



DEVELOPING SAINT MARTIN ISLAND THROUGH LANDSCAPING THEORY

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Abstract:

Bangladesh has only one coral island naming Saint Martin which is a prime source of income of this country. The geological formation of this island is very unique. This island has distinctive ecosystem, rich biodiversity and unique landscaping features. Each year Saint Martin Island attracts huge of tourist, so this island is very crucial for Bangladesh. This island is rich which various types of coral these coral serves as an important nesting ground for endangered sea turtles. Saint Martin island also play an important role in geo political issues in the Bay of Bengal due to its location and resources. Saint Martin island is largely made up by sandstone, shale, limestone. Some area of this beach are composed of conglomerate and concretion. The limestone of Saint Martin island is made by coquina bed. This coquina bed has shelly limestone and coral cluster which is coralline limestone. Saint Martin is the only coral island of Bangladesh so it is a natural treasure. These coral colonies has significant ecological value. Because which is one of the rare persisting nesting places in the area for various species of globally endangered marine turtles. This island is also a flyway and wintering site for migratory birds of the East Asian and Australasian countries. In this paper the author discuss the policy of developing Saint Martin beach through landscaping theory, sensitivity analysis, regression analysis method.

Key Words: Landscape, Saint Martin Island, Beach, Sensitivity Analysis, Regression Analysis, Coral, Loose Part Theory

Introduction:

Bangladesh has only one tropical island which has coral and rich biodiversity name Saint Martin island. This island is composed of different types of organic materials originated from associate organism of coral ecosystem. It is the only offshore island of Bangladesh which is rich with various types of unique coral. This small island is located in Bay of Bengal at about 10 km south from the south-easternmost tip of the mainland and lies between 20°34' & 20°39' N latitude, and 92°18' & 92°21' E longitude. The geo morphology of Saint Martin island is very unique, it is distinguished by its sedimentary continental structure. This island includes exposed marine sedimentary rocks and a surrounding rocky reef. Saint Martin is a dumbbell shaped island. On the flank of an antiline, with its land forms shaped by sea-level changes, tectonic activity, geo morphic processes and human activity. The prime characteristics of Saint Martin island involve sandstone, shale and limestone (carrying mollusc coquina and coral clusters) sand dunes, mangrove formation and scattered boulders.

The Saint Martin island has rich bio diversity which comprise coral reefs, mangroves and lagoons, supporting a wide array of species such as over 200 species of fish, 66 species of coral, 120 species of birds, sea weeds and sea turtles. Though this bio diversity is under threat from different types of problems like over-tourism, destructive fishing practices and the illegal removal of corals and other resource. In this research the author apply landscaping theory and sensitivity analysis in order to develop the Saint Martin island of Bangladesh.

Objective of the Study:

- To determine how coral retain the ecological balance of Saint Martin Island.
- Perform sensitivity analysis of Saint Martin Island.
- To analysis the biodiversity of Saint Martin island.
- To analysis the ecology & ecosystem of Saint Martin island.
- To determine the coral & seaweed growth & culture of Saint Martin Island.
- To analysis the Geo morphology & formation of Saint Martin Island.

Literature Review:

Saint Martin's Island, Bangladesh, features a unique landscape with a rocky platform, sandy beaches, sand dunes, and coral clusters. It's the only coral island in Bangladesh and is known for its beautiful coastal scenery, including coral reefs, beaches, and a small connected island called Chhera Dwip. The island's landscape is influenced by both natural phenomena like tides and human activities, particularly tourism, which has led to changes in land use and vegetation.

Geographic Features:

The island is characterized by a rocky platform, sandy beaches, and sand dunes that fringe the shoreline. The presence of coral clusters, particularly in the subtidal and offshore zones, adds to the island's unique appeal.

Tidal Influence:

The island is affected by tides, with a significant portion of the landmass sinking during high tide.

Land Use Changes:

While the island is known for its agricultural land and vegetation, tourism development has led to a shift in land use, with built-up areas expanding and agricultural land decreasing.

Ecosystem:

The island's ecosystem includes coral communities, a tidal zone, and various other habitats.

Tourism and Development:

The island's popularity as a tourist destination has resulted in changes to its landscape, including increased construction and infrastructure development.

Conservation Concerns:

The changes in land use and potential damage to coral reefs due to human activities have raised concerns about the island's ecological sustainability. Saint Martin's Island in Bangladesh faces several environmental and socio-economic challenges due to tourism and other factors. These include waste management issues, coral reef degradation, deforestation, and disruptions in essential services like electricity and communication.

Environmental Problems:

- **Waste Management:** The island struggles with inadequate waste management, particularly plastic waste, due to a lack of proper infrastructure and the indifference of some tourists.
- **Coral Reef Degradation:** Tourism activities, including construction, pollution, and unsustainable practices, are damaging the coral reefs, which are vital for the island's ecosystem.
- **Deforestation:** Increased demand for hotels and resorts leads to deforestation, impacting the island's natural environment and biodiversity.
- **Pollution:** Untreated sewage, plastic waste, and other pollutants contaminate the land, sea, and air, threatening marine life and human health.
- **Sea Level Rise:** The island is vulnerable to sea level rise due to climate change, potentially leading to coastal erosion and inundation.
- **Overfishing:** Destructive fishing practices are causing damage to the reefs and marine life.

Socio-Economic Problems:

- **Disruptions to Essential Services:** Frequent disruptions in electricity and communication networks impact residents' daily lives and businesses.
- **Dependence on Tourism:** Many islanders rely on the hospitality industry for their livelihoods, making them vulnerable to fluctuations in tourism and potential restrictions.
- **Limited Healthcare and Sanitation:** Healthcare services are inadequate, and sanitation facilities are lacking, impacting both residents and tourists.

Government and Community Initiatives:

- **Restricting Tourist Movement:** The government has implemented a nine-month tourist ban (February to October) to allow the island's ecosystem to recover.
- **Waste Management Initiatives:** Organizations like the UNDP Accelerator Lab are working on sustainable waste management solutions for the island.
- **High Court Intervention:** The High Court has issued a ruling to regulate tourism and control pollution on the island.
- **Community Awareness:** Efforts are being made to educate both locals and tourists about the importance of environmental conservation.

Landscaping theory can help mitigate some problems on Saint Martin's Island by promoting sustainable land use and ecological restoration. By carefully designing and managing landscapes, it's possible to address issues like habitat loss, erosion, and water quality problems stemming from human activities and natural factors. This involves integrating ecological principles into urban and agricultural planning to create a more resilient and balanced environment.

Addressing Habitat Loss and Fragmentation:

Ecosystem Restoration:

Landscaping can be used to restore degraded areas by reintroducing native vegetation, creating wildlife corridors, and improving soil health. This can help mitigate the loss of biodiversity and habitats caused by construction and other human activities.

Green Infrastructure:

Integrating green spaces like parks, gardens, and green roofs into urban areas can provide habitats for wildlife, improve air and water quality, and create more aesthetically pleasing environments. This can help reduce the impact of development on natural ecosystems.

Managing Water Resources and Erosion:

- **Rainwater Harvesting:** Implementing rainwater harvesting systems in urban and agricultural areas can reduce reliance on groundwater and surface water sources. This can help alleviate water scarcity and improve water quality.
- **Permeable Pavements:** Using permeable pavements in parking lots and walkways can help reduce storm water runoff and allow rainwater to infiltrate into the ground, replenishing groundwater and reducing erosion.
- **Vegetated Buffers:** Planting vegetation along shorelines and waterways can help stabilize soil, prevent erosion, and filter pollutants from runoff before they enter the water bodies.

Sustainable Agriculture:

- **Agro Forestry:** Integrating trees and shrubs into agricultural systems can improve soil health, increase biodiversity, and provide multiple benefits like food and fuel. This can help reduce the need for intensive agriculture and its associated environmental impacts.
- **Crop Rotation and Cover Cropping:** Rotating crops and using cover crops can improve soil fertility, reduce erosion, and suppress weeds, leading to more sustainable agricultural practices.

