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Environmental Education and Sustainable Development: Assessing Its Impact on Environmental Management Practices

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Abstract: Purpose: This study examined how environmental education influences environmental management practices among households living adjacent Mbololo Forest in Taita-Taveta County, Kenya. It sought to determine whether environmental education improves awareness, encourages positive attitudes toward conservation, and promotes the adoption of sustainable forest management practices.

Approach: A quantitative cross-sectional survey was conducted among households residing adjacent Mbololo Forest. The target population consisted of 4,138 households, from whom a sample of 365 respondents were selected using Yamane's formula. Data were collected using structured questionnaires. A total of 353 completed questionnaires were returned and analyzed, resulting in a response rate of 96.7%. Descriptive statistics and regression analysis were used to examine the relationship between environmental education and environmental management practices.

Findings: The results showed that 69.4% of respondents had participated in environmental education programs, which helped increase environmental awareness and improve attitudes toward sustainability. Regression analysis indicated a positive and statistically significant relationship between environmental education and environmental management practices ($\beta = 0.52$, $p < 0.05$). Environmental education explained about 45% of the variation in sustainable practices. Households exposed to environmental education were more likely to practice proper waste management, participate in community conservation activities, and use forest resources more responsibly.

Originality/value: The study provides empirical evidence from a rural forest-adjacent community in Kenya, showing that environmental education can play an important role in promoting sustainable environmental management.

Keywords: environmental education; sustainable development; environmental management; forest-adjacent communities; pro-environmental behavior; Kenya.

JEL Classification: Q01; Q28; Q56; I25; O13.

Introduction

Environmental degradation, climate change, biodiversity loss, and the unsustainable use of natural resources have become serious global challenges that threaten ecosystems and human well-being. As populations grow, urbanization increase and economic activities expand, the demand for natural resources continues to increase. This makes effective environmental management essential for long-term sustainability. As a result, sustainable development has become a major global priority, especially after the adoption of the United Nations 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). These global commitments stress the need to balance environmental protection, economic growth, and social well-being to ensure a sustainable future (Velempini 2025).

Education plays an important role in promoting sustainability by shaping people's awareness, attitudes, and behavior toward the environment. Environmental education (EE) is therefore widely recognized as an effective way to support sustainable development and encourage responsible environmental practices. It helps people gain the knowledge, skills, values, and motivation needed to understand environmental problems and adopt sustainable lifestyles. By improving environmental understanding, environmental education enables individuals and communities to make informed decisions that support environmental conservation and responsible resource use (Chavula *et al.* 2024).

Policymakers increasingly recognize the importance of environmental education in achieving sustainability across sectors such as tourism, natural resource management, and community development. Research suggests that environmental education can influence people's attitudes and behaviors toward the environment, encouraging more responsible decision-making and sustainable management practices (Mensah 2015). Awareness campaigns and sustainability training programs have also been shown to strengthen people's commitment to protecting the environment and encourage environmentally responsible practices in tourism areas and local communities (Nasution *et al.* 2025).

Environmental management practices refer to the strategies, policies, and actions taken by organizations, institutions, and communities to reduce environmental harm and promote the sustainable use of natural resources. These practices may include waste management, energy conservation, biodiversity protection, pollution control, and sustainable land use. Effective environmental management depends not only on policies and technology but also on individuals who are aware of environmental issues and willing to apply sustainable practices in their daily lives and work. In this context, environmental education plays an important role in strengthening environmental governance and supporting sustainable management efforts (Lestari and Wahyuni 2024).

Despite increasing recognition of environmental education as an important tool for sustainability, there is still limited empirical evidence showing how it directly influences environmental management practices. Many studies focus mainly on environmental awareness or attitudes, while fewer examine whether environmental education leads to actual environmental actions. This gap is especially important in developing countries and emerging tourism destinations where environmental pressures are increasing and effective management strategies are urgently needed.

This study examined the relationship between environmental education and sustainable development by assessing its influence on environmental management practices. Specifically, the study explored how environmental education encourages the adoption of sustainable environmental management strategies and supports broader sustainability goals. By providing empirical evidence on the role of environmental education in promoting sustainable environmental practices, this study contributes to the growing body of knowledge on sustainability education and environmental governance. The findings will offer useful insights for policymakers, educators, and environmental managers seeking to strengthen environmental education programs and promote sustainable development.

Null Hypothesis

H_0: Environmental education has no statistically significant effect on environmental management practices in the context of sustainable development.

1. Literature Review and Theoretical Orientation

1.1 Environmental Education and Environmental Literacy

Environmental education has increasingly become an important way of building environmental literacy and encouraging sustainable environmental practices. Environmental literacy refers to the knowledge, attitudes, skills, and willingness that enable people to understand environmental issues and take part in environmental decision-making. Environmental education helps develop this literacy by providing people with the knowledge and practical skills needed to engage in environmentally responsible activities (Ardoin *et al.* 2020). Some studies shows that environmental education programs can improve people's understanding of ecological systems and environmental challenges. Learning about sustainability, ecological awareness, and environmental responsibility helps individuals think critically about environmental problems and identify possible solutions. According to Ardoin *et al.* (2020), environmental education not only increases environmental knowledge but also helps people develop problem-solving skills and competencies related to sustainability.

Environmental education has also been integrated into school curricula and community development programs to increase sustainability awareness. Educational institutions, government agencies, and non-governmental organizations now run environmental education programs to strengthen environmental responsibility

among students and community members. These programs often include practical learning activities such as field visits, environmental campaigns, and sustainability projects that encourage people to actively engage with environmental issues. A study by Liu *et al.* (2024) suggests that participatory and experiential learning approaches are especially effective in increasing environmental awareness and changing behavior. These learning methods allow participants to interact directly with nature, which can strengthen their emotional connection to the environment. According to Stevenson *et al.* (2012), such experiences can increase people's commitment to environmental protection and encourage long-term conservation attitudes and behaviors.

Environmental education also helps people develop sustainability competencies such as systems thinking, critical thinking, teamwork, and problem-solving skills. These abilities are important for addressing complex environmental problems that require cooperation and knowledge from different disciplines. Studies show that these competencies can improve people's ability to take part in environmental management initiatives (Odell *et al.* 2020). Therefore, environmental education plays an important role in equipping individuals with the knowledge and skills needed to support sustainable environmental management practices.

The studies reviewed in this section assumed a linear relationship between knowledge acquisition and behavioural change, reflecting a knowledge-deficit model that overlooks social, economic, and cultural barriers influencing pro-environmental behaviour (Dong *et al.* 2026). Although environmental literacy is defined, the discussion does not engage with competing perspectives that emphasize values, action competence, and civic participation, limiting theoretical rigor. The cited studies are presented with little attention to their methodological limitations or contextual variability. For instance, participatory and experiential learning approaches are portrayed as universally effective, despite their dependence on resources and local contexts (Bartels 2023). The success of environmental education programs is generalised without addressing inequalities in access, particularly in resource-constrained settings. The practical challenges such as inadequate teacher training, curriculum constraints, and weak policy implementation have also not been addressed (Buabeng and Amo-Darko 2025).

1.2 Environmental Education and Pro-Environmental Behavior

The relationship between environmental education and pro-environmental behavior has attracted significant attention from researchers. Pro-environmental behavior refers to actions that people take to reduce environmental harm or support environmental sustainability. These actions may include recycling, saving energy, reducing waste, protecting biodiversity, and supporting environmental policies. Environmental education has been found to positively influence pro-environmental attitudes and behavior. Knowledge gained through environmental education increases awareness of environmental problems and encourages individuals to adopt environmentally responsible practices. Otto and Pensini (2017) note that environmental education can strengthen people's emotional connection to nature, which often encourages responsible environmental behavior.

However, Amoah and Addoah (2021) point out that environmental knowledge alone does not always lead to behavioral change. Other factors such as environmental attitudes, social expectations, and personal motivation also influence people's actions. Environmental education plays an important role in shaping these factors by encouraging environmental values and a sense of responsibility for environmental protection. Studies conducted in higher education institutions show that sustainability-focused programs can influence students' environmental attitudes and behavior. Students who take part in environmental education programs often show stronger commitment to environmental protection and are more likely to participate in sustainability activities in their communities (Cebrián *et al.* 2020).

Environmental education programs can also influence collective environmental behavior by encouraging community participation and environmental responsibility (Gupta *et al.* 2024). Community-based environmental education initiatives often involve activities such as tree planting, waste management, and ecosystem restoration. In the tourism sector, environmental education has also been shown to influence responsible behavior among tourists and tourism stakeholders (Yu *et al.* 2024). Tourism activities can put pressure on natural ecosystems, making environmental awareness essential for promoting sustainable tourism practices. Educational programs targeting tourists and tourism operators can therefore increase awareness about conservation and encourage responsible tourism behavior (Mensah 2015). Overall, research shows that environmental education helps people develop behaviors that support environmental protection and sustainable environmental management.

The authors note that the studies analyzed tends to generalize the effectiveness of environmental education programs without critically addressing methodological limitations, contextual variability, or long-term impacts. For example, the cited studies focus primarily on short-term behavioral outcomes, neglecting the sustainability of these behaviors over time (Wang et al. 2024). The studies also assume a largely positive influence of environmental education while insufficiently considering structural barriers such as socio-economic constraints, cultural

differences, and institutional support, which can limit the translation of knowledge into action (Harahap and Uthman 2024).

1.3 Environmental Management Practices

Environmental management practices refer to the actions taken by organizations, institutions, and communities to reduce environmental impacts and promote sustainable use of natural resources (Awewomom *et al.* 2024). These practices may include waste reduction, pollution control, energy conservation, biodiversity protection, and sustainable land management. Many organizations are now adopting environmental management systems to improve environmental performance and comply with environmental regulations. Such systems provide structured approaches for identifying environmental risks, implementing solutions, and monitoring environmental performance (Ronalter *et al.* 2023).

