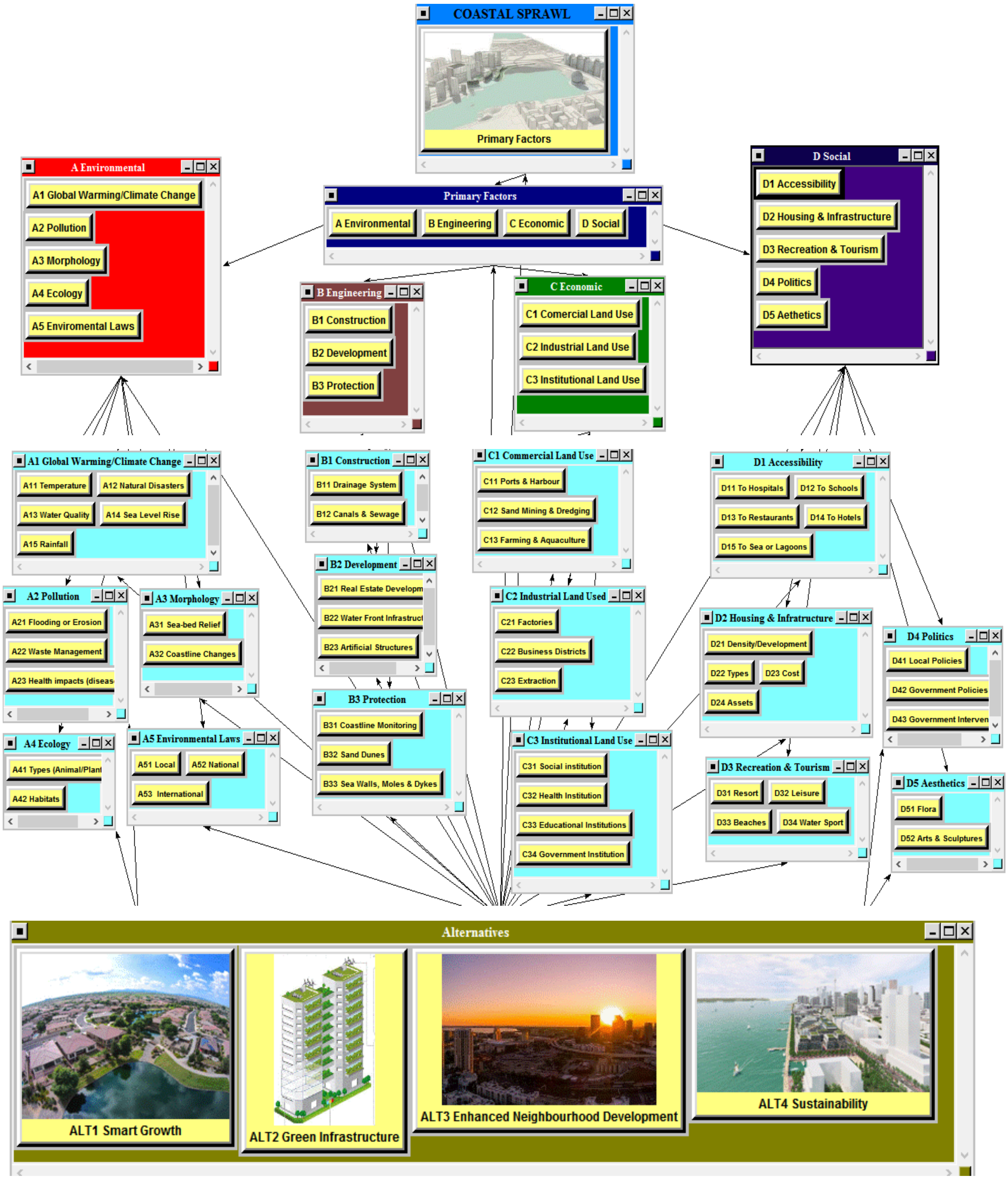


Figure 5: ANP model for the identified coastal sprawl analysis criteria (Researchers' design)