Tourism Management:

- **Controlled Access:** Implementing designated pathways, viewing platforms, and controlled access points can help minimize the impact of tourism on sensitive ecosystems.
- **Ecological Tourism:** Promoting eco-friendly tourism practices, such as responsible waste management and supporting local businesses, can help minimize the negative impacts of tourism on the environment.

By integrating these landscaping principles, Saint Martin's Island can move towards a more sustainable and resilient future. However, it's crucial to remember that effective implementation requires careful planning, community involvement, and strong enforcement of regulations.

The picturesque coral island of Saint Martin's, frequently visited by tourists and nature lovers, has recently become the subject of controversy due to access restrictions. These regulations have a direct impact on the local businesses of Saint Martin's Island. Stakeholders are concerned that the future of this popular Bangladeshi tourist spot, as the once-thriving tourist hub, now requires a written pass for access.

Coral reefs support a rich marine ecology while serving as natural barriers that prevent erosion. They are extremely vulnerable to environmental changes including pollution, rising water bodies, and unsustainable tourism. It seems that the government decided to limit access to the island in order to lessen these dangers and give the ecology a better shot at recovery.

However, the restrictions have greatly affected the local economy. Tourism has traditionally been a major part of Saint Martin's economy, with businesses serving travellers from all over the world. The decline in tourists has caused a collapse in the livelihoods of resorts, travel agencies, and local vendors.



Numerous entrepreneurs have expressed frustration, claiming that their uncertain situation is the result of unclear communication and lack of planning. The sudden halt has impacted not only revenue but also the mental state of its people in an economy heavily dependent on tourism.



The limitations' effects go beyond only human misery. According to reports, the logistical difficulties of transporting food have caused significant problems for stray dogs on the island. Numerous deaths have resulted from maltreatment as a result of fewer visits and interrupted supply networks.

This unfortunate result highlights the unforeseen repercussions of the abrupt limitations and presents moral dilemmas about the use of conservation laws.

The circumstances of Saint Martin's Island demonstrate how difficult it is to strike a balance between environmental preservation and long-term economic viability. Conservationists worry that the island's distinctive biodiversity may be permanently lost if immediate action is not taken. They emphasise how urgent it is to save ecosystems like Saint Martin's Island, which are important for the environment and help fight climate change.

Nonetheless, some who oppose the restrictions believe that a more sophisticated strategy is required. Sustainable tourism strategies, like restricting the number of visitors, encouraging eco-friendly accommodation, and funding coral restoration initiatives, may accomplish conservation objectives without severely harming the local economy.

Abdul Aziz, a resident of St Martin's Island in Teknaf upazila of Cox's Bazar, was on a morning walk along the island's southern shoreline when he noticed a thick layer of snail and oyster shells deposited along the coastal kaya trees. In recent days, the number of snails and oysters washing ashore has visibly increased.

"These changes might be happening because the island has remained undisturbed for over a month after the tourist season ended," said Aziz, an environmental activist. Speaking to locals, it was learned that the island's biodiversity is undergoing a

remarkable restoration. A layer of snail and oyster shells has sedimented along the shoreline, the number of turtles arriving to lay eggs has increased, and mangrove forests in different parts of the island are flourishing as human and vehicular movement has significantly declined.

Local resident Joynal Abedin said a mangrove forest is emerging over more than an acre of rocky coastline in the island's southern region, including Diyar Matha. Md Jamir Uddin, deputy director of the Department of Environment's (DoE) Cox's Bazar office, said with tourist activities and battery-powered vehicles restricted, at least seven to eight kilometres of beach along the island's southeast and west have seen an accumulation of seashells. These shells help prevent beach erosion and protect the island's dunes. Previously, locals collected and sold these shells to traders who used them to make showpieces and jewellery.

He said drones were used to locate waste deposits, leading to the collection of over 930 kilogrammes of waste in a cleanup operation that began on February 12. Around 90 percent of the waste consisted of chips packets, polythene bags, and biscuit wrappers. He said the number of Olive Ridley turtles coming to the island to lay eggs is rising, as artificial lights and loudspeakers major deterrents for turtles -- have been restricted.

Authorities are also protecting the turtles and their eggs from stray dogs that previously attacked them. Various studies have identified 1,076 species of biodiversity on St Martin's, including corals, seaweed, turtles, shellfish, marine fish, birds, mammals, and crabs. The island's sandy shores are a critical nesting site for endangered turtles. However, unregulated infrastructure development, excessive tourism, and environmental pollution have put the island's ecosystem at risk.



To protect the island, authorities set a deadline of January 31 for tourist visits this year, allowing only 2,000 visitors per day for two months. In previous years, the island remained open for tourists from October to April, with over 5,000 visitors arriving daily. Due to unchecked tourism, the island's biodiversity was being destroyed, said environmental activists. Tourists roamed every corner of the island on battery-run vehicles or motorbikes, which damaged the beach and mangrove forests. They also took away snail and oyster shells.

Last year, conservationists collected around 1,400 turtle eggs from 13 turtles. This breeding season, they have already collected 2,500 eggs from 19 turtles. Over 160 eggs have hatched, and the baby turtles have been released into the sea. In 1999, the DoE declared St Martin's an Ecologically Critical Area. On January 4, 2023, the environment ministry designated 1,743 square kilometres of the Bay of Bengal adjacent to St Martin's as a Marine Protected Area. However, Habibur Rahman, a former member of St Martin's Union Parishad, said some marginalised people are breaking corals into small pieces to sell as construction materials. Local people and hoteliers are buying these stones. "They are doing this because their income has dropped significantly due to the restrictions on tourism," he said. Despite the tourism curbs, many locals continue fishing, drying fish for trade, and cultivating vegetables and watermelons for their livelihoods.

The St Martin's island on the Bay of Bengal, having an area of eight square kilometres, is known as 'Narikel Jinjira' to the local people. This island is mentioned as the one and only coral island of Bangladesh on different local and international websites. That's why majority of the people in this country know St Martin as a coral island. Cox's Bazar district portal and open encyclopedia Wikipedia also categorises St Martin as a coral island. But, is St Martin actually a coral island? Those doing research on marine biodiversity however have a different opinion on this topic. Associate professor at the institute of marine sciences in Chittagong University, Mohammad Shah Nawaz Chowdhury is doing research on the biodiversity of St Martin's island including the coral. The last time he visited St Martin's island was on 15 February. He led a research team consisting of teachers and students for several consecutive days there.

When asked if St Martin's island is a 'coral island', Shah Nawaz Chowdhury told Prothom Alo this is a misconception. St Martin's island is not a coral island actually. It's a rocky island enriched in coral. Coral islands are created because of coral. St Martin's island is a rocky island. (Prothom Alo)

Several landscape theories can be applied to understanding and managing coastal areas, with a focus on both natural processes and human impact. These include ecological principles, coastal geomorphology, and human perception of coastal landscapes.

Ecological Principles:

- **Ecosystem-Based Management:** This approach emphasizes the interconnectedness of coastal ecosystems, including beaches, dunes, and near shore waters, and considers how human activities impact these systems.
- **Habitat Restoration and Conservation:** Coastal landscapes are often fragile and require careful management to protect vulnerable species and habitats.

- Sustainability: Coastal development and management practices should aim to minimize environmental impact and ensure long-term ecological health.

Coastal Geomorphology:

- Coastal processes: Understanding how waves, tides, currents, and sediment transport shape coastal landforms is crucial for managing beaches and shorelines.
- Erosional and depositional landforms: Coastal landscapes are shaped by both erosion (e.g., cliffs, wave-cut platforms) and deposition (e.g., beaches, sand dunes).
- Sea-level rise adaptation: Understanding how rising sea levels will impact coastal areas is critical for planning and implementing adaptation strategies.