Environmental management practices are influenced by several factors including organizational culture, environmental policies, technological capacity, and environmental awareness (Khalid *et al.* 2024). Among these factors, environmental awareness and education play an important role in shaping environmental management behavior. Educational institutions, for example, have introduced green campus initiatives that incorporate environmental management practices into daily operations. These initiatives often involve sustainability policies, waste management programs, environmental monitoring systems, and energy conservation efforts. Research suggests that environmental education programs in educational institutions help support the implementation of these environmental management initiatives (Lozano *et al.* 2021).

Environmental management practices are also widely applied in tourism management to promote sustainable tourism development. Many tourism destinations depend on natural ecosystems, making environmental conservation essential for maintaining tourism sustainability. As a result, tourism organizations are adopting environmental management practices aimed at reducing environmental damage and protecting natural resources (Baloch *et al.* 2023). Studies show that environmental awareness and environmental education programs can improve the adoption of environmental management practices among tourism stakeholders. Tourism operators who understand environmental issues are more likely to implement sustainable practices such as waste reduction, energy efficiency, and ecosystem protection (Wang *et al.* 2024).

Community participation also plays a key role in the success of environmental management initiatives. Environmental education programs that involve communities in conservation activities can strengthen local environmental governance and encourage sustainable resource management. Overall, existing studies show that environmental education supports environmental management practices by increasing environmental awareness, encouraging positive environmental attitudes, and promoting responsible environmental behavior.

While environmental education is presented as a key driver of environmental management, the studies have not sufficiently addressed structural or institutional barriers such as limited resources, organizational inertia, or inconsistent policy enforcement that may hinder implementation as observed by Yuan (2026).

1.4 Theoretical Orientation

Understanding how environmental education influences environmental management practices requires a theoretical framework that explains how knowledge, values, and attitudes affect human behavior. This study is guided by three related theoretical perspectives namely the Theory of Planned Behavior, the Value–Belief–Norm Theory, and Sustainable Development Theory.

1.4.1 Theory of Planned Behavior

The Theory of Planned Behavior (TPB), developed by Icek Ajzen, is widely used to explain how people form intentions and behaviors. The theory states that behavior is influenced by three main factors. The factors are attitudes toward the behavior, subjective norms, and perceived behavioral control (Rapi and Kassim 2023). Attitudes refer to how individuals evaluate a behavior, while subjective norms refer to social pressure or expectations from others. Perceived behavioral control refers to a person's belief about whether they are capable of performing a certain behavior.

Environmental education can influence all three components of the theory (Fauzi *et al.* 2024). Education increases environmental knowledge, which can lead to positive attitudes toward environmental protection. It also helps create social expectations that encourage environmentally responsible behavior. In addition, environmental education provides practical skills that increase people's confidence in their ability to practice sustainable behaviors.Several studies have used the Theory of Planned Behavior to explain environmental behavior in sustainability contexts. Research shows that environmental attitudes, social expectations, and perceived behavioral

control significantly influence people's willingness to adopt environmentally responsible behaviors (Zulkepeli *et al.* 2024). This theory provides a useful framework for understanding how environmental education can influence environmental management practices.

1.4.2 Value–Belief–Norm Theory

The Value–Belief–Norm (VBN) Theory provides another useful perspective for understanding environmentally responsible behavior. According to this theory, people's environmental values influence their beliefs about environmental problems, which then shape their personal norms and behavior (Batool *et al.* 2024). Environmental education can strengthen environmental values and beliefs by increasing awareness about environmental challenges and promoting environmental responsibility. When people develop strong environmental values, they are more likely to feel morally responsible for protecting the environment. Studies using the VBN framework show that environmental awareness and personal responsibility strongly influence sustainable behavior, especially in areas such as environmental conservation and sustainable tourism (Negm 2024). The VBN theory therefore complements the Theory of Planned Behavior by focusing on the moral and ethical aspects of environmental behavior.

1.4.3 Sustainable Development Theory

Sustainable Development Theory provides a broader framework for understanding the role of environmental education in sustainability. The theory emphasizes the need to balance economic growth, social well-being, and environmental protection in order to achieve long-term sustainability (Islam and Wang 2023). Education is widely recognized as an important driver of sustainable development because it equips people with the knowledge and skills needed to address sustainability challenges. Environmental education specifically supports sustainable development by promoting environmental awareness, sustainability competencies, and responsible environmental behavior (Odell *et al.* 2020). Within this framework, environmental education can be seen as an important tool for strengthening environmental governance and supporting sustainable environmental management practices.

1.5 Synopsis of Literature

The literature reviewed shows that environmental education plays an important role in shaping environmental knowledge, attitudes, values, and behavior. It helps build environmental literacy, encourages pro-environmental behavior, and supports the adoption of sustainable environmental management practices. Theoretical perspectives such as the Theory of Planned Behavior, the Value–Belief–Norm Theory, and Sustainable Development Theory help explain how environmental education influences environmental behavior and sustainability outcomes. Although research on environmental education and sustainability has grown significantly, there is still a need for more empirical studies examining how environmental education influences environmental management practices in different social and institutional contexts. This study therefore contributes to existing knowledge by examining the relationship between environmental education and environmental management practices within the broader context of sustainable development.

1.6 Contribution in Relation to Existing Literature

The existing literature demonstrates that environmental education enhances environmental literacy, encourages pro-environmental behavior, and supports sustainable environmental manageHowever, this research assumed a linear knowledge-to-action pathways and tends to overlook structural, socio-economic, and contextual factors that mediate outcomes. Previous studies have largely focused on short-term behavioral changes, with limited attention to long-term sustainability, resource constraints, organizational inertia, and inequities in access to environmental education programs. While theoretical frameworks such as the Theory of Planned Behavior, Value–Belief–Norm Theory, and Sustainable Development Theory explain mechanisms linking education to behavior, empirical applications across diverse institutional and community contexts have not received adequate attention.

This study contributes to the literature by addressing these gaps through an empirical examination of how environmental education influences environmental management practices within multiple social and institutional settings. By integrating theoretical insights with real-world applications, it explores not only knowledge acquisition and attitude formation but also the structural, cultural, and resource-based factors that affect the adoption of sustainable management practices. The study helps explain how education influences people's intentions and actual environmental actions, and it provides practical, research-based suggestions for improving policies and programs.

2. Research Methodology

2.1 Research Design

This study adopted a quantitative research approach using a cross-sectional survey design to examine the relationship between environmental education and environmental management practices in the context of sustainable development. A cross-sectional design was considered appropriate because it allows the collection of data from respondents at a single point in time while examining relationships between variables within a defined population. Quantitative research methods are widely used in environmental management studies because they enable researchers to analyze patterns, relationships, and causal associations among variables using statistical techniques.

The study focused on assessing how environmental education influences environmental management practices among households living adjacent to forest ecosystems. Forest-adjacent communities often play a significant role in environmental conservation and sustainable resource management, making them an important population for investigating environmental education and sustainability outcomes.

2.2 Study Area

The study was conducted in Mbololo Forest, which is located in Taita Hills within Taita-Taveta County in Kenya. Mbololo Forest forms part of the Eastern Arc Mountains, a biodiversity hotspot known for its unique flora and fauna and high levels of endemism. The forest plays a crucial role in supporting ecological stability, water catchment functions, and biodiversity conservation in the region.

Communities residing around Mbololo Forest depend heavily on forest resources for their livelihoods, including fuelwood, medicinal plants, grazing, and small-scale agriculture. As a result, human activities around the forest have important implications for environmental sustainability and forest conservation. Environmental education initiatives implemented by government agencies, conservation organizations, and community groups in the region aim to promote sustainable resource use and encourage environmentally responsible behavior among local communities. The selection of Mbololo Forest as the study area was therefore appropriate because it provides an ideal context for examining the relationship between environmental education and environmental management practices among forest-adjacent households.

2.3 Target Population

The target population for this study consisted of households living adjacent to Mbololo Forest. According to local administrative records, the total population of households residing near the forest is approximately 4,138 households (County Government of Taita Taveta 2023).These households represent communities that interact frequently with forest resources and therefore play a critical role in forest conservation and environmental management. Household heads or adult representatives were selected as respondents because they are typically responsible for household decision-making related to resource use, environmental practices, and participation in environmental education programs.

2.4 Sample Size Determination

The sample size for this study was determined using the Yamane (1967) formula for sample size calculation. The Yamane formula is widely used in social science research to determine an appropriate sample size when the population size is known. The formula is expressed as follows:

$$n = N/\{1 + N(e\text{^}2)\}$$

Where:
n = sample size
N = population size
e = margin of error

In this study, the population size (N) was 4,138 households, and the margin of error (e) was set at 0.05, corresponding to a 95% confidence level. Using the formulae, the study determined a sample size of 365 respondents, which was considered adequate to represent the target population and allow reliable statistical analysis.

2.5 Sampling Procedure

A multistage sampling technique was used to select the respondents for this study. First, villages located adjacent Mbololo Forest were identified using administrative records. Secondly, households in these villages were selected using systematic random sampling so that each household had an equal chance of being included in the study. From each selected household, the household head or another adult member was invited to take part in the survey. This approach helped ensure that the respondents had adequate knowledge about household environmental practices and their participation in environmental education activities.

Data were collected over a three-month period, from June to August 2025. Respondents were recruited using a combination of face-to-face household visits and digital platforms. Specifically, in-person recruitment was conducted by trained research assistants within the selected villages. Supplementary recruitment and follow-up communication were facilitated through mobile phone calls and messaging platforms such as WhatsApp. This mixed approach enhanced response rates and ensured broader participation, particularly in cases where initial contact required scheduling flexibility.

2.6 Data Collection Methods

Primary data for the study were collected using a structured questionnaire that was administered to the selected respondents. The questionnaire contained both closed-ended questions and Likert-scale questions to gather information about environmental education and environmental management practices.The questionnaire was divided into several sections. The first section collected demographic information about respondents, such as age, gender, education level, and occupation. The second section focused on respondents' exposure to environmental education programs and their level of environmental knowledge and awareness. The third section examined environmental management practices adopted by households, including waste management, conservation practices, and sustainable use of natural resources. Using a structured questionnaire made it possible to collect consistent data that could easily be analyzed using statistical methods. Before the main data collection began, the questionnaire was pretested with a small group of respondents to ensure that the questions were clear and reliable.