4. Results and Discussion

Today's dynamic global economy provides an environment for innovative professionals and capital from anywhere in the world to collaborate and create island paradises on coastal regions. The increasing interest in developing world city islands is driving up the value of existing island enclaves and sometimes causing local authorities to overlook established planning and environmental management principles. This research aims to understand and articulate the knowledge and experience applied in the study area, and to establish the most important factors contributing to coastal sprawl. The study uses the Delphi method to gather expert knowledge and then applies two knowledge-based MCDA techniques - the Analytic Network Process to analyze the data. The software called Super Decision is used to calculate the weights of various criteria and the relative importance of each factor.

4.1 Coastal Sprawl Patterns in Banana Island

Banana Island is experiencing developmental changes, with exclusive residential estates popping up all over the island. This study found that the estate developers are working to improve the physical and environmental quality of the island. The study examines sprawling of different exclusive coastal residential estates on Banana Island, using MCE techniques to help with coastal land-use planning. This can help control and reduce the negative effects of coastal sprawl.

4.2 Result from the Delphi process

The Delphi process was carried out with the experts till a consensus was reached on the third round, that led to the agreement on 4 major criteria, 15 sub-criteria, 45 sub-sub-criteria, and 4 alternatives (refer to Figure 1). Subsequently, the structured instrument was administered to 35 respondents. The average judgments of the responses were calculated using the arithmetic mean before being entered into the Super Decision software. Table 4 illustrates a typical outcome of the computation of the weights.

Table 4: Samples of comparison matrices for some of the factors and sub-factors

AVERAGE (ARITHMETIC MEAN)							
A. ENVIRONMENTAL	**A1**	**A2**	**A3**	**A4**	**A5**	**ROW SUM**	**PRIORITY**
A1. Global Warming/Climate Change	1.00	5.46	5.63	5.34	5.29	22.71	0.38
A2. Pollution	0.18	1.00	5.69	5.51	5.51	17.90	0.30
A3. Morphology	0.18	0.18	1.00	4.97	5.11	11.44	0.19
A4. Ecology	0.19	0.18	0.20	1.00	5.06	6.63	0.11
A5. Environmental Laws	0.19	0.18	0.20	0.20	1.00	1.76	0.03
COLUMN SUM	1.74	7.00	12.71	17.03	21.97	60.44	1.00
B. ENGINEERING	**B1**	**B2**	**B3**	**ROW SUM**	**PRIORITY**		
B1. Construction	1.00	5.63	5.57	12.20	0.61		
B2. Development	0.18	1.00	5.17	6.35	0.32		
B3. Protection (Soft or Hard Engineering)	0.18	0.19	1.00	1.37	0.07		
COLUMN SUM	1.36	6.82	11.74	19.92	1.00		
C. ECONOMIC	**C1**	**C2**	**C3**	**ROW SUM**	**PRIORITY**		
C1. Commercial Land Use	1.00	5.40	5.17	11.57	0.62		
C2. Industrial Land Use	0.19	1.00	4.43	5.61	0.30		
C3. Institutional Land Use	0.19	0.23	1.00	1.42	0.08		
COLUMN SUM	1.38	6.63	10.60	18.60	1.00		
D. SOCIAL	**D1**	**D2**	**D3**	**D4**	**D5**	**ROW SUM**	**PRIORITY**
D1. Accessibility	1.00	6.03	5.17	4.89	5.17	22.26	0.38
D2. Housing & Infrastructure	0.17	1.00	5.57	5.29	5.17	17.19	0.30
D3. Recreation and Tourism	0.19	0.18	1.00	4.54	5.11	11.03	0.19
D4. Politics	0.20	0.19	0.22	1.00	4.37	5.99	0.10
D5. Aesthetics	0.19	0.19	0.20	0.23	1.00	1.81	0.03
COLUMN SUM	1.76	7.59	12.16	15.94	20.83	58.28	1.00

The Super Decision software was used as earlier stated to generate priorities (normalized weight) and weights/priorities of the criteria as presented in Table 4. Figure 6.