Human Perception of Coastal Landscapes:

- Coastal scenery and tourism: Coastal areas are valued for their scenic beauty and recreational opportunities, which can be analyzed using landscape perception studies.
- Cultural landscapes: Coastal areas often have cultural significance, shaped by historical uses, traditional practices, and local knowledge.
- Public participation: Engaging local communities in coastal management decisions is essential for ensuring that landscapes are valued and protected.

4. Landscape Engineering:

- Coastal engineering: This involves applying engineering principles to manage coastal hazards, such as erosion and flooding.
- Beach nourishment and coastal defenses: Techniques like beach nourishment, seawalls, and groins can be used to protect coastlines, but they must be carefully designed and implemented to minimize environmental impacts.

In essence, managing coastal landscapes requires a holistic approach that integrates ecological, geomorphological, and human perspectives. It involves understanding the natural processes that shape coastal environments, recognizing the value of coastal scenery and cultural heritage, and implementing sustainable management practices that minimize environmental damage and enhance community well-being.

Problem of Saint Martin Island:

Saint Martin's Island in Bangladesh faces a multitude of problems including environmental degradation, threats to its coral ecosystem, and the impact of tourism. The island, Bangladesh's only coral island, is experiencing the consequences of unchecked human activity and natural disasters.

Environmental Degradation:

Coral Reef Destruction:

The island's coral reefs, vital for its biodiversity and coastal protection, are under threat due to various factors including sedimentation from coastal development, pollution from tourism and fishing, and destructive fishing practices.

Water Quality Issues:

Pollution from human waste and other sources is degrading water quality, impacting marine life and potentially affecting human health.

Waste Management Problems:

The island lacks adequate waste management infrastructure, leading to the accumulation of garbage and further pollution of land and water.

Erosion and Land Degradation:

Natural disasters like cyclones and coastal erosion, exacerbated by sea-level rise, are impacting the island's landmass.

Socio-Economic Challenges:

- Unsustainable Tourism: While tourism contributes to the local economy, the rapid increase in tourist numbers without proper planning is putting a strain on resources and infrastructure.
- Overpopulation: A growing population, combined with limited resources, is creating pressure on the island's fragile ecosystem.
- Resource Depletion: Overfishing and unsustainable harvesting of natural resources are impacting the island's biodiversity and long-term sustainability.

Geopolitical Concerns:

- Strategic Importance: Saint Martin's Island is strategically important in the Bay of Bengal, and geopolitical tensions in the region could pose security challenges for the island.
- Addressing the Problems:
- Sustainable Tourism: Implementing measures to manage and control tourist numbers, promote responsible tourism practices, and develop eco-friendly infrastructure is crucial.
- Environmental Protection: Enacting and enforcing regulations to protect the coral reefs, manage waste, and prevent pollution is essential.
- Community Involvement: Engaging local communities in conservation efforts and promoting sustainable livelihoods is vital for long-term success.
- Research and Monitoring: Conducting further research to understand the island's ecology and the impact of various activities is needed to inform effective management strategies.

Saint Martin's Island, Bangladesh, is facing severe coral degradation due to a combination of natural and human-induced factors. The island's coral reefs, which are Bangladesh's only coral-rich area, are experiencing coral bleaching, reduced coral cover, and a decline in coral species diversity. These issues are primarily driven by pollution from tourism, unsustainable fishing practices, and climate change impacts like rising sea temperatures.

Coral degradation at St. Martin's Island, Bangladesh, is causing significant ecological and economic damage. Rising sea temperatures, pollution, and unsustainable tourism practices are leading to coral bleaching, habitat loss, and declining biodiversity. This impacts local livelihoods, especially fishing and tourism, and threatens the island's long-term sustainability.

Ecological Impacts:

- **Coral Bleaching:** Increased sea temperatures, exacerbated by climate change, cause coral bleaching, where corals expel the symbiotic algae that provide them with food, leading to starvation and death.
- **Habitat Loss:** Degraded coral reefs mean a loss of vital habitat for numerous marine species, including fish, turtles, and other invertebrates, disrupting the food chain and reducing biodiversity.
- **Erosion:** Coral reefs act as natural barriers against waves and erosion. Their degradation makes the island more vulnerable to coastal erosion and storm surges, particularly during cyclones.
- **Water Quality:** Pollution from land-based sources (sewage, agricultural runoff, and plastic waste) contaminates the water, further harming coral and other marine life.
- **Decreased Fish Populations:** As coral reefs are vital feeding and breeding grounds for many fish species, their degradation leads to declining fish populations, impacting the local fishing industry.

Economic Impacts:

- **Reduced Fishing Income:** Declining fish populations due to habitat loss and pollution directly impact the livelihoods of fishermen, who rely on healthy coral reefs for their catch.
- **Tourism Decline:** The island's attractiveness as a tourist destination is closely tied to its natural beauty, including its coral reefs. Degraded reefs lead to fewer visitors, impacting businesses like hotels, restaurants, and tour operators.
- **Loss of Ecosystem Services:** Coral reefs provide essential ecosystem services like water purification and shoreline protection. Their degradation leads to increased costs for local communities and governments to address these issues.

Specific Examples:

- A study showed that between 2015 and 2022, coral reef degradation reached 25%.
- The island's land surface temperature has increased, and vegetation cover has decreased, linked to unregulated tourism.
- Some reports suggest that as much as 67% of the coral on St. Martin's Island has been damaged.
- The increasing number of tourists has led to increased waste generation and inadequate waste management, further contributing to pollution and coral damage.
- Cyclone Mocha caused significant damage to the island, including coastal erosion and destruction of infrastructure, highlighting the vulnerability of the island to extreme weather events.

Addressing the Problems:

- **Sustainable Tourism:** Implementing sustainable tourism practices, such as limiting tourist visits, enhancing waste management, and protecting sensitive ecological areas, is crucial.
- **Pollution Reduction:** Improving waste management, reducing pollution from land-based sources, and addressing sewage and chemical pollution are essential.
- **Climate Change Mitigation:** Reducing greenhouse gas emissions and implementing adaptation strategies to deal with rising sea levels and temperatures are vital for the long-term survival of the island and its coral reefs.
- **Community Involvement:** Engaging local communities in conservation efforts and promoting sustainable livelihoods is essential for effective and long-lasting solutions.

Planting coral on Saint Martin Island involves several steps, including obtaining coral fragments, preparing the substrate and attaching the coral fragments. It's crucial to consider environmental factors like water quality, light and water flow to ensure successful coral growth. Restoration efforts often involve removing healthy coral from the ocean, growing them in nurseries, and then planting them on degraded reefs.

Obtaining Coral Fragments:

- **From the sea:** Healthy coral fragments can be collected from areas of the reef where they are growing prolifically.
- **From Nurseries:** Coral fragments can also be grown in land based or under water nurseries, which are often used to protect and propagate coral.

Preparing the Substrate:

- **Identifying Suitable Location:** Choose areas on the reef that have been damaged or degraded, but where conditions are suitable for coral growth.
- **Cleaning the Areas:** Remove any debris, algae, or sediment from the area where the coral fragments will be planted.
- **Attaching the Fragments:** Use techniques like epoxy, cement or specialized devices like Coral clips to secure the coral fragments to the substrate.

Planting and Monitoring:

- **Proper Placement:** Ensure the coral fragments are placed in a way that allows them to receive adequate light and water flow.
- **Water quality:** Maintain stable levels of salinity, temperature and other water parameters that are optimal for coral growth.
- **Regular Monitoring:** Observe the planted corals regularly to assess their growth and health, and to identify and potential problems.

Environmental Consideration:

- **Water Temperature:** Most corals grow best in water temperatures between 73 degrees and 84 degrees Fahrenheit (23 degree -20degree Celsius)
- **Salinity:** Corals requires salt water with a salinity level between 32 and 42 parts per thousand.