2.7 Measurement of Variables

The main independent variable in this study was environmental education. It was measured using indicators such as environmental knowledge, participation in environmental education programs, and environmental awareness. Environmental knowledge was measured using the following items: "I understand the causes of environmental degradation," *and* "I am aware of the importance of conserving forest resources.*"* Environmental awareness included the following items: *"*Environmental problems in my area affect my daily life," and "Protecting the environment is a personal responsibility.*"* Participation in environmental education was measured using the following items: *"*I have attended environmental education training," and "I actively engage in community environmental awareness activities

The dependent variable was environmental management practices. This was measured using indicators such as waste management practices, participation in conservation activities, sustainable use of forest resources, and adoption of environmentally friendly behaviors. The items used were: "I practice proper waste disposal and recycling," "I participate in tree planting or conservation activities," "I use forest resources responsibly," and "I adopt practices that reduce environmental harm."

The Likert-scale measurement helped the researcher quantify respondents' perceptions and behaviors related to environmental education and environmental management. All items were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), enabling quantification of attitudes and behaviors.

2.8 Data Analysis

The collected data were analyzed using statistical techniques suitable for quantitative research. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize respondents' demographic characteristics and the main study variables. Inferential statistical analysis was also conducted to examine the relationship between environmental education and environmental management practices. Regression analysis was used to determine whether environmental education significantly influences environmental management practices among households living near Mbololo Forest. The analysis was conducted using appropriate statistical software to ensure accuracy and reliability of the results. The significance level for hypothesis testing was set at 0.05, meaning that relationships between variables were considered statistically significant when the p-value was equal to or less than 0.05.

2.9 Ethical Considerations

Ethical considerations were observed throughout the research process. Participation in the study was voluntary, and respondents were informed about the purpose of the research before completing the questionnaire. The confidentiality and anonymity of respondents were protected by ensuring that no personal identifying information was included in the data analysis or reporting of results. Respondents were also informed that the information they provided would be used only for the purposes of the study. These measures helped ensure that the research followed accepted ethical standards in social science research.

3. Research Results

A total of 365 questionnaires were distributed to households living near Mbololo Forest in Taita-Taveta County, Kenya. Out of these, 353 questionnaires were properly completed and returned, giving a response rate of 96.7%. Twelve questionnaires were either not returned or were incomplete, so they were excluded from the analysis. The high response rate was considered adequate to provide reliable data for statistical analysis and proper representation of the target population.

3.1 Demographic Characteristics of Respondents

The demographic characteristics of the respondents were analyzed to better understand the households living near Mbololo Forest. The results showed that 56.4% (n = 199) of the respondents were male, while 43.6% (n = 154) were female. This indicates that male household heads were slightly more represented in the survey, which may reflect the role they often play in household decision-making related to environmental matters in the community. Regarding age distribution, 33.7% (n = 119) of respondents were between 31 and 40 years, 27.5% (n = 97) were between 41 and 50 years, 22.1% (n = 78) were between 21 and 30 years, and 16.7% (n = 59) were above 50 years. These findings show that most respondents were within the economically active age groups, which are commonly involved in natural resource use and environmental management activities. The level of education among respondents varied. The results indicated that 34.8% (n = 123) had completed secondary education, 30.6% (n = 108) had primary education, 21.8% (n = 77) had tertiary education, and 12.8% (n = 45) had no formal education. This suggests that most respondents had at least basic education, which may help them understand environmental education programs and adopt sustainable environmental practices.

3.2 Environmental Education Awareness

Respondents were asked whether they had participated in environmental education programs related to forest conservation and sustainable environmental practices. The results showed that 69.4% (n = 245) had participated in environmental education programs, while 30.6% (n = 108) had not participated. Further analysis indicated that environmental education had a positive influence on respondents' awareness and understanding of environmental conservation. About 74% of respondents agreed that environmental education programs improved their knowledge of forest conservation, while 70% said that these programs influenced their attitudes toward protecting the environment. These results suggest that environmental education initiatives in communities surrounding Mbololo Forest have helped increase environmental awareness and understanding of sustainable environmental practices.

3.3 Environmental Management Practices

The study also examined the environmental management practices adopted by households living near Mbololo Forest. Respondents were asked about their involvement in different environmental conservation and sustainability activities. The results showed that 66% of respondents practiced proper waste management, including safe disposal and separation of household waste. In addition, 60% reported participating in community conservation activities such as tree planting and forest protection programs. About 63% of respondents indicated that they used forest resources sustainably, for example by collecting firewood in a regulated manner and following community forest management guidelines. A total of 57% reported practicing environmentally friendly behaviors such as protecting water sources and reducing the use of forest products. These findings demonstrate that many households living near Mbololo Forest have adopted practices that support sustainable forest conservation.

3.4 Relationship Between Environmental Education and Environmental Management Practices

Regression analysis was conducted to examine the relationship between environmental education and environmental management practices. The results showed a positive and statistically significant relationship between the two variables ($\beta = 0.52$, $p < 0.05$). This means that respondents who had greater exposure to environmental education programs were more likely to adopt environmentally responsible practices such as proper

waste management, conservation activities, and sustainable use of natural resources. The regression model also showed that environmental education explained about 45% of the variation in environmental management practices ($R^2 = 0.45$) among households living near Mbololo Forest.

3.5 Hypothesis Testing

The study tested the null hypothesis that environmental education has no statistically significant effect on environmental management practices. The regression results showed that environmental education had a statistically significant positive effect on environmental management practices ($p < 0.05$). Based on this result, the null hypothesis was rejected and the alternative hypothesis was accepted. This means that environmental education significantly influences environmental management practices among households living near Mbololo Forest.

3.6 Synopsis of Findings

These findings show that environmental education plays an important role in promoting sustainable environmental management practices among communities living near Mbololo Forest. Environmental education programs helped increase environmental awareness, improve attitudes toward conservation, and encourage the adoption of environmentally responsible practices. These results highlight the importance of environmental education as a key strategy for strengthening community participation in environmental conservation and promoting sustainable development in communities located near forest areas.

4. Discussions

This study examined how environmental education influences environmental management practices among households living near Mbololo Forest in Taita-Taveta County, Kenya. The results showed that environmental education has a strong positive influence on environmental management practices such as proper waste management, participation in conservation activities, and the sustainable use of forest resources. This section explains these findings by relating them to previous studies, relevant theories, and their implications for practice, policy, and future research.

4.1 Environmental Education and Community Awareness

One important finding of this study was that most respondents (about 69.4%) had participated in environmental education programs. These respondents also showed higher levels of environmental awareness and more positive attitudes toward sustainability. This finding agrees with earlier studies which show that environmental education helps people understand environmental issues and develop environmental literacy. Environmental literacy includes knowledge about the environment, awareness of environmental problems, and the skills and values needed to support sustainable behavior (Ardoin *et al.*, 2020). When people understand the consequences of unsustainable practices, they are more likely to make better decisions about how natural resources are used. This finding is particularly important in areas like Mbololo Forest where local communities rely heavily on natural resources for their livelihoods. In Kenya, studies on environmental education in major forest ecosystems such as Cherangany, Mt. Kenya, Aberdares, and Kakamega show that environmental awareness and sustainable forest management are strengthened by education, community participation, and supportive government policies (Chisika & Yeom, 2024). These findings support the results of the present study, which show that environmental education can strongly influence environmental awareness and attitudes within communities.

Research in Kenya has also shown that environmental education programs in schools can influence students' attitudes and behaviors toward conservation (Saro *et al.*, 2025). These studies suggest that environmental values can be developed at an early stage and later influence people's actions toward the environment. In communities like those around Mbololo Forest, where adults have different levels of education, expanding environmental education initiatives could further strengthen long-term conservation outcomes.

4.2 Environmental Education and Pro-Environmental Behaviour

The positive relationship between environmental education and environmental management practices found in this study is consistent with earlier research showing that education encourages behavior change in different social and environmental settings. Studies have shown that environmental education helps develop pro-environmental attitudes and behaviors by increasing environmental awareness and helping people internalize ecological values (Simiyu *et al.*, 2022; Estrada *et al.*, 2023).

For example, Simiyu *et al.* (2022) found that environmental knowledge, together with social influences such as community norms and peer pressure, plays an important role in shaping pro-environmental behavior among university students in Kenya. The present study extend this understanding beyond students to households. This suggests that the influence of environmental education is not limited to schools or universities but can also affect behavior within communities where knowledge interacts with social norms and everyday experiences. Similarly, studies among young people in Kenya have found a positive relationship between environmental education programs and behaviors such as waste sorting, tree planting, and water conservation (Malwa, 2024). These findings are similar to those of the present study, where households that were more aware of environmental issues through education were more likely to adopt sustainable practices.

One explanation for this pattern is that environmental education strengthens both the knowledge and emotional aspects of behavior. Education increases environmental knowledge, encourages positive attitudes toward the environment, and builds people's confidence in their ability to take action. This idea is supported by the Theory of Planned Behavior, which suggests that behavior is influenced by attitudes, social expectations, and people's belief in their ability to perform certain actions (Ajzen, 1991). When environmental education strengthens these factors, individuals are more likely to adopt sustainable behaviors.

4.3 Environmental Education and Environmental Management Practices

Another important contribution of this study is the evidence that environmental education significantly predicts environmental management practices among households living near forests. The regression analysis showed that environmental education explained about 45% of the differences in environmental management practices ($R^2 \approx 0.45$). This means that environmental education plays an important role in encouraging sustainable environmental practices.

This finding agrees with earlier studies showing that environmental education supports responsible behaviors such as proper waste management, participation in conservation programs, and sustainable use of natural resources (Mensah, 2015; Wang *et al.*, 2024). For example, Mensah (2015) found that environmental education significantly influenced responsible tourist behavior in tourism areas. Although that study focused on tourism rather than rural communities, the basic idea is similar: when people become more aware of environmental issues, they are more likely to act responsibly.