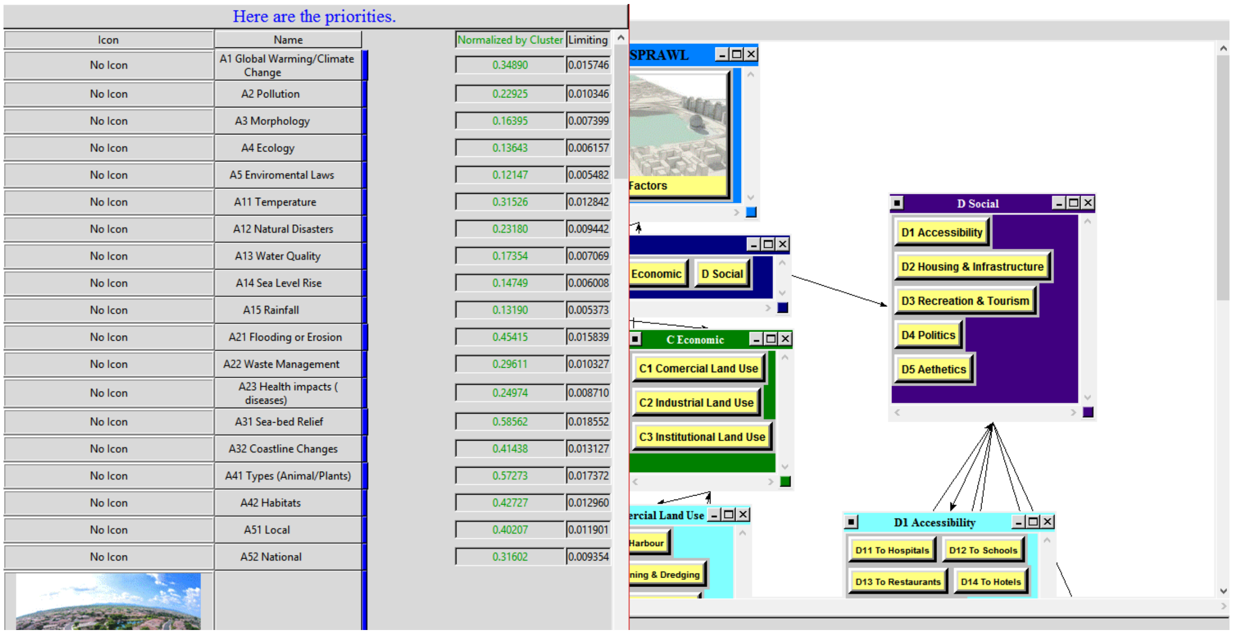


Figure 6: Priorities of the factors in Super Decision software

4.3. Analysis based on the overall weights

This involves normalizing criteria within the Super Decision software and conducting further ANP analysis. Clusters were used to represent the influence of each criterion with others. There are local and global weights that are used to evaluate and rank the various driving forces for coastal sprawl. The weighted mean is calculated when certain values in a dataset are more important than others. A weight (w_i) is attached to each of the values (x_i) to reflect this importance. The global weights are then used for the final decision on the driving criteria. Table 5 shows the final values of the weights and those obtained by cluster normalization.

In Table 5, the Normalisation results highlight the prioritization of factors in the context of sprawl in a study area. The outcome of the study revealed the Environmental factor accounts for over 40%, while the social factor is the least prioritized at 15.53%. Among the Environmental sub-factors (A1-A5), the impact of climate change, particularly high temperatures at 31.53%, is the most prioritized, while rainfall has the lowest prioritization at 13.19%. Pollution, depicted as A21-A23, accounts for 23%, with flooding/erosion being the highest form at 45.42%. This is not too surprising since there is a regularity of flood incidences on the island, which could be attributed to inadequate drainage and run-off systems within the island and the adjourning vicinities Environmental laws were only considered at 12%, contributing to sprawl. It is crucial to prioritize the morphology and ecology of the study area.