- Light: Coral need sufficient light for photosynthesis and different species may have different light requirements.
- Water Flow: Appropriate water flow is essential for providing nutrients and removing waste products.

Community Involvement:

- Local Participation: Engaging the local community is crucial for the success of any coral restoration project.
- Education & Awareness: Raising awareness about the importance of coral reefs and the need for conservation can help protect them from further damage.

Restoring coral reefs on Saint Martin's Island, Bangladesh, is a pressing need due to coral degradation. While there's no specific information on large-scale planting initiatives currently underway, there are ongoing efforts to protect and restore the island's coral reefs, including research, monitoring, and the establishment of a Marine Protected Area. These efforts are crucial for preserving the island's unique biodiversity and protecting it from further damage.

Protecting and restoring coral reefs on Saint Martin's Island, Bangladesh, involves several steps: retreating from the island, regeneration, and regulation. This includes limiting tourism, managing waste, and carefully controlling development to minimize environmental impact. Additionally, methods like coral gardening, where fragments are grown in nurseries and then transplanted, are employed to restore degraded reefs.

Landscaping Theory:

The "Theory of Loose Parts", developed by Simon Nicholson is a landscaping theory often applied to beach environment. This theory emphasizes the importance of providing a variety of flexible, natural materials that encourage exploration, creativity, and play which are abundant on beaches with shifting sands, flotsam and shells.

The theory of Loose Part & Beach Landscaping:

- Abundance of materials: Beaches naturally offer a wide variety of materials like sand, shells, pebbles, driftwood and seaweed.
- Dynamic Environment: The constant movement of tides and wind creates a constantly changing landscape, providing new opportunities for interaction and discovery.
- Encourage Creativity: The freedom to manipulate these materials allows for imaginative play, building and exploration, fostering a sense of wonder and engagement.
- Adaptability: This theory can be applied to various beach setting, from natural dunes to more developed coastal areas, adapting to the specific context and resources available.
- Connection to Nature: The theory encourages a direct connection with the natural environment, promoting appreciation for its dynamic and ever changing nature.

In essence the Theory of Loose Parts provides a framework for designing beach landscapes that are not only visually appealing but also encourage active engagement, creativity and a deeper connection with the coastal environment.

Sensitivity Analysis:

Sensitivity analysis in beach landscaping involves assessing how changes various factors (like plant species, soil composition or coastal erosion) impact the overall stability, aesthetics and ecological health of the landscaped area. This analysis helps in understanding which factors are most critical for achieving desired outcomes and mitigating potential negative impacts.

Key Areas for Sensitivity Analysis in Beach landscaping:

Erosion Control:

Sensitivity analysis can assess the effectiveness of different plant species or hard scaping features in resisting erosion caused by waves, tides, and wind. Factors like root structure, plant height and density can be analyzed to determine their impact on soil stability.

Salt Tolerance:

Coastal environments are harsh, with high salinity. Analyzing the sensitivity of different plant species to salt spray and soil salinity is crucial for selecting plants that will thrive and contribute to a healthy landscape.

Water Requirement:

Beach areas often have limited fresh water availability. Sensibility analysis can help determine the water needs of different plant species and identify drought- tolerant options that minimize reliance on irrigation.

Storm Impacts:

Coastal areas are vulnerable to storms. Analyzing the sensitivity of the landscaping to high winds, storm surges and flooding is essential for designing resilient landscapes that can withstand extreme weather events.

Aesthetic Consideration:

Sensitivity analysis can also evaluate how different landscaping choices affect the visual appeal of the beach. Factors like plant color, texture, and height can be analyzed to create a visually pleasing and harmonious landscape.

Ecological Function:

Beach landscaping can play a vital role in supporting coastal eco system. Sensitivity analysis can help assess how different landscaping choices affect factors like wild life habitat, nutrient cycling and water quality.

How Sensitivity Analysis is Conducted:

- Identify Key Variables: Determine which factors (e.g plant species, soil tye, slope, wave energy) are most likely to influenced the desired outcomes of the landscaping projects.
- Define ranges: Establish the range of value for each key variables (e.g, different plant species , with varying salt tolerance, different soil types, with varying drainage characteristics)
- Model the system: Develop a model (either physical or computational) that stimulates the behavior of the beach eco system under different conditions.
- Run Simulations: Systematically vary the input variables within their defined ranges and observe the resulting changes in the model's output (e.g erosion rates , plant survival , water quality).

- **Analyze Results:** Identify which variables have the greatest impact on the model's output. This helps determine which factors require the most careful consideration during the design and implementation of the beach landscaping project.

By conducting a sensitive analysis, landscape architects and coastal managers can make informed decisions about beach landscaping that promote both ecological health and aesthetic appeal, while also ensuring the resilience of the landscape to the challenges posed by the coastal environment.

Sensitivity analysis in the beach environment helps understand how changes in various factors (like wave patterns, sediment transport, or human activities) affect beach behavior, such as erosion, accretion, or overall stability. This analysis is crucial for coastal management, helping to identify which factors are most critical for beach health and how they respond to different conditions or interventions.

Sensitivity Analysis in a Beach Environment:

Sensitivity analysis involves systematically changing input parameters in a model or system (representing the beach environment) and observing how the model's output (e.g., beach profile changes, erosion rates) responds. Beaches are dynamic systems, constantly shaped by waves, currents, tides, and other factors. Understanding how these factors influence the beach helps in:

- **Predicting Beach Behavior:** Models incorporating sensitivity analysis can predict how a beach might respond to future scenarios like sea-level rise, increased storm frequency, or human development.
- **Assessing the effectiveness of coastal defenses:** By testing the impact of different coastal protection structures (like seawalls or breakwaters) on the beach, sensitivity analysis can help optimize their design and placement.
- **Managing beach resources:** Understanding the sensitivity of beaches to human activities like recreation or construction can help manage these activities to minimize negative impacts and ensure beach sustainability.

Examples of Factors Analyzed in Beach Sensitivity Studies:

- **Wave parameters:** Wave height, wave period, wave direction, and wave breaking patterns can significantly impact beach erosion and accretion.
- **Sediment characteristics:** Grain size, sediment sorting, and sediment supply (from rivers or offshore sources) play a crucial role in beach stability.
- **Sea-level rise:** Rising sea levels can lead to increased erosion and inundation of beaches.
- **Human activities:** Coastal development, construction of structures, and recreational use can all affect beach morphology and stability.
- **Climate change:** Increased frequency and intensity of storms, changes in precipitation patterns, and sea-level rise can all have significant impacts on beaches.

Methods Used in Beach Sensitivity Analysis:

- **Numerical modeling:** Here the author used Computer models simulating beach processes are used to test the sensitivity of the beach to different input parameters.
- **Field measurements and observations:** The author monitoring beach changes over time and collecting data on various factors allows for validation of models and identification of critical parameters.
- **Statistical methods:** Here the researcher used Statistical techniques to analyze data and quantify the relationships between different factors and beach response.