In forest-adjacent communities, sustainable practices often depend on how relevant environmental issues are to people's daily lives and whether they feel responsible for protecting the environment. Studies on environmental literacy show that awareness of environmental problems, understanding the effects of human actions, and believing that individual actions matter can strongly influence sustainable behaviors (Ardoin *et al.*, 2023). In the case of Mbololo Forest, households that received environmental education may feel more responsible for protecting the forest and therefore participate in activities such as waste recycling, controlled harvesting of forest products, and conservation initiatives.

4.4 Community-Level and Cultural Dimensions

This study highlights the importance of community and cultural factors in environmental learning and action. In Kenya, research has shown that cultural practices and indigenous knowledge systems often play an important role in environmental conservation. For instance, among the Ogiek community living near the Mau Forest, cultural beliefs and sacred traditions contribute to the protection of forests, water sources, and sacred areas (Kiage, 2019). These traditional forms of environmental knowledge show that conservation can also be influenced by cultural education and local values. Although the present study mainly focused on formal environmental education programs, indigenous knowledge and cultural traditions may also influence environmental behavior within communities. Combining formal environmental education with local cultural practices could strengthen conservation efforts. This approach may be particularly useful in areas like Mbololo, where cultural beliefs and community traditions still influence how natural resources are used and managed.

4.5 Theoretical Implications

4.5.1 Theory of Planned Behavior

This study supports the Theory of Planned Behavior, which states that human behavior is influenced by attitudes, social expectations (subjective norms), and perceived behavioral control (Ajzen, 1991). Environmental education appears to strengthen these factors by improving attitudes toward environmental protection, encouraging supportive social norms, and increasing people's confidence in their ability to carry out sustainable practices.

For example, respondents who had participated in environmental education programs were more likely to believe that they could adopt sustainable environmental practices and that environmental protection was important within their community. These findings support the idea that behavioral change occurs when both psychological and social influences are strengthened. Other studies have also shown that environmental knowledge and attitudes are strong predictors of sustainable behavior (Simiyu *et al.*, 2022).

4.5.2 Value – Belief - Norm Theory

The results of this study are also consistent with the Value-Belief-Norm Theory. This theory explains that people's environmental values and beliefs influence their personal norms and behaviors. When individuals believe that environmental problems are serious and that their actions can help address them, they are more likely to act in environmentally responsible ways.

Environmental education may help develop these values by showing the importance of protecting natural systems and the possible consequences of environmental degradation. In communities around Mbololo Forest, households that receive environmental education may develop stronger conservation values, which then motivate them to participate in forest protection activities, proper waste management, and sustainable use of forest resources.

4.5.3 Sustainable Development Framework

The results of this study also support the sustainable development framework, which emphasizes balancing environmental protection, social wellbeing, and economic development for long-term sustainability. Environmental education plays an important role in this process because it encourages responsible environmental behavior and promotes community participation in natural resource management.

In Kenya, different studies have shown that sustainable forest management improves when environmental education is combined with community engagement and collaboration among stakeholders such as government institutions, local communities, and conservation organizations (Chisika & Yeom, 2024). This shows that environmental education can support broader environmental governance systems that encourage inclusive decision-making and responsible resource management.

4.6 Practical and Policy Implications

The findings of this study have several important implications for environmental policy and practice.

1.Scaling Environmental Education Programs**:** Since in this study the environmental education was strongly linked to sustainable practices, policymakers should expand environmental education programs in communities located near forests. Such programs should include formal education, community training, and practical learning activities.

2.Integrating Indigenous Knowledge: Environmental education programs should also incorporate indigenous ecological knowledge. Traditional cultural practices and local knowledge systems can complement formal education and strengthen conservation efforts resulting in sustainability.

3.Institutional Support and Partnerships: Successful environmental education programs require support from institutions. Collaboration between government agencies, schools, non-governmental organizations, and community leaders can strengthen the implementation of environmental education initiatives.

4.Behavior-Focused Educational Design: Environmental education should go beyond raising awareness and should focus on encouraging actual behavior change. This can be achieved through practical activities such as community conservation projects, demonstration sites, and participatory environmental programs.

4.7 Managerial Implications

The managerial implications of this study are;

1.Program Planning and Resource Allocation: Managers in educational institutions, NGOs, and environmental agencies should prioritize the expansion of environmental education programs by allocating adequate financial, human, and technical resources.

2.Program Design and Implementation: Managers should design environmental education programs that are action-oriented and context-specific, incorporating experiential learning and community engagement to enhance effectiveness.

3.Stakeholder Coordination: Effective management of environmental initiatives requires active coordination and partnership-building among key stakeholders, including government bodies, community groups, and development organizations.

4.Monitoring and Evaluation Systems: Managers should establish robust monitoring and evaluation frameworks to assess program outcomes, track behavioral changes, and inform continuous improvement of environmental education strategies.

4.8 Limitations and Directions for Future Research

Although this study provides useful insights, several limitations should be acknowledged. First, the cross-sectional design limits the ability to establish causal relationships, as data were collected at a single point in time. Future studies could adopt longitudinal approaches to better examine changes in environmental behavior over time. Secondly, the study relied on self-reported data to measure environmental management practices and participation in environmental education. Such data may be affected by social desirability bias and recall errors, where respondents may overstate environmentally responsible behaviors. Future research could incorporate objective measures such as direct observation or environmental audits to enhance validity. Thirdly, the sample was limited to households located near Mbololo Forest and mainly involved adult respondents, which may restrict the generalizability of the findings to other populations and contexts. Future studies should consider larger and more diverse samples across different regions and socio-economic groups. Finally, adopting mixed-methods approaches and conducting comparative studies across different ecosystems would provide deeper and more context-sensitive insights into the role of environmental education in shaping environmental management practices.

Conclusions and Further Research

This study examined how environmental education influences environmental management practices among households living near Mbololo Forest in Taita-Taveta County, Kenya. The results showed that environmental education plays an important role in promoting sustainable environmental management at the community level. Households that had participated in environmental education programs showed higher levels of environmental awareness, more positive attitudes toward conservation, and greater involvement in activities such as proper waste management, participation in community conservation programs, and sustainable use of forest resources.

The results of this study also confirmed a strong positive relationship between environmental education and environmental management practices. These results support both the Theory of Planned Behavior and the Value-Belief-Norm Theory. Environmental education helped strengthen people's attitudes toward environmental protection, increased social support for conservation actions, and improved individuals' confidence in their ability to practice sustainable behaviors. In addition, environmental education helped shape values and beliefs that encourage people to act in environmentally responsible ways. This shows that these behavioral theories are also useful for understanding environmental actions in rural communities located near forests.

From a practical point of view, the study shows that environmental education can be an effective and affordable way to improve sustainable forest management. Educational programs that increase knowledge, raise awareness, and encourage community participation can influence household behavior and promote better management of natural resources. The outcome suggest that policymakers, conservation organizations, and local communities should focus on expanding environmental education programs and linking them with community activities such as tree planting, forest monitoring, and community training workshops.

The study also highlights the importance of designing environmental education programs that consider local contexts and cultural practices. Including local knowledge, traditions, and cultural values in environmental education can make these programs more meaningful and acceptable to communities. In the case of Mbololo Forest, combining formal environmental education with traditional conservation practices could make conservation efforts more effective and encourage responsible use of forest resources.

The study further contributes to broader efforts toward sustainable development by showing that environmental education can help balance environmental protection, social well-being, and economic needs at the community level. When households gain knowledge, skills, and motivation through education, they are better able to support conservation efforts, maintain sustainable livelihoods, and protect natural ecosystems in the long term.

This study has demonstrated that environmental education does more than simply provide information. It can change attitudes, influence behavior, and improve how communities manage natural resources. Continued investment in environmental education, combined with strong community involvement and supportive policies, will be important for promoting sustainable forest management and environmental protection in communities living near forests in Kenya and similar regions around the world.

Declarations

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Credit Authorship Contribution Statement:

Humphrey M. Mwambeo: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft preparation, Visualization.
Lydiah N. Wambugu: Supervision, Methodology, Validation, Writing – review and editing.
Raphael O. Nyonje: Supervision, Methodology, Validation, Writing – review and editing.
James T. Kariuki: Conceptualization, Supervision, Project administration, Writing – review and editing.

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Rice Cultivation Systems in Latin America: Diversity and Climate Vulnerability

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Abstract: Rice cultivation systems in Latin America exhibit substantial heterogeneity driven by geographic, climatic, technological, and institutional factors. These differences shape productivity outcomes, exposure to climate risks, greenhouse gas emissions, and producers' adaptive capacity. This article provides a system-oriented analysis of the main rice production systems in the region, distinguishing among irrigated, partially irrigated, and rainfed systems, as well as mechanized, semi-mechanized, and traditional (no mechanized) production models. It examines how water management, mechanization, cropping intensity, and socioeconomic conditions interact to influence climate vulnerability and the feasibility of adaptation and mitigation strategies. The analysis highlights the importance of differentiated system-sensitive climate-smart agriculture pathways aligned with local production contexts and producer realities across Latin America.

Keywords: rice cultivation systems; Latin America; climate vulnerability; irrigated rice; rainfed agriculture; climate-smart agriculture; food security; agricultural sustainability; water management; methane emissions.

JEL Classification: Q13; Q15; Q16; Q18; Q54.

Introduction

Rice is a staple crop and a strategic component of food security and rural livelihoods in Latin America. Rice production in the region unfolds across a wide spectrum of agroecological environments, water availability conditions, farm sizes, and technological intensities. From highly mechanized irrigated lowland systems to rainfed and traditional subsistence-oriented practices, this diversity profoundly influences productivity, resilience to climate variability, and environmental performance.