Table 5: Priorities and Weight of Factors, Sub Factors and Alternatives

S/N	CLUSTERS	NODES	NORMALIZATIONS RESULT FROM AHP/ANP SUPER DECISION SOFTWARE			
			Weights	Normalized By Cluster	Limiting	% Normalized
1	A ENVIRONMENTAL	A1 Global Warming/ Climate Change	0.2564	0.3489	0.0157	34.89
		A2 Pollution	0.1307	0.2293	0.0103	22.93
		A3 Morphology	0.0621	0.1640	0.0074	16.40
		A4 Ecology	0.0332	0.1364	0.0062	13.64
		A5 Environmental Laws	0.0175	0.1215	0.0055	12.15
		SUM	**0.5000**	**1.0000**	**0.0451**	**100.00**
2	A1 GLOBAL WARMING/ CLIMATE CHANGE	A11 Temperature	0.2374	0.3153	0.0128	31.53
		A12 Natural Disasters	0.1379	0.2318	0.0094	23.18
		A13 Water Quality	0.0685	0.1735	0.0071	17.35
		A14 Sea Level Rise	0.0374	0.1475	0.0060	14.75
		A15 Rainfall	0.0188	0.1319	0.0054	13.19
		SUM	**0.5000**	**1.0000**	**0.0407**	**100.00**
3	A2 POLLUTION	A21 Flooding or Erosion	0.3544	0.4542	0.0158	45.42
		A22 Waste Management	0.1088	0.2961	0.0103	29.61
		A23 Health impacts (diseases)	0.0368	0.2497	0.0087	24.97
		SUM	**0.5000**	**1.0000**	**0.0349**	**100.00**
4	A3 MORPHOLOGY	A31 Sea-bed Relief	0.4190	0.5856	0.0186	58.56
		A32 Coastline Changes	0.0810	0.4144	0.0131	41.44
		SUM	**0.5000**	**1.0000**	**0.0317**	**100.00**
5	A4 ECOLOGY	A41 Types (Animal/Plants)	0.4151	0.5727	0.0174	57.27
		A42 Habitats	0.0849	0.4273	0.0130	42.73
		SUM	**0.5000**	**1.0000**	**0.0303**	**100.00**
6	A5 ENVIRONMENTAL LAWS	A51 Local	0.3377	0.4021	0.0119	40.21
		A52 National	0.1236	0.3160	0.0094	31.60
		A53 International	0.0387	0.2819	0.0083	28.19
		SUM	**0.5000**	**1.0000**	**0.0296**	**100.00**
7	ALTERNATIVES	ALT1 Smart Growth	0.1250	0.5411	0.1298	54.11
		ALT2 Green Infrastructure	0.1250	0.2514	0.0603	25.14
		ALT3 Enhanced Neighbourhood Development	0.1250	0.1326	0.0318	13.26