In essence, sensitivity analysis in the beach environment provides a powerful tool for understanding, predicting, and managing the complex dynamics of our coastline

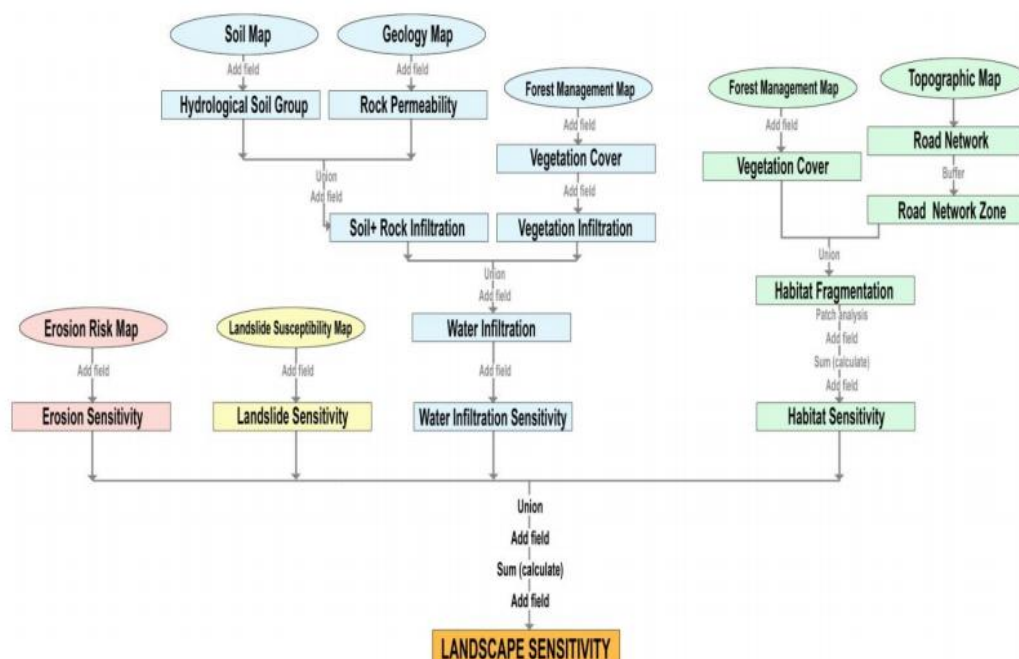


Figure 2: Landscape sensitivity analysis model (parameters, data, and analysis process)

Landscape sensitivity total score = Erosion sensitivity score + Landslide sensitivity score
+ Water infiltration sensitivity score + Habitat sensitivity score

Data Analysis & Interpretation:

Saint Martin's Island is a coral island in the northeastern part of the Bay of Bengal, located 9 km south of the Cox's Bazar-Teknaf peninsula. Its geographical coordinates are between 20°34'20" raised to the composed with power 34 prime 20°34' and 20°39'N latitude and 92°18'92" raised to the composed with power 18 prime 92°18' and 92°21'E longitude. The island is roughly 9 km long, with varying widths from 60 meters to 1.8 km, and an area of about 2666 acres. It is known for its rich biodiversity, which includes over 150 species of fish, 66 coral species, 200 types of birds, 20 mammals, and various flora, including coconut trees and mangroves.

Key Data:

- Location: Northeastern Bay of Bengal, about 9 km south of the Teknaf peninsula.
- Area: Approx. 2666 acres or 8 sq. km.
- Dimensions: Length ~9 km; width varies from 60 m to 1.8 km.
- Geographic Coordinates: Between 20°34'20" raised to the composed with power 34 prime 20°34' and 20°39'N latitude and 92°18'92" raised to the composed with power 18 prime 92°18' and 92°21'E longitude.
- Local Name: "Narical Gingira" (Coconut Island).
- Unique Features: It is the only coral island in Bangladesh.
- Connected Area: Chera Dwip, a part of the island, is a separate small islet formed from the coral reef.

Ecosystem and Biodiversity:

- Flora: Coconut trees, mangrove forests, agricultural land (rice, watermelon, maize, etc.).
- Fauna:
 - Fish: 150+ species
 - Mollusks: 300+ species
 - Birds: 200+ species
 - Mammals: 20 species
 - Amphibians: 5 species
 - Corals: 66 species

Population:

Approximately 7,000 people with fishing and tourism as major occupations.

Socio-Economic & Environmental Data:

- Principal Activities: Fishing, fish drying, agriculture, and tourism.
- Infrastructure: 17 hotels, 12 restaurants, schools, cyclone shelters, and government offices.
- Environmental Concerns: High tourist pressure has led to significant coral reef degradation, a decrease in vegetation cover, and increasing land surface temperature. Waste management and pollution are major issues.
- Government Action: The island has been declared an Ecological Conservation Area (ECA), and some restrictions have been imposed to control tourism and prevent environmental degradation. Landscaping data for Saint Martin Island shows rapid changes, with shrinking agricultural land and expanding built-up areas due to tourism and population growth. Key landscaping features include its coral beaches, coconut groves, and kewra plants, though these are being impacted by these changes.

Key Landscaping Data:

Overall Shape and Size:

An 8-square-kilometer, dumbbell-shaped island with a length of 9 km and width ranging from 60m to 1.8 km.

Dominant Features:

- | | |
|-----------------|--------------------------------------|
| • Coral Reefs | • Kewra Plants (Mangrove Formations) |
| • Sandy Beaches | • Sand Dunes |
| • Coconut Trees | • Rock Formations |

Land Use Changes:

- Built-up areas: Expanded significantly, particularly in northern regions, from 2.06 ha (1974) to 28.62 ha (2021).
- Agriculture: Land under agriculture has dwindled, with some studies showing a decrease of up to 3.87%.
- Vegetation: Fluctuated, with some increases noted in certain periods due to factors like urbanization and reforestation efforts.

Environmental and Ecological Context:

Biodiversity:

The island hosts a rich ecosystem, including corals, algae, and nesting grounds for endangered species like the Olive Ridley sea turtle.

Ecological impact:

- Habitat loss and degradation due to construction and tourism.
- Soil erosion and decreased water bodies.
- Disruption of hydrological cycles.

Primary Drivers of Change:

- Population growth.
- Intensive tourism development.

- Other human activities like coral mining.

Data Sources and Methods:

GIS and Remote Sensing:

Studies have utilized technologies like Landsat 5, Landsat 8, and Sentinel 2 imagery to generate land use maps and track changes over time.

Field Surveys:

The researcher collecting data on geological, physical, biological, and environmental conditions.

Geomorphic Feature of Saint Martin Island:

Geomorphic Unit	Area (Sq. KM)	% of Total Area
Alluvial Plain	2.65	33.17
Low land	0.27	3.40
Lagoon	0.47	5.82
Coastal Dunes (High)	0.08	1.05
Coastal Dunes (Low)	0.31	3.86
Hillocks	0.06	0.71
Sandy Beach	0.83	10.34
Shale Beach	0.16	2.01
Tidal Plain	0.52	6.53
Saltmarsh	0.04	0.50
Rocky Corals	2.61	32.62
Spit	0.08	0.98

Here the author used various types of formula for analysis these geomorphic data of Saint Martin island.

1. Landform Classification:

Landform classification involves grouping different surface features based on their morphology, genesis, material composition, and processes that formed them. Here's a classification of the listed geomorphic units:

Landform Type	Geomorphic Unit	Process Origin
Fluvial	Alluvial Plain, Low Land	Riverine deposition
Marine / Coastal	Sandy Beach, Shale Beach, Spit	Wave & current action
Eolian (Wind)	Coastal Dunes (High & Low)	Wind-blown deposition
Lagoonal	Lagoon	Coastal/marine isolation
Estuarine/Tidal	Tidal Plain, Saltmarsh	Tidal/fluvial-marine mix
Karst / Biological	Rocky Corals	Coral reef formation
Structural / Residual	Hillocks	Tectonic/uplifted remnants

Output:

A landform classification map can be made by digitizing each unit in GIS using given area data and satellite imagery or DEM.

2. Coastal Zone Management (CZM):

CZM uses geomorphic and ecological data to guide sustainable development, disaster mitigation, and ecosystem preservation along coasts.

Key Applications for Each Unit:

Unit	Management Strategy
Sandy Beach	Beach nourishment, tourism zoning, erosion control measures
Rocky Corals	Marine protected areas, tourism regulation, biodiversity conservation
Lagoon & Saltmarsh	Flood buffering zones, ecological conservation, water quality monitoring
Spit	Monitor for erosion/accretion trends, navigation channel management
Tidal Plain	Erosion control, mangrove restoration (if present), pollution buffering
Dunes (High & Low)	Dune stabilization (vegetation planting), construction control, wind erosion barriers
Alluvial Plains & Low Lands	Flood zoning, agricultural planning, drainage infrastructure

Output:

A Coastal Zone Management Plan map layered with hazard zones, sensitive ecosystems, and human activity zones.