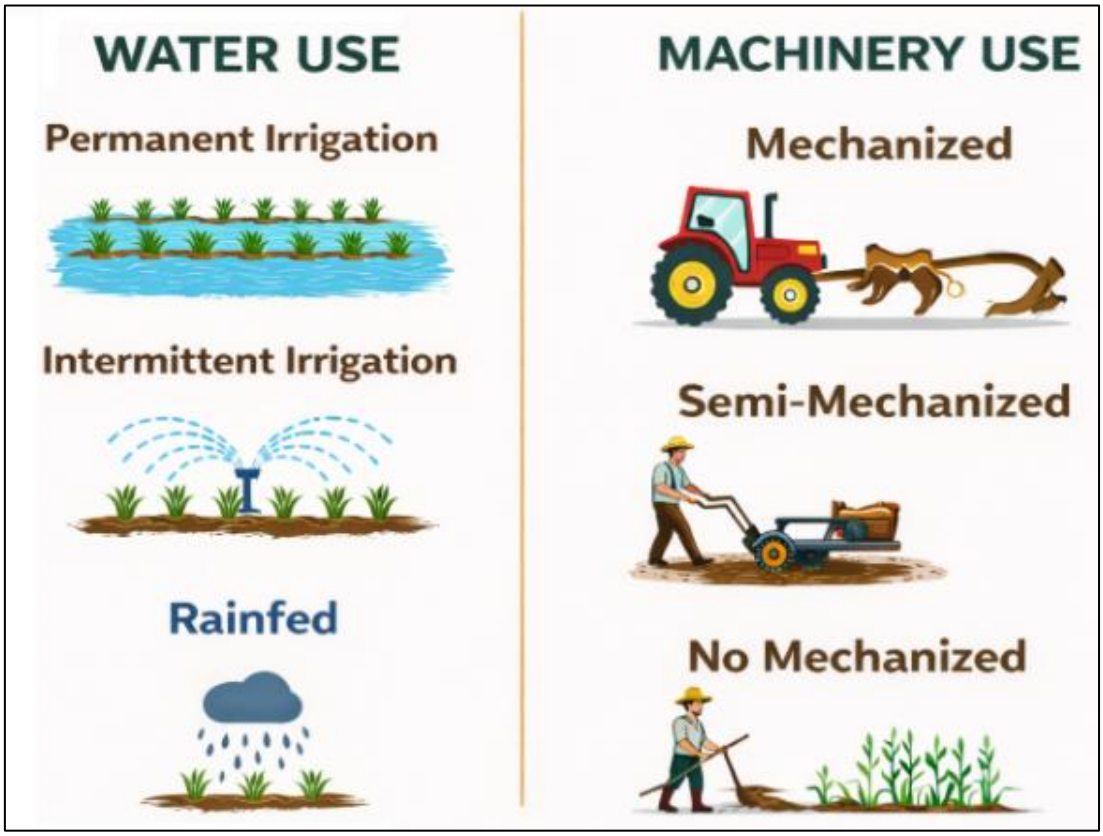
This article synthesizes the main rice cultivation systems in Latin America and analyzes their differentiated vulnerabilities and opportunities for climate-smart transformation.

The article is structured as follows. The first section examines the main rice cultivation systems. The second section analyzes the socioeconomic profiles of rice producers. The third section explores system-specific vulnerabilities to climate variability. The last section presents the conclusions.

1. Main Rice Cultivation Systems

Agricultural production can be understood through two key dimensions: water use and machinery use (Figure 1). Systems may be irrigated, partially irrigated, or rainfed, while production models range from mechanized to semi-mechanized and traditional (no mechanized).

Figure 1. Rice Cropping Systems



Irrigated Lowland Rice Systems

Irrigated lowland rice systems based on permanent or near-permanent flooding dominate commercial rice production in Latin America and account for the majority of total regional output (Chirinda *et al.* 2018). These systems depend on controlled water delivery from rivers, reservoirs, and canal networks, typically maintaining flooded or near-flooded soil conditions throughout much of the cropping cycle.

A defining characteristic of irrigated lowland systems is their high and relatively stable yield potential, attributable to reliable water supply and the capacity to regulate critical stages of crop development (Bouman *et al.* 2007). However, this performance is highly contingent upon the availability, effective operation, and maintenance of irrigation infrastructure, as well as robust basin-level water governance mechanisms that ensure equitable and predictable water allocation (Bouman *et al.* 2007).

Compared with rainfed systems, irrigated lowland rice production typically involves higher levels of external inputs, including fertilizers, improved seed varieties, mechanization, and energy for water conveyance and pumping. While these inputs contribute to higher productivity and yield stability, they also increase production costs and intensify farmers' dependence on well-functioning input, credit, and service markets, thereby exposing producers to additional economic and institutional risks (FAO, 2015).

Prolonged flooded conditions create anaerobic soil environments that favor methanogenesis, making irrigated lowland rice a significant source of agricultural methane (CH_4) emissions (Yan *et al.* 2009). Importantly, the presence of irrigation infrastructure also provides a critical foundation for mitigation and adaptation innovations. Improved water management practices, most notably Alternate Wetting and Drying (AWD), have demonstrated substantial potential to reduce methane emissions, enhance water-use efficiency, and strengthen system resilience under increasing water scarcity and climate variability (Sander *et al.* 2015).

Rainfed Rice Systems

Rainfed rice systems rely entirely on natural precipitation, rendering them inherently vulnerable to climate variability, seasonal fluctuations, and extreme events such as droughts and floods (Pandey *et al.* 2010). These systems are typically found in regions with limited or nonexistent irrigation infrastructure and are commonly associated with smallholder producers.

Compared with irrigated systems, rainfed rice systems are characterized by lower and more variable yields, reflecting their strong dependence on the amount, timing, and spatial distribution of rainfall. Variability in the onset and cessation of the rainy season, as well as irregular intra-seasonal precipitation patterns, translates into substantial production risks from one season to the next (Pandey *et al.* 2010).

Capital investment and the use of external inputs such as fertilizers and agrochemicals tend to be lower in rainfed systems, reducing production costs but also constraining yield potential and limiting opportunities for intensification. The absence of controlled water infrastructure severely restricts farmers' ability to manage water stress and respond proactively to increasing climate variability. In this context, strengthening the resilience of water-related investments to climate shocks and extreme events becomes a critical component of effective adaptation planning (FAO, 2013).

Adaptation strategies in rainfed rice systems therefore tend to prioritize risk reduction and livelihood resilience rather than yield maximization. Key measures include the adoption of drought- and flood-tolerant and early-maturing rice varieties, improved soil and nutrient management, crop diversification, and income diversification (FAO, 2013; Zorrilla *et al.* 2013).

Partially Irrigated and Supplemental Irrigation Systems

Between fully irrigated and purely rainfed systems lies a continuum of partially irrigated rice production systems that combine seasonal rainfall with supplemental irrigation. These systems can buffer short-term rainfall deficits, reduce exposure to intra-seasonal dry spells, and lower production risk compared with fully rainfed systems, while requiring lower capital investment and less complex infrastructure than permanent irrigation schemes (Bouman & Tuong, 2001).

The performance of partially irrigated systems depends critically on the timing, reliability, and effective management of supplemental water supply, as well as farmers' capacity to adjust agronomic practices - such as planting dates, variety selection, and nutrient management - in response to evolving climatic conditions (Bouman & Tuong, 2001). Under conditions of increasing climate variability and uncertainty, these systems are likely to play a growing role as transitional and adaptive production models (FAO, 2016a).

Technological Intensity

Levels of mechanization vary widely across rice cultivation systems in Latin America and are linked to farm size, access to capital, labor availability, and market integration (Daum, 2022). Highly mechanized systems, often associated with large-scale commercial operations, incorporate technologies such as laser land leveling, precision seeding and transplanting, advanced harvesting equipment, and digital decision-support tools. These innovations enhance labor productivity, optimize water distribution, and facilitate the implementation of climate-smart practices (FAO, 2013).

As a result, mechanized systems tend to achieve higher yields and lower emission intensity per unit of output (Yuan *et al.* 2021). In contrast, semi-mechanized and non-mechanized systems remain more reliant on manual labor and basic equipment, with structural constraints limiting opportunities for productivity growth and climate risk management (Daum, 2022).

Cropping intensity

Cropping intensity varies widely across the region and exerts a strong influence on both productivity and environmental performance (FAO, 2016b). While some areas, particularly rainfed and semi-mechanized systems, support only one rice crop per year, other regions with irrigated and mechanized systems sustain two or even three cropping cycles annually. This increases total output but also intensifies pressure on water resources and nutrient balances (Dobermann & Fairhurst, 2000). These trade-offs underscore the need to align intensification pathways with sustainable resource management (Yuan *et al.* 2021).

2. Socioeconomic Profiles of Rice Producers

Rice producers in Latin America comprise a highly heterogeneous group, ranging from smallholders cultivating only a few hectares to large commercial enterprises managing thousands of hectares. These differences in scale and resource endowment strongly shape production strategies, adaptive capacity, and exposure to climate risks (FAO, 2014).

Mechanized irrigated systems are typically operated by commercial producers with greater access to certified seeds, improved varieties, extension services, and financial resources. In contrast, smallholder and

traditional rice producers often face limited access to credit, insurance, climate information services, and technical assistance, constraining their ability to adopt climate-smart practices despite their importance for national food security (FAO, 2014).

Socioeconomic vulnerability further amplifies exposure to climate impacts and undermines resilience. Factors such as aging farmer populations, limited formal education, insecure land tenure, and persistently low incomes interact to constrain adaptive capacity across many rice-producing areas in the region (Birkmann *et al.* 2022).

3. System-Specific Climate Vulnerabilities

Rice cultivation systems exhibit differentiated vulnerability profiles shaped by their dependence on water resources, levels of technological intensity, and institutional contexts. Irrigated systems, while generally associated with higher yields, remain vulnerable to basin-scale water scarcity and governance failures, particularly during prolonged droughts (Bouman *et al.* 2007).

Rainfed systems are especially sensitive to rainfall variability and extreme climate events, resulting in pronounced yield instability and livelihood risks for smallholders (Pandey *et al.* 2010). Highly mechanized systems display greater farm-level resilience but remain exposed to systemic risks such as input price volatility, labor shortages, and supply-chain disruptions (FAO, 2016a).

Recognizing these differentiated vulnerabilities is essential for designing effective, equitable, and system-appropriate adaptation strategies (FAO, 2016a).

Conclusions

Rice cultivation systems in Latin America reflect deep heterogeneity in water management, technological intensity, cropping intensity, and socioeconomic conditions. This diversity fundamentally shapes productivity outcomes, climate vulnerability, and the feasibility of adaptation and mitigation interventions.