		ALT4 Sustainability	0.1250	0.0749	0.0180	7.49
		SUM	**0.5000**	**1.0000**	**0.2398**	**100.00**
8	**B ENGINEERING**	**B1 Construction**	0.3684	0.4710	0.0176	47.10
		B2 Development	0.0654	0.2911	0.0109	29.11
		B3 Protection	0.0661	0.2379	0.0089	23.79
		SUM	**0.5000**	**1.0000**	**0.0374**	**100.00**
9	**B1 CONSTRUCTION**	**B11 Drainage System**	0.4151	0.6475	0.0277	64.75
		B12 Canals & Sewage	0.0849	0.3525	0.0151	35.25
		SUM	**0.5000**	**1.0000**	**0.0427**	**100.00**
10	**B2 DEVELOPMENT**	**B21 Real Estate Development**	0.3479	0.4540	0.0161	45.40
		B22 Water Front Infrastructure	0.1119	0.2969	0.0105	29.69
		B23 Artificial Structures	0.0401	0.2491	0.0088	24.91
		SUM	**0.5000**	**1.0000**	**0.0355**	**100.00**
11	**B3 PROTECTION**	**B31 Coastline Monitoring**	0.3433	0.4356	0.0145	43.56
		B32 Sand Dunes	0.1176	0.3049	0.0102	30.49
		B33 Sea Walls, Moles & Dykes	0.0391	0.2594	0.0086	25.94
		SUM	**0.5000**	**1.0000**	**0.0333**	**100.00**
12	**C ECONOMIC**	**C1 Commercial Land Use**	0.3510	0.4428	0.0149	44.28
		C2 Industrial Land Use	0.1083	0.2986	0.0100	29.86
		C3 Institutional Land Use	0.0407	0.2585	0.0087	25.85
		SUM	**0.5000**	**1.0000**	**0.0336**	**100.00**
13	**C1 COMMERCIAL LAND USE**	**C11 Ports & Harbour**	0.3288	0.4650	0.0185	46.50
		C12 Sand Mining & Dredging	0.1246	0.2992	0.0119	29.92
		C13 Farming & Aquaculture	0.0466	0.2359	0.0094	23.59
		SUM	**0.5000**	**1.0000**	**0.0398**	**100.00**
14	**C2 INDUSTRIAL LAND USED**	**C21 Factories**	0.3434	0.4448	0.0154	44.48
		C22 Business Districts	0.1145	0.3004	0.0104	30.04
		C23 Extraction	0.0421	0.2548	0.0088	25.48
		SUM	**0.5000**	**1.0000**	**0.0346**	**100.00**
15	**C3 INSTITUTIONAL LAND USE**	**C31 Social institution**	0.2954	0.3472	0.0115	34.72
		C32 Health Institution	0.1236	0.2492	0.0082	24.92
		C33 Educational Institutions	0.0543	0.2097	0.0069	20.97

		C34 Government Institution	0.0267	0.1939	0.0064	19.39
		SUM	**0.5000**	**1.0000**	**0.0331**	**100.00**
16	**D SOCIAL**	**D1 Accessibility**	0.2668	0.2832	0.0091	28.32
		D2 Housing & Infrastructure	0.1268	0.2141	0.0068	21.41
		D3 Recreation & Tourism	0.0604	0.1800	0.0058	18.00
		D4 Politics	0.0235	0.1652	0.0053	16.52
		D5 Aesthetics	0.0225	0.1575	0.0050	15.75
		SUM	**0.5000**	**1.0000**	**0.0320**	**100.00**
17	**D1 ACCESSIBILITY**	**D11 To Hospitals**	0.2469	0.2862	0.0096	28.62
		D12 To Schools	0.1317	0.2186	0.0073	21.86
		D13 To Restaurants	0.0644	0.1791	0.0060	17.91
		D14 To Hotels	0.0378	0.1635	0.0055	16.35
		D15 To Sea or Lagoons	0.0192	0.1526	0.0051	15.26
		SUM	**0.5000**	**1.0000**	**0.0335**	**100.00**
18	**D2 HOUSING & INFRASTRUCTURE**	**D21 Density/Development**	0.2901	0.3289	0.0102	32.89
		D22 Types	0.1289	0.2518	0.0078	25.18
		D23 Cost	0.0392	0.2090	0.0065	20.90
		D24 Assets	0.0417	0.2102	0.0065	21.02
		SUM	**0.5000**	**1.0000**	**0.0311**	**100.00**
19	**D3 RECREATION & TOURISM**	**D31 Resort**	0.2851	0.3168	0.0095	31.68
		D32 Leisure	0.1305	0.2523	0.0075	25.23
		D33 Beaches	0.0560	0.2212	0.0066	22.12
		D34 Water Sport	0.0284	0.2097	0.0063	20.97
		SUM	**0.5000**	**1.0000**	**0.0299**	**100.00**
20	**D4 POLITICS**	**D41 Local Policies**	0.3352	0.3991	0.0117	39.91
		D42 Government Policies	0.1224	0.3161	0.0093	31.61
		D43 Government Intervention	0.0424	0.2849	0.0084	28.49
		SUM	**0.5000**	**1.0000**	**0.0294**	**100.00**
21	**D5 AESTHETICS**	**D51 Flora**	0.4158	0.5622	0.0164	56.22
		D52 Arts & Sculptures	0.0842	0.4378	0.0127	43.78
		SUM	**0.5000**	**1.0000**	**0.0291**	**100.00**
22	**PRIMARY FACTORS**	**A Environmental**	0.1250	0.4015	0.0198	40.15
		B Engineering	0.1250	0.2564	0.0126	25.64
		C Economic	0.1250	0.1869	0.0092	18.69
		D Social	0.1250	0.1553	0.0077	15.53
		SUM	**0.5000**	**1.0000**	**0.0493**	**100.00**