3. Geomorphic Mapping

Geomorphic mapping is about visually representing landforms and their spatial distribution. The author also suggest a geomorphic map using:

- GIS layers: digitize the provided units
- Base maps: satellite images or topographic maps
- Attributes: include area (km²), percent of total, landform type, process origin

Suggested Symbolization:

Landform	Color Code	Pattern/Symbol
Alluvial Plain	Light green	Diagonal lines
Sandy Beach	Yellow	Wavy line fill
Coral Reefs	Pink/Red	Coral pattern symbol
Saltmarsh	Light blue	Dot fill

Dunes	Tan	Dotted texture
Lagoon	Blue	Solid fill
Hillocks	Brown	Hillshade or relief lines

Output:

A geomorphic map showing spatial distribution and relative area of each unit using clear cartographic design.

Data Integration:

The author also combine geomorphic unit data with satellite imagery, DEM, and tidal data for detailed analysis.

Field Verification:

The author also validate key landforms via ground surveys or drone imagery.

Tools to Use:

- GIS Software: QGIS or ArcGIS for mapping and analysis
- Remote Sensing: Google Earth Engine, Sentinel-2 or Landsat for recent imager
- DEM Sources: SRTM, ASTER for elevation and slope analysis

Relative Relief Classification (Qualitative Assessment):

Based on the names of the geomorphic units, the author can estimate their relative positions in terms of elevation or relief qualitatively:

Geomorphic Unit	Assumed Relief Category	Justification
Hillocks	High	Elevated terrain
Coastal Dunes (High)	Moderate to High	Elevated ridges near coast
Coastal Dunes (Low)	Moderate	Lower than high dunes
Rocky Corals	Low (Marine)	Subtidal or intertidal
Tidal Plain	Very Low	Flat, near-sea level
Saltmarsh	Very Low	Low-lying, inundated
Lagoon	Very Low	Near sea level, water-filled
Shale Beach	Low	Coastal, flat
Sandy Beach	Low	Flat, coastal
Low land	Low	Flat terrain
Alluvial Plain	Moderate	Flat but slightly above tidal areas
Spit	Very Low	Formed at sea level

1. Correlation Analysis:

The researcher calculates the Pearson correlation between "Area (Sq. KM)" and "% of Total Area".

Since:

$$\text{\% of Total Area} = \frac{\text{Area}}{\text{Total Area}} \times 100$$

They are linearly dependent, and the correlation will be perfect (i.e., $r = 1$).

Result:

Pearson correlation (r) between area and % of total area: 1.0
This is expected due to direct proportionality.

2. Regression Analysis:

The researcher can run a simple linear regression:
Dependent Variable (Y) = % of Total Area
Independent Variable (X) = Area
Since % of Total Area = $(\text{Area} / \text{Total Area}) \times 100$, we expect:
 $Y = \beta X + \epsilon$

Where:

$$\beta = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sum (X_i - \bar{X})^2} = \frac{100}{\sum (X_i - \bar{X})^2} = \frac{100}{8.88} \approx 11.26$$

Let's compute:

$$\begin{aligned} \text{Total Area} &= \text{sum of all individual areas} \\ &= 2.65 + 0.27 + 0.47 + 0.08 + 0.31 + 0.06 + 0.83 + 0.16 + 0.52 + 0.04 + 2.61 + 0.08 \\ &= 8.88 \text{ Sq. KM} \end{aligned}$$

So:

$$\text{\% of Total Area} = \frac{\text{Area}}{8.88} \times 100 = 11.26 \times \text{Area}$$

Regression Equation:

$$\begin{aligned} \text{\% of Total Area} &= 11.26 \times \text{Area} \\ \text{Intercept } (\beta_0) &= 0 \\ \text{Slope } (\beta_1) &\approx 11.26 \\ R^2 &= 1.0 \text{ (perfect fit)} \end{aligned}$$

3. T-test (One-sample):

We can test whether the mean area differs significantly from a hypothesized value, e.g., 0.74 (arbitrary choice for demonstration).

Let's compute:

$$\begin{aligned} \text{Mean area} &= \frac{8.88}{12} \approx 0.74 \\ \text{Standard deviation of area} &= 0.74 \\ \text{Then apply one-sample t-test.} & \\ \text{Since the sample mean equals the test mean (0.74), } T &= 0, \text{ and p-value} = 1, \text{ no significant difference.} \end{aligned}$$

Result:

$$T = 0$$

$$p = 1.0$$

No significant difference between sample mean and 0.74

F-test

An F-test can be used in ANOVA or regression to test whether the model explains a significant amount of variance.

In our regression:

F-statistic is very large (since $R^2 = 1$)

$$p\text{-value} \approx 0$$

Result:

$$F = \infty \text{ (or very high)}$$

$$p \approx 0$$

Model is statistically significant (trivially, because % is computed from area)

Summary Table:

Analysis	Result
Correlation (Area vs %)	1.0 (perfect)
Regression Equation	% = $11.26 \times \text{Area}$
T-test (mean area vs 0.74)	$T = 0, p = 1$
F-test (regression)	$F \gg 1, p \approx 0$
Heat Conduction	Needs physical parameter

1. Governing Equation:

The author use the one-dimensional heat conduction (diffusion) equation (assuming lateral uniformity)

$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2} \quad \frac{\partial u}{\partial x} \bigg|_{x=0} = 0 \quad u(x,0) = u_0$$

Where,

$u(x,t)$ is temperature [$^{\circ}\text{C}$] (or K, same difference) at depth x and time t .

α = thermal diffusivity of the material [m^2/s], where

$$\alpha = \frac{k}{\rho c}$$

with k = thermal conductivity [$\text{W}/(\text{m}\cdot\text{K})$], ρ = density [kg/m^3], c = specific heat capacity [$\text{J}/(\text{kg}\cdot\text{K})$].

x is depth (distance into the ground) [m]; often we set $x=0$ at surface.

Boundary/initial conditions might be:

At surface $x=0$: a given surface temperature variation (e.g., sinusoidal diurnal or seasonal cycle).

As $x \rightarrow \infty$: temperature tends to some mean ground temperature (or geothermal gradient).

At time $t=0$: known initial temperature distribution.

The author can solve (analytically or numerically) for $u(x,t)$.

A classical result for a sinusoidal surface variation is that amplitude decays with depth and phase lags by depth, with decay factor $\exp(-x\sqrt{\omega/(2\alpha)})$ etc.

2. Choosing Parameters for Different Geomorphic Units:

The researcher has a list of geomorphic units: Alluvial Plain, Low land, Lagoon, Coastal Dunes (High/Low), Hillocks, Sandy Beach, Shale Beach, Tidal Plain, Saltmarsh, Rocky Corals, Spit. Each will have different thermal properties. The researcher choose representative approximate values for thermal diffusivity α (or equivalently k, ρ, c) based on literature.

Approximate Values from Literature:

For sandy soils / loose sand: thermal diffusivity typical $\sim 0.5 \times 10^{-6}$ to $1.0 \times 10^{-6} \text{ m}^2/\text{s}$ (for dry/wet conditions)

For more compact rocks (sedimentary, metamorphic): diffusivity may be larger, e.g. for some rocks $\sim 1.0 \times 10^{-6}$ to $1.4 \times 10^{-6} \text{ m}^2/\text{s}$. Thermal conductivity for soils is in range $\sim 0.3\text{--}2 \text{ W}/(\text{m}\cdot\text{K})$ depending on moisture, porosity, etc.