Effective climate action in the rice sector must therefore avoid one-size-fits-all approaches and instead pursue differentiated, system-sensitive pathways aligned with local production contexts and producer realities. Aligning water management innovations, technological development, capacity building, and policy instruments with the diversity of rice cultivation systems is critical to enhancing resilience, reducing emissions, and supporting sustainable and inclusive rice-based agrifood systems across Latin America.

Declarations

Declaration of Competing Interest: The author declares that he have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of use of generative AI and AI-assisted technologies: The author declares that he has not used generative AI and AI-assisted technologies during the preparation of this work.

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Kinetic Analysis of Solar-Dried Mango (*Mangifera Indica L.*) Slices Via Thin-Layer Models

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Abstract: Drying is an important technology for preserving crops and reducing post-harvest losses. Solar dryers play a significant role in drying some vegetable and fruit crops. They are economical, technically cost-effective, and energy-saving, as they rely on sunlight for drying. This study aimed to investigate the drying kinetics of thin mango slices in a multi-mode solar dryer. The experiment was conducted on three slice thicknesses (4, 6, and 8 mm) during drying. The results showed that several thin-layer drying models were fitted to the experimental data. Based on the highest R^2 (coefficient of determination) values and the lowest χ^2 (chi-square) and RMSE (root mean square error) values, the Page model was determined to be the most appropriate for describing the drying kinetics, with R^2 value was 0.9971. The effective moisture diffusion coefficient (Deff) was calculated using Fick's second law and ranged from 3.31×10^{-10} to 9.77×10^{-10} m²/s, increasing with increasing air velocity and decreasing slice thickness. A simulation model based on Page's equation and empirical relationships for (Deff) was measured and successfully validated against experimental data, proving it to be an effective tool for predicting drying behavior and optimizing solar drying processes for mango slices.

Keywords: mango; solar drying; drying kinetics; simulation; moisture diffusivity; Page Model.

JEL Classification: Q26; Q18; Q12.

Introduction

Postharvest Technology of Horticultural Crops is a specialized field within horticulture, offered by national and international institutions to researchers and academics to address the issue of postharvest losses in fruits and vegetables (Fung *et al.* 2018). This field encompasses various disciplines focused on the handling and processing of horticultural products, including drying and wet storage techniques that reduce losses and enable reuse. Fruits and vegetables, alongside food grains, are major income sources for farmers, making postharvest losses a critical concern due to their short shelf life, high market demand, and diverse postharvest applications Cheng & Languish (2023). Harvest timing, techniques, and conditions significantly influence product quality and market price. The maturity stage at harvest affects shelf life and long-term storage potential. Optimal harvesting depends on climate, market distance, crop variety, and growing conditions. Farmers are often unaware of how their harvesting and handling practices impact the final quality of produce. Once harvested, fruits and vegetables are cut off from their nutrient supply especially water leading to visible deterioration within days of sale or storage (FAO, 2021). Solar drying is an ancient and widely used technique for drying fruits and vegetables in many parts of the world.

This method involves placing various materials on the ground or rooftops, then placing the produce to be dried on top, exposing it to direct sunlight. However, this type of drying has several drawbacks, including

contamination, exposure to dust, dirt, and insects, and potential spoilage (Akpan *et al.* 2022). To address these problems, solar dryers have been developed. Their primary purpose is to provide sufficient heat for drying the produce, and they may be equipped with a collector, drying chamber, and chimney (Nnamchi *et al.* 2025). Drying is carried out using three methods: direct, indirect, and mixed, in each method, an absorber is used to capture solar energy within a solar collector (Lamrani *et al.* 2021). The absorbed radiation is then transferred to the air, facilitating its flow into the drying chamber (Ndukwu *et al.* 2023). If properly developed and executed, this method offers several advantages over traditional solar drying, including faster drying time, reduced risk of spoilage, and higher product quality (Nnamchi *et al.* 2025). However, the problem of continuous drying time arises due to intermittent solar radiation for any reason. This can be solved by using hybrid solar-powered systems that combine solar energy with non-solar heating sources, such as thermal storage materials, biomass heaters, or electric heating elements (Tyagi *et al.* 2024). This ensures energy availability and continuous drying during periods of low solar radiation. Recent studies have shown that most solar dryers are small-scale, operate using natural convection, and are designed for domestic use or for use in rural areas (Kanfa *et al.* 2020). In response to rising demand for high-quality, affordable processed foods, including fish, fruits, and vegetables, various drying technologies have emerged. These include solar-assisted dehumidification systems, solar cabinet dryers, V-groove solar collectors, indirect solar-electric hybrid dryers, indirect natural convection dryers (IDTSDs), and rack-type solar dryers for greenhouses. Among these, solar drying is considered reliable due to its low cost and environmental sustainability. Solar dryers can be constructed using locally available materials, reducing both initial and operational costs. However, current designs face challenges such as uneven drying rates, inefficiency during cloudy days, and extended drying times (Kabeel *et al.* 2021). Hybrid solar dryers have been developed to address these issues, but their high-power requirements increase operating costs. To mitigate this, phase change materials (PCMs) are used to maintain temperature at night, and vortex elements are added to the drying chamber inlet to ensure uniform airflow. Future research aims to reduce accessory components to minimize dryer weight and space, helping entrepreneurs and researchers select cost- and time-efficient drying methods (Sendhil *et al.* 2022).

Mango (*Mangifera indica L.*) is a fruit of high nutritional and economic value. However, its seasonal nature and high perishability lead to postharvest losses estimated at 25–40% in many producing countries (FAO, 2021). Drying is one of the oldest and most effective preservation methods, reducing water activity and microbial growth while facilitating transport and storage (Chobot *et al.* 2024). Open sun drying remains common due to its low cost, but it suffers from contamination, weather unpredictability, poor product quality, and long drying durations. Solar drying using engineered dryers offers a sustainable alternative with better process control and improved product quality (Lingayat *et al.* 2020). Thin-layer drying is a fundamental concept in food engineering, assuming that the product dries as a single layer with uniform exposure to drying conditions (Popescu *et al.* 2023). Drying behavior is typically modelled using theoretical, semi-empirical, or empirical models to estimate moisture content and drying time under known temperature and humidity conditions. Numerous studies have applied thin-layer drying models to products such as potato slices, onion slices, sweet cherry, and okra (Elmsaad *et al.* 2025; Matouk *et al.* 2021; Chezanoglou *et al.* 2024; Nwakuba *et al.* 2025). Researchers have tested various models and identified those best fitting experimental data. Despite extensive literature on drying kinetics for various food products, limited research exists on modelling the solar drying of mango slices. Understanding the kinetics of this process through mathematical modelling is essential for dryer design, optimization of operating conditions, and performance prediction (Gebeyehu *et al.* 2025). While several studies have explored mango drying, comprehensive investigations combining experimental analysis of operational parameters (*e.g.*, air velocity, slice thickness) with robust simulation models are still needed. Given the climatic challenges in arid and semi-arid regions, there is a growing need to develop effective preservation techniques for seasonal fruits like mango. Solar drying is among the most sustainable and cost-effective methods, yet traditional approaches such as open sun drying often result in quality degradation and contamination. This study aims to investigate the drying kinetics of thin mango slices using controlled solar dryers, analysing the influence of operational factors such as temperature, relative humidity and slice thickness, on the drying rate. It also seeks to identify the most suitable mathematical model to describe drying behavior accurately, thereby improving dryer design and offering practical recommendations for implementation in desert environments.

The originality of this research lies in its presentation, particularly in arid and hot regions (such as the Arabian Gulf and North Africa), of previously unpublished local data, along with a hybrid solar drying system designed for this purpose (using an auxiliary fan + direct drying). This system is more suitable for the physical characteristics of mango slices in terms of their fibrous structure, thickness, and high moisture content, according to models selected based on the effective diffusion coefficient. Furthermore, the study's recommendations offer

several methods and suggestions directly applicable to small-scale producers and farmers, thus bridging the gap between academic research and practical application. The study's contribution is not limited to the theoretical aspect; it also provides cost-effective and highly efficient technical solutions to a real problem faced by mango-producing regions in developing countries. This research aims to investigate the kinetics of post-harvest mango slice drying using a thin-film solar dryer and to develop an accurate mathematical model describing this process, with a focus on its practical applications.

The main objective of this study is to evaluate and study the drying characteristics of mango slices using a thin-film solar dryer, develop an accurate mathematical model, and determine the relationship between product quality and drying parameters to provide practical application recommendations, and Specific Objectives:1. To design and manufacture a hybrid solar dryer (direct drying + auxiliary fan) suitable for drying thin-film mango slices.2. To investigate the effect of slice thickness (4, 6, 8 mm) on the drying rate and total drying time.3. To measure experimental drying data such as moisture content versus time and calculate the effective moisture diffusion coefficient (D_eff) using Vic's second law.4. To test and compare three mathematical models (Lewis, Page, Henderson, and Pabis) to determine the most suitable model. The thickness of the mango slice (4, 6, 8 mm) has a significant effect on the drying rate and total drying time, with the time increasing non-linearly as the thickness increases. The drying kinetics of the mango slices can be accurately described using the Lewis or Page model, with an expected R^2 value greater than 0.995. The effective moisture diffusion coefficient (D_eff) of the mango slices ranges from 2.5×10^{-9} to 9.5×10^{-9} m²/s and increases exponentially with increasing temperature.