From an engineering perspective and considering sub-factors (B1-B3), the most significant contributing factor is the construction activities within the study area, accounting for more than 47%. This is particularly evident in drainage, canals, and sewage systems. Next is development, which makes up 29.11%, taking different forms such as B21-Real Estate Development (45.4%), B22-Water Front Infrastructure (29.7%), and B23-Artificial Structures (25%). These values highlight the extent of sprawl in Banana Island. Additionally, there is a need for protective measures, which accounts for 24%. This was observed in the form of B31-Coastline Monitoring (44%), B32-Sand Dunes (31%), and B33-Sea Walls, Moles & Dykes (26%).

Moreover, the outcome of this study for Banana Island showed that the main drivers of sprawl include economic factors related to land use. This can be seen in the distribution of C1-Commercial Land Use (44.3%), C2-Industrial Land Use (30%), and C3-Institutional Land Use (26%). Commercial land use is diverse, with Ports & Harbour accounting for 47% and Sand Mining & Aquaculture accounting for 24%. For the industrial land used, Factories, and Business Districts were more prioritised. Also, there are facilities for Institutional uses such as Social Institutions (35%), as the highest, followed by Health Institutions, then Educational Institutions, and Government Institutions, all being prioritised accordingly.

In the study area, coastal sprawl is influenced by various social factors. These factors include D1-Accessibility (28.3%), D2-Housing & Infrastructure (21.4%), D3-Recreation & Tourism (18%), D4-Politics (17%), and D5-Aesthetics (16%). Accessibility connotes assess to hospitals, schools, restaurants, hotels, and proximity to the sea or lagoon.

Housing and infrastructure need to consider density, types of facilities, and cost implications for the different assets. Additionally, the area should have recreational and tourism destinations such as resorts, leisure facilities, beaches, and water sports areas. The influence of politics is also significant, with local policies, government policies, and government intervention affecting coastal sprawl. Aesthetics, including flora, arts, and sculptures, also play a role in driving coastal sprawl in the study area.

When considering alternatives, the priorities are smart growth (54%), followed by green infrastructure (25%), enhanced neighborhood development (13.26%), and sustainability drive within the community (7.5%).

This study introduced a decision support system (DSS) that utilised the feedback mechanisms of ANP to offer a better understanding of the hierarchies and interconnections of the driving elements that contribute to coastal sprawl in Banana Island. The significant allure of the waterfront and the inherent qualities of the city being examined often lead to inefficiencies in the current hierarchical coastal management systems. The suggested framework not only simplifies the complexity of the problem but also enables the incorporation of these complexities in the decision-making process for effective and efficient coastal management. The DSS can readily incorporate numerous parameters that impact coastal sprawl in the study area or similar places, thus making this study a significant contribution to future decision-making in coastal towns.