Assigning Values:

Here the author assigns approximate diffusivities for each unit (order-of-magnitude) for modelling:

Geomorphic unit	Assumed α (m^2/s)	Comment
Alluvial Plain	8.0×10^{-7}	fairly loose alluvium, moderate moisture.
Low land	7.0×10^{-7}	similar but maybe more saturated.
Lagoon	6.0×10^{-7}	wet sediment, lower diffusivity.
Coastal Dunes (High)	9.0×10^{-7}	dry sand dunes, high porosity $\rightarrow$ somewhat faster diffusion but low heat capacity.
Coastal Dunes (Low)	8.5×10^{-7}	slightly wetter/lower dunes.
Hillocks	8.0×10^{-7}	maybe rocky or mixed.
Sandy Beach	9.0×10^{-7}	loose sand, exposed.
Shale Beach	1.2×10^{-6}	shale is more compact rock $\rightarrow$ higher diffusivity.
Tidal Plain	6.5×10^{-7}	saturated fine sediments.
Saltmarsh	5.5×10^{-7}	very wet, organic, lower diffusivity.
Rocky Corals	1.3×10^{-6}	coral/rock material, high diffusivity.
Spit	8.0×10^{-7}	sandy/spit deposit.

These are approximations only.

3. Representative Scenario & Setup:

Let's model the temperature evolution over one daily cycle of surface temperature oscillation. Suppose surface temperature varies sinusoidally:

$$T_{\text{surface}}(t) = T_{\text{mean}} + A \sin(\omega t) \quad T_{\text{surface}}(t) = T_{\text{mean}} + A \sin(\omega t)$$

Where,

$$T_{\text{mean}} = 25^\circ \text{C}$$

$$T_{\text{mean}} = 25^\circ \text{C (typical ambient),}$$

$$\text{amplitude } A = 5^\circ \text{C (so surface swings from } 20^\circ \text{C to } 30^\circ \text{C),}$$

$$\omega = 2\pi/P \quad \omega = 2\pi/P \text{ with period } P = 24 \text{ h} = 86400 \text{ s} \quad \omega = 2\pi/86400 \text{ s} = 2.31 \times 10^{-5} \text{ s}^{-1}$$

$$\omega \approx 7.27 \times 10^{-5} \text{ s}^{-1} \quad \omega \approx 7.27 \times 10^{-5} \text{ s}^{-1}$$

The author also look at how deep the oscillation penetrates and how the amplitude decays with depth for each material.

From theory, for sinusoidal forcing, the amplitude at depth xxx decays roughly as:

$$\text{Amplitude at depth } x = A \exp(-x \sqrt{\frac{\omega}{2\alpha}}) \quad \text{Amplitude at depth } x = A \exp(-x \sqrt{\frac{\omega}{2\alpha}})$$

And the phase lag is $\theta(x) = x \sqrt{\frac{\omega}{2\alpha}}$ (in radians).

The author choose some representative depths: say $x = 0.1 \text{ m}$ (10 cm), $x = 0.5 \text{ m}$, $x = 1.0 \text{ m}$.

Let's pick one unit as example: Sandy Beach, with $\alpha = 9 \times 10^{-7} \text{ m}^2/\text{s}$.

Compute:

$$\omega = 7.27 \times 10^{-5} \text{ s}^{-1} \quad \alpha = 9.0 \times 10^{-7} \text{ m}^2/\text{s} \quad \omega/\alpha = 8.08 \times 10^{-2} \text{ s}^{-1} \text{m}^{-2} \quad \sqrt{\omega/\alpha} = 0.284 \text{ s}^{-1/2} \text{m}^{-1} \quad \sqrt{\omega/2\alpha} = 0.2 \text{ s}^{-1/2} \text{m}^{-1}$$

Then at depths:

$$\text{At } x = 0.1 \text{ m: amplitude} \approx 5 \times \exp(-0.636 \times 0.1) = 5 \times \exp(-0.0636) \approx 5 \times 0.938 \approx 4.69^\circ \text{C}$$

$$\text{At } x = 0.5 \text{ m: amplitude} \approx 5 \times \exp(-0.636 \times 0.5) = 5 \times \exp(-0.318) \approx 5 \times 0.727 \approx 3.64^\circ \text{C}$$

$$\text{At } x = 1.0 \text{ m: amplitude} \approx 5 \times \exp(-0.636 \times 1.0) = 5 \times \exp(-0.636) \approx 5 \times 0.529 \approx 2.65^\circ \text{C}$$

So for the sandy beach material, the daily surface temperature variation penetrates only ~0.1 m with substantial amplitude (~2.6 °C), by 0.5 m it's nearly suppressed (~0.2 °C), by 1 m it's negligible.

The author can repeat for the rocky corals unit ($\alpha = 1.3 \times 10^{-6} \text{ m}^2/\text{s}$). Compute:

$$\omega/\alpha = 5.59 \times 10^{-2} \text{ s}^{-1} \text{m}^{-2} \quad \sqrt{\omega/\alpha} = 0.236 \text{ s}^{-1/2} \text{m}^{-1} \quad \sqrt{\omega/2\alpha} = 0.167 \text{ s}^{-1/2} \text{m}^{-1}$$

$$\text{At } x = 0.1 \text{ m: amplitude} \approx 5 \times \exp(-0.529 \times 0.1) = 5 \times \exp(-0.0529) \approx 5 \times 0.948 \approx 4.74^\circ \text{C}$$

$$\text{At } x = 0.5 \text{ m: } \sim 5 \times \exp(-0.2645) \approx 5 \times 0.768 \approx 3.84^\circ \text{C}$$

$$\text{At } x = 1.0 \text{ m: } \sim 5 \times \exp(-0.529) \approx 5 \times 0.591 \approx 2.96^\circ \text{C}$$

4. Interpretation for All Units & Insights:

Loose, wet, low-density sediments (e.g., lagoon, tidal plain, saltmarsh) with lower $\alpha \rightarrow$ slower conduction, meaning surface fluctuations persist slightly shallower, but because diffusivity is low the penetration is shallow. Dry, sandy materials (dunes, beach) will see rapid conduction near surface but also rapid decay of amplitude with depth (thin "skin depth"). Compact rock/coral units will have higher diffusivity $\rightarrow$ slightly deeper penetration of fluctuation, but still on the order of decimetres to 1 m for daily cycles. From the depths computed: for all units the daily variations are largely attenuated by ~0.5 m depth or less. So subsurface temperatures a metre down are almost constant (i.e., insulated from daily swings).

The author considered seasonal cycles (period of ~1 year), the "penetration depth" is deeper (because ω is smaller) and the skin depth $= 2\alpha/\omega$ is larger.

Implications:

For these landforms, surface temperature control (sun, air) dominates the very shallow depth (top 10-30 cm). Subsurface thermal behavior at depths >0.5–1 m will be much more stable and governed by mean temperature, thermal conductivity, and geothermal gradient. Differences among units in thermal diffusivity will affect how quickly the near-surface zone responds to changes (e.g., climate, surface heating) and how quickly it "forgets" a perturbation.

5. Some Additional Extensions:

- The researcher could model transient heating pulses (e.g., a strong solar event or heat influx) and compute the temporal evolution of temperature in each unit using the equation numerically.
- The author incorporate boundary conditions such as convective heat transfer at surface (air-ground interface) and variable surface flux (radiation, evaporation) rather than simple sinusoidal temperature.
- The author compare two units side-by-side (say sandy beach vs rocky coral) to see how the same surface heat pulse yields different subsurface temperature rise/time to equilibrium.

In summary:

- The author wrote the heat conduction equation and explained how thermal diffusivity matters. The author assigned representative diffusivities for each geomorphic unit. The researcher modeled a daily surface temperature oscillation and computed how deep and how strongly it penetrates in two exemplar units (sand, rock).
- The researcher concluded that differences in landform material properties matter for the shallow (top decimetres) thermal response, but all units show strong attenuation by ~0.5 m depth for daily cycles.

Water Sample Analysis:

Temperature	pH	EC	TDS
28.4	7.2	2.6	1440.2

To perform a comparative analysis based on the values for Temperature, pH, EC (Electrical Conductivity), and TDS (Total Dissolved Solids), the author can analyze these parameters against typical water quality standards or ranges (for example, for drinking water, agriculture, or environmental monitoring).