1. Materials and Methods

1.1 Sample Preparation

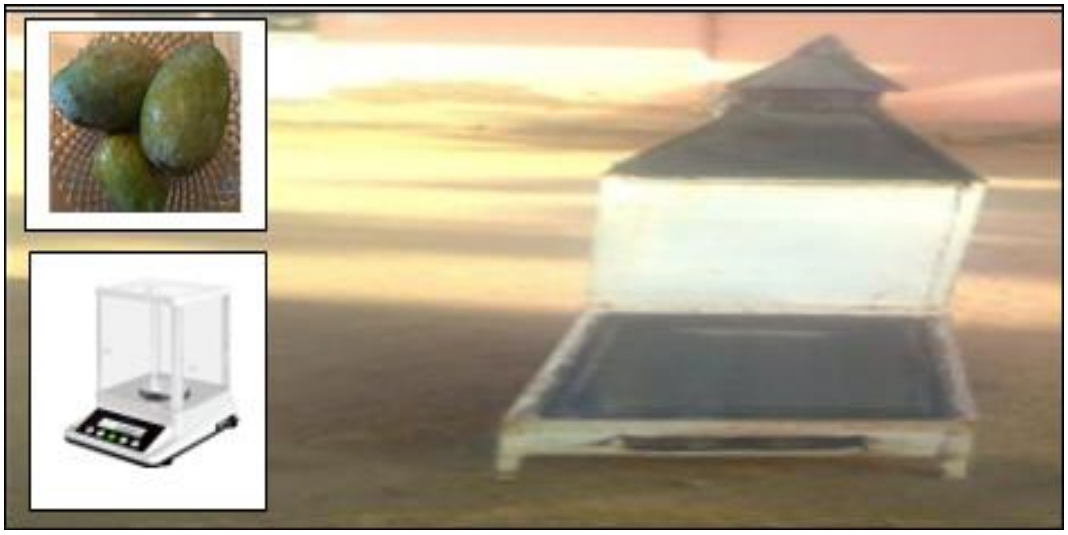
This experiment was conducted at King Faisal University, College of Agricultural and Food Sciences (latitude 26° 23' 18.56″ N, longitude 50° 11' 16.01" *E,* and an altitude of 142 m above sea level). To prepare the crop to be dried, fresh ripe mangoes (cv. Tommy Atkins) were purchased from local markets, thoroughly washed and sterilized with an aqueous solution of sodium hypochlorite at a concentration of 1 mg per litre of free chloride for 30 minutes, then rinsed with water and peeled, and cut into rectangular slices of 4- 6- and 8 mm thickness using an electric vegetable slicer to ensure uniformity. The samples were weighed at as much as 50g with the analytical balance 0.0001g Digital Lab Precision Balance Scale 0.1mg 120g 220g, at hourly intervals for the first few hours and then every 30 minutes thereafter until a constant final moisture content was achieved (approximately 10% wet basis). All experiments were performed in triplicate The initial moisture content was determined using a standard oven drying method at 105°C for 24 h until a constant value of moisture content was reached, and average values were used for calculation.

1.2 Solar Drying Unit

The experiment was conducted using a mixed-mode solar dryer. It consists of three detachable components: a solar collector (air heater), a drying chamber, and an air duct and drying tray. A rectangular solar collector measuring 150 x 40 cm was used. It consists of a corrugated zinc absorber plate, painted black to increase radiation absorption. The corrugated zinc was used to increase the surface area of the absorber plate. Two 4 mm thick glass plates, each measuring 70 x 35 cm, were fixed to the overall frame of the collector and enclosed with wooden pieces to contain any thermal expansion due to heating. A type of white glass was used as a transparent cover because it is a good conductor of solar radiation. The glass also acts as a barrier between the wind and the absorber plate. The collector frame was made of 2.65 x 2.65 cm iron angles with 0.09 cm thick metal sheets at the bottom of the packaging box. 4 cm thick glass wool was used as insulation and placed between the collector and the sides of the dryer, except for the top. The front opening of the collector was rectangular, measuring 30 x 7 cm. It was oriented south-facing and angled to form an angle of 16.5° with respect to the ground, which is the latitude of the experimental site (Fig. 1). The drying chamber was used to place the product for drying. It consisted of a box with 30 x 30 cm wire mesh trays made of steel angles. The dimensions of the drying chamber were 50 cm long, 25 cm wide, and 90 cm high. The distance between the top of the drying chamber (where the mango slices were placed in a single layer on the wire mesh trays) and the ground was 120 cm. A metal plate was fixed to each side of the drying chamber. Two tray supports made of angle iron (2.65 x 2.65 cm) were installed to hold the trays. At the bottom of the drying chamber, there was a 30 x 40 cm opening to promote airflow. The top of the drying chamber was pyramid-shaped. The top was equipped with a central 25 x 40 cm opening for air to escape. The drying chamber was designed to accommodate two trays. These trays were made of wire mesh to allow hot air to circulate through the material being dried. The trays were movable for easy placement and removal within the drying chamber for loading and unloading the product. The frame of each tray

was made of angle iron with dimensions of 2.55 cm x 2.55 cm and 35 cm x 25 cm, while the tray's surface area was 35 cm x 25 cm, its depth was 3 cm, and its effective area was 35 cm x 25 cm. The door was tightly sealed to prevent air leakage between the perimeter and the drying curve. The door was used for loading and unloading the trays into the drying chamber. The interior wall and floor of the chamber were lined with 4 mm thick monzonite to minimize heat loss from the drying chamber to the surrounding environment (Fig. 2). Figure 3 was drawn using GenAI after all the dimensions of the solar dryer parts used in the experiment had been entered.

Figure 1. Solar dryer with mango sample and Analytic balance

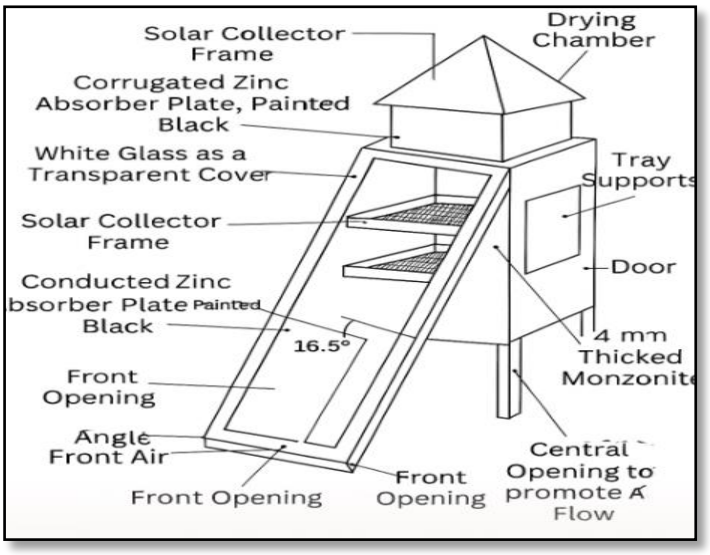


Source: The authors captured all experimental photographs during the experimental work.

Figure 2. Drying chamber with drying tray

Source: The authors captured all experimental photographs during the experimental work.

Figure 3. Mix mode solar dryer



Source: Drawing photos the authors using Figma

1.3 Measuring Instruments

The temperature and relative humidity of the air at the inlet and outlet of the drying chamber, were recorded throughout the drying period using data loggers (GSM Temperature & Humidity datalogger SMS Alarm S500EX), as well as solar radiation intensity measured by (PV204 Digital Solar Meter).

1.4. Drying Kinetics Analysis

Equations (1 and 2) are used to determine the initial moisture content (Mi) and calculate the moisture content at time t (Mt), respectively (Raaf *et al.* 2022). However, under equilibrium conditions, moisture is trapped due to bound water. This method has been observed in highly porous materials, as shown in studies on porous materials such as green plantain (*Musa paradisiaca L.)* peels, peeled cassava root slices, and cellulose Equation 1 can be applied under experimental conditions and is consistent with experimental drying models for plants Altgen *et al.* (2023), Equation (2) allows the moisture content (Mt) to be calculated as the ratio of the difference between the current sample weight (wt) and the final weight (wf), standardized to the initial weight (wi). The residual moisture persists under equilibrium conditions. In equations (1) and (2), wi, wf, and *wt* are, respectively, the initial weight of the sample (g), the final weight (g), and the weight of the sample at time t.

$$Mi = \frac{wi - wf}{wi} \quad (1)$$

$$Mt = \frac{Wt - Wd}{Ww} \quad (2)$$

The equilibrium moisture content (EMC) was determined for each treatment by continuing the drying process until a constant weight was recorded in successive observations of the mango slices. The moisture ratio (MR) was calculated using the following equation (Kusuma *et al.* 2024):

$$MR = \frac{Mt - Me}{Mi - Me} \quad (3)$$

where Mt, Mi, and Me represent the moisture content at time t, the initial moisture content, and the equilibrium moisture content, respectively. The equilibrium moisture content (Me) was obtained experimentally under controlled drying conditions, as reported by Noguera & Iturgaiz (2023). This process ensures accurate normalization in line with standard methods. Furthermore, for accurate data normalization, the importance of incorporating into thin-layer drying models is highlighted by (De Paula *et al.* 2020). Macedo *et al.* (2020) presented experimental methods and practices for extracting me under different drying conditions. Together, these references validate the approach used in this study and ensure consistency with established practices in thin-layer drying research. The drying rate is defined as the amount of water that can evaporate from the product

over a specified period of time. The mango drying rate (DR) is calculated by dividing the time difference between the previous moisture content and time t at that moment by the time difference (Gasa *et al.* 2020).

$$Dr = \frac{Mt - Mt+\Delta t}{\Delta t} \quad (4)$$

In Equation (4), Mt+Δt is the water content at the drying time starting at time t+Δt (minutes), while Δt is the time difference (minutes).

1.5 Mathematical Models

The following assumptions were made to develop a suitable mathematical model for thin-bed drying of mango slices:
1. The temperature across all mango slices was uniform.
2. Convection was the primary cause of heat transfer.
3. Internal resistance to moisture movement was minimal.
4. Moisture was removed from the product during the period of sunlight and only in the vertical direction.
5. Liquid diffusion is the mechanism governing moisture transfer.
6. Evaporation occurred entirely on the surface of the mango slices.

Semi-theoretical models are generally derived by simplifying or modifying the general series solutions of Fick's second law and are valid within the range of temperature, relative humidity, airflow velocity, and moisture content for which they were developed (Owoh *et al.* 2025).