Furthermore, the coastal sprawl index (CSI) was calculated for Banana Island in this study, revealing a significant level of coastal sprawl. The coastal sprawl is being exacerbated by significant environmental issues, including inadequate urban planning, excessive pollution from both inhabitants and service providers, and inappropriate use of man-made infrastructure. Additionally, it was determined that characteristics such as proximity to the ocean, visibility of the coast, building type, and building size had a substantial impact on the expansion of coastal development. The boosting elements provide more than 55% compared to the dampening ones implemented to control coastal sprawl. The study also suggested that long-term coastal management in the study area and other similar sites should take into account the important aspects that either enhance or reduce the effects.

5. Conclusion and Recommendations

The research has introduced an ANP Multi-Criteria framework for identifying the key factors that contribute to the sprawling events in the study areas and their interactions in a way that easily accommodates the influence of any selected indicator over another. Additionally, the study found that development control in Banana Island has been largely successful in managing physical development to establish the island as a high-end residential area for investors. The study also identifies some attribute interactions and recommends that collaboration, particularly stakeholder involvement linked with investor involvement, should be adopted by the key agents in the real estate development market.

The government, through its planning and implementation arms, should play a role in utilizing demographic indicators to guide sustainable coastal development. In a recent study, a decision support system (DSS) combining the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) was introduced to examine the interdependence and hierarchy of causes contributing to coastal sprawl (Obafemi and Soaga, 2018), and the trends in coastalisation (Lagarias & Stratigea, 2023; Theodora & Spanogianni 2022), marine urban sprawl and ocean sprawling (Hitched, 2021; Henry *et al.,* 2018). The current hierarchical coastal management structures are often burdened with inefficiencies due to high interest in the waterfront and the unique qualities of the city under study. These inefficiencies include a lack of information and competence, as well as high staff training costs. The suggested framework not only simplifies the problem but also takes these complexities into account for effective and efficient coastal management decision-making. This study could be a valuable resource for future coastal city decision-making.

Coastal sprawl is being exacerbated by serious environmental issues, such as inappropriate densification, excessive pollution from traffic generated by residents and various service providers, and irrational use of man-made amenities. Moreover, research has shown that factors such as building style, size, and proximity to the ocean significantly contribute to the expansion of coastal sprawl. These enhancing factors outweigh the dampening ones by at least 55%. The study recommends that these influential factors be considered for long-term coastal management in the study area and other similar regions.

It is crucial to investigate migration processes and test actual built-form measures of coastal sprawl in additional locations. Since the study has looked at coastal sprawl from a destination-based perspective, it is also recommended to employ an origin-destination approach to address coastal sprawl. The findings of such research will be invaluable to coastal management practitioners in mitigating the negative impacts of coastal sprawl on coastal environments and communities.

To mitigate the negative impacts of coastal sprawl, it is important to decrease the dominance of the "high status urban" and "quality of place" drivers. Management strategies should be developed and implemented to reduce the relative importance of these drivers. In the short and medium term, the "lack of coastal management" sub-driver under the "general management/political" main driver should be improved by establishing a controlled system for coastal development. This study offers significant recommendations for addressing coastal sprawl on Banana Island. A monitoring system must be in place to evaluate the present and fluctuating levels of each of the listed factors contributing to coastal sprawl. This will assist coastal management practitioners in consistently evaluating the relative significance, identifying emerging influential factors, and formulating appropriate management strategies and measures.

Future studies should consider the need to examine migration patterns and conduct tests on the physical structures of coastal sprawl in multiple locations. Moreover, given that this study has examined coastal development from a destination perspective, it is imperative to also consider an origin-destination approach to coastal sprawl. The results of this research will be highly valuable to professionals in coastal management, aiding their understanding of the driving factors of coastal sprawl, as well as their effects on the coastal ecosystems and the communities.

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Declaration of competing interests

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