Data Provided:

Parameter	Value	Unit
Temperature	28.4	°C
pH	7.2	-
EC	2.6	mS/cm
TDS	1440.2	mg/L (ppm)

Comparative Analysis:

1. Temperature (28.4°C):

Typical Range:

Drinking water: 10–25°C

Aquatic life: Optimal < 25°C

Analysis:

28.4°C is slightly above the ideal range, especially for drinking and aquatic ecosystems. Higher temperatures can affect dissolved oxygen levels and biological activity.

2. pH (7.2):

Ideal Range::

Drinking water: 6.5–8.5 (WHO standard)

Agriculture: 6.0–8.5

A pH of 7.2 is neutral and within the safe range for most uses, including drinking and irrigation. No concern here.

3. Electrical Conductivity (EC = 2.6 mS/cm):

Typical Interpretation:

<0.7 mS/cm: Low salinity

0.7–3 mS/cm: Medium salinity (suitable for many crops)

3 mS/cm: High salinity (restrictive for sensitive crops)

EC of 2.6 mS/cm indicates moderate to high salinity.

Not ideal for drinking. May be acceptable for agriculture, depending on crop tolerance.

4. TDS (1440.2 mg/L):

Standard Guidelines:

Drinking water (WHO): < 1000 mg/L (ideal), up to 1500 mg/L (acceptable upper limit)

Agriculture: < 500 mg/L (ideal); 500–2000 mg/L (moderate use)

1440.2 mg/L is above ideal for drinking but within tolerable limits for agriculture.

It suggests a high mineral content, possibly due to salts, which correlates with the high EC.

Table

Parameter	Result	Suitability
Temperature	Slightly high	Not ideal for aquatic life
pH	Neutral and within range	Good
EC	Moderately high	Limited for some uses
TDS	High	Marginal for drinking, okay for agriculture

Recommendations:

For Drinking: Requires treatment, especially to reduce TDS and EC.

For Agriculture: Suitable for moderate to salt-tolerant crops.

For Aquatic Life: Temperature may need control, depending on species.

Table: Sensitivity parameter areas in the study area (%)

Sensitivity Degree	Sensitivity parameters			
	Erosion Sensitivity Area (%)	Landslide Sensitivity Area (%)	Water Infiltration Sensitivity Area (%)	Habitat Sensitivity Area (%)
Very High	21.4	12.8	0.4	---
High	18.2	21.7	11.6	33.1
Medium	11.4	23.6	80.6	3.4
Low	19.5	16.8	4.2	16.8
Very Low	29.5	15.6	3.2	--

Based on the data the author can carry out a sensitivity analysis to interpret how different sensitivity degrees (from "Very low" to "Very high") affect four environmental sensitivity parameters:

Erosion sensitivity area (%)

Landslide sensitivity area (%)

Water infiltration sensitivity area (%)

Habitat sensitivity area (%)

Here's a breakdown and analysis of each parameter and their relation to sensitivity degrees:

1. Erosion Sensitivity Analysis:

Sensitivity Degree	Erosion Sensitivity Area (%)
Very high	21.4

High	18.2
Medium	11.4
Low	19.5
Very low	29.5

Surprisingly, the "Very low" sensitivity degree corresponds to the highest erosion sensitivity area (29.5%), while "Medium" shows the lowest (11.4%).

This suggests a possible inverse or non-linear relationship areas categorized as "very low" in overall sensitivity still face high erosion sensitivity. This might indicate land cover issues or soil instability, even in otherwise "less sensitive" zones.

2. Landslide Sensitivity Analysis:

Sensitivity Degree	Landslide Sensitivity Area (%)
Very high	12.8
High	21.7
Medium	23.6
Low	16.8
Very low	15.6

Observation: Medium sensitivity areas are most prone to landslides (23.6%), while Very high only shows 12.8%.

Interpretation: Similar to erosion, landslide risk doesn't strictly increase with overall sensitivity degree. "Medium" areas may have steep slopes or certain geologies, making them more prone to landslides even if their overall sensitivity is moderate.

3. Water Infiltration Sensitivity Analysis:

Sensitivity Degree	Water Infiltration Sensitivity Area (%)
Very high	0.4
High	11.6
Medium	80.6
Low	4.2
Very low	3.2

Medium sensitivity areas dominate water infiltration sensitivity (80.6%), far surpassing other classes.

Possibly, these areas have permeable soils or vegetation cover that promote infiltration, or policies target them for water management. The extremely low values in "Very high" and "Very low" might indicate impermeable surfaces or compacted soils.

4. Habitat Sensitivity Analysis:

Sensitivity Degree	Habitat Sensitivity Area (%)
Very high	---
High	33.1
Medium	3.4
Low	16.8
Very low	---

High sensitivity areas contain the largest proportion of habitat sensitivity (33.1%).

These may be ecologically rich or protected zones. Missing data for "Very high" and "Very low" suggests those classes might not have been evaluated or do not include habitats in the dataset

General Insights:

- No linear correlation: None of the environmental parameters consistently increase with overall sensitivity degree.
- Water infiltration is heavily concentrated in Medium areas.
- Habitat sensitivity is only prominent in High and Low areas data is missing for extremes.
- "Very low" sensitivity areas still show high erosion potentially due to environmental degradation.

Recommendations:

- Re-evaluate classification thresholds: The overlap in sensitivity values across categories suggests that sensitivity classes might not be fully reflective of actual environmental risk.
- Prioritize field validation in areas showing unexpected results (e.g., high erosion in "very low" zones).

Target Interventions:

- Erosion control in "Very low" areas.
- Landslide prevention in "Medium" zones.
- Water infiltration management in "Medium" zones.
- Habitat conservation in "High" areas.

Discussion & Analysis:

From the data analysis section the author has draw some conclusions. Here the author found that the landscaping data of Saint Martin island has rapidly changed because the landscaping area is shrinking with agricultural land and expanding built-up areas due to tourism and population growth. The key landscaping features of this island are coral beaches, coconut groves, and kewra plants, though these are being impacted by these changes. The author found that the Coastal Zone Management Plan map layered with hazard zones, sensitive ecosystems, and human activity zones. The researcher also found that ageomorphic map showing spatial distribution and relative area of each unit using clear cartographic design.

The researcher showed that the drinking water of Saint Martin island requires treatment, especially to reduce TDS and EC. The researcher showed that the water of this island is suitable for moderate to salt-tolerant crops. The researcher found that for aquatic life the temperature of Saint Martin island may need control, depending on species. Here the researcher showed that in

terms of erosion landslide risk doesn't strictly increase with overall sensitivity degree. The medium areas of this island may have steep slopes or certain geologies. Which making these areas more prone to landslides even if their overall sensitivity is moderate.

The researcher also found that erosion control is possible in very few areas of this beach. Landslide prevention is done in medium zones of Saint Martin island. Water infiltration management is applied in "Medium" zones of this island. The author also found that Habitat conservation available in "High" areas of this island

Conclusion:

The Saint Martin island landscaping involves using salt-tolerant, drought-resistant plants like grasses and succulents, incorporating natural materials such as driftwood, pebbles, and seashells, and designing functional features like pergolas, walkways, and fire pits. In order to develop the Saint Martin beach the researcher suggests creating a low-maintenance, resilient space that mimics the natural coastal environment while providing a relaxing and attractive outdoor area.

Here the researcher found that the Sensitivity analysis of Saint Martin's Island primarily focuses on the hybrid energy system, examining how variables like solar radiation, wind speed, salinity, coastal erosion affect the landscaping development of the beach.

The other analyses of the researcher have explored the island's environmental vulnerability to climate change impacts like sea-level rise and increased salinity. Moreover the author found that, sensitivity of this beach has been assessed for land-use changes and the socio-economic impacts of tourism.

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