1.5.1 Lewis Model

This model is derived from the semi-theoretical Lewis model of thin-film drying. It is similar to Newton's law of cooling, where k is the drying constant (min $^{-1}$) and t is the drying time (min) (Ambawat *et al.* 2022)

$$MR = \exp(-k \times t) \quad (5)$$

1.5.2 Page Model

The drawbacks of the Lewis model were overcome by empirically modifying the time limit by adding non-dimensional constants (*n*), both k and *n* were related to various process variables (air drying temperature and speed, initial moisture content, etc.) and were used to study the drying behavior of corn husks (Bozkir *et al.* 2020).

$$MR = \exp(-k \times t^{n}) \quad (6)$$

1.5.3 Henderson and Pabis Model

The Henderson and Pabis model are a modification of another model using the basic Lewis model or the Page model (Kusuma *et al.* 2024). The Henderson and Pabis model are considered the first model used for kinetic drying and was used in the general solution of Fick's law (Hartati *et al.* 2018). Henderson and Pabis also modified the Lewis model by adding an empirical constant (a) to their kinetic drying model.

$$MR = a \times \exp(-k \times t) \quad (7)$$

1.5.4 Diffusivity Calculation

For thin fruit slices (treated as infinite slices), Fick's second law gives an analytical solution for the moisture content (MR) when internal diffusion controls the drying process and external resistance is negligible, this model is used when the Lewis or Page models cannot accurately represent the two drying phases (i.e., when the curve exhibits a double-slope pattern).

$$MR = a.\exp(-k.t) + (a-1).\exp(-k.b.t) \quad (8)$$

MR: Moisture Ratio the dimensionless ratio representing the remaining moisture content. a: Fraction coefficient representing the contribution of the fast-drying phase. k: Drying rate constant [s^{-1}] indicates the speed of moisture removal during drying. b: Correction factor reflecting the relative difference in the drying rate of the second phase. t: Time [s].

Relationship with effective moisture diffusivity, the model represents two simultaneous diffusion phases within the sample: The first term, a exp. (−k t) corresponds to the fast diffusion of surface moisture (near the outer surface). The second term, (1−a) exp (−k b t), represents the slow diffusion of internal moisture bound within the

cellular structure. Since each exponential term can be related to Fick's second law of diffusion, each component describes a separate moisture transfer mechanism occurring during the drying process (Ma *et al.* 2022).

1.6. Statistical Analysis

The accuracy of the model fit was evaluated using the Coefficient of Determination (R^2), Chi-square (χ^2), and Root Mean Square Error (RMSE) and Average absolute difference (AAD). The model with the highest R^2 and the lowest χ^2 and RMSE values was considered to determine the best-fit model, some statistical parameters are used as follow as (Pham *et al.* 2019; Xu *et al.* 2025) reported that the parameters used in the statistical validation include the followings:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MRexp,i-MR\quad pre,i\right)^2}{\sum_{i=1}^{N}(MRexp,i-MRave,i)^2} \quad (9)$$

$$X^2 = \frac{\sum_{i=1}^{N}(MRexp,i-MRpre,i)^2}{N} \quad (10)$$

$$SSE = 1 - \sum_{i=1}^{N}(MR\ exp,i - MRpre,i)^2 \quad (11)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{\exp,i} - Mr_{pre,i})^2}{N-n}} \quad (12)$$

$$MSE = \frac{\sum_{i=1}^{N}(MR_{\exp e,i} - MR_{pre,i})^2}{N-n} \quad (13)$$

$$AAD = \frac{\sum_{i=1abs}^{N}(MR_{\exp e,i} - MR_{pred,i})}{n} \quad (14)$$

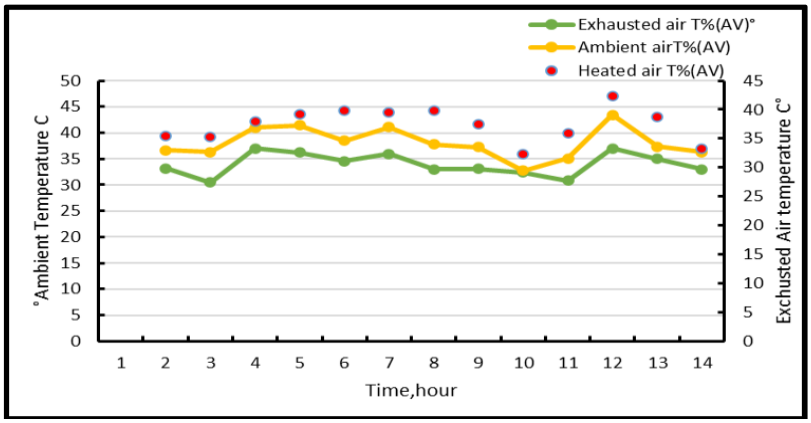
where: $MR_{exp,\,i}$ and $MR_{pre,\,i}$ are the experimental and predicted moisture ratios, respectively, N is the number of observations, and z is the number of constants in the model.

2. Results and Discussion

2.1 Drying Performance of the Solar Dryer

Figure 4 shows the temperatures of the ambient air, heated air, and exhaust air for the experimental period. It was observed that the heated air temperature increased during the afternoon and decreased during the evening over time. This is consistent with the results of (Getachew *et al.* 2024). The obtained solar collector temperatures (heated air temperatures) were higher than the ambient and exhaust air temperatures. This demonstrates the effectiveness of using the solar collector as a heat source for drying purposes.

Figure 4. The temperatures of the ambient air, heated air, and exhaust air during experimental period

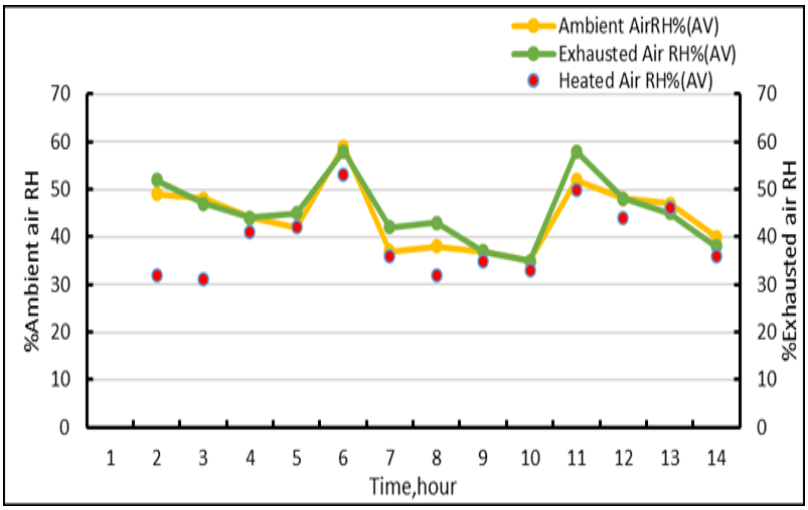


Source: Authors' own experimental data

Figure 5 illustrates the relationship between the relative humidity of the ambient, heated, and exhausted air inside the dryer during the drying period. Relative humidity tends in the opposite direction to temperature. The

results show that the relative humidity of the heated air is lower than that of the ambient and exhausted air. When the air is heated, its relative humidity decreases, its temperature increases, and thus its ability to remove moisture from the product increases. In addition, the heated air extracts more moisture from the product than unheated air. This demonstrates that the solar dryer is a suitable device for drying applications, where the air used for drying must have a high temperature and low relative humidity (Gomez *et al.* 20 23).

Figure 5. Relative humidity of ambient, heated and exhausted air during the drying experiment



Source: Authors' own experimental data

2.2 Solar Drying Properties of Mango Slices

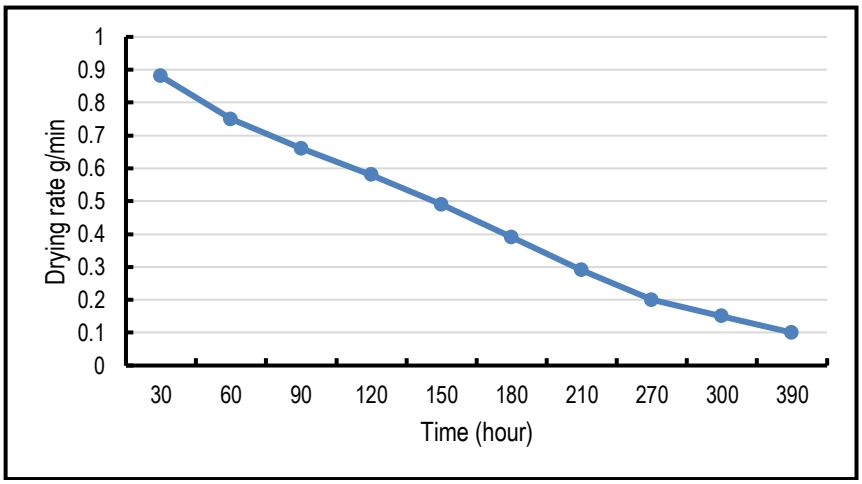
Table 1 shows the measured weight and moisture content values for both dry and wet states of mango slices. The data indicated that the mango slices were dried from an initial moisture content of approximately 80% (dry) to a final moisture content of approximately 15% (dry). The final moisture content of sun-dried mango (15%) is lower than the typical moisture content of 18% (dry) for dried fruit Therefore, the sun-dried mango slices obtained under the present conditions have acceptable moisture levels for preservation and storage according to (López *et al.* 2024). The drying process involves heat and mass transfer processes, which lead to changes in the product structure, shape, and quality (Dasore *et al.* 2020). In general, two drying periods can be observed: fast and slow drying. The fast-drying period occurs when there is a diffusion process on the outer surface of the material (Ntsowe *et al.* 2025). In this case, the water content decreases rapidly and the humidity percentage decreases rapidly because the water evaporates from the outer surface quickly. This usually occurs during the first drying period, especially in the first minutes of the drying process, as shown in Fig. 6. In the second drying period, drying slows down until the equilibrium point is reached due to the slow diffusion rate of water evaporation. This is attributed to the fact that the diffusion of liquid or vapor occurs from the inside of the material to its surface due to the difference in humidity concentration (Raaf *et al.* 2022). The slow drying period can be seen in Fig. (6), from minute 30 to end.

Moisture content is an important parameter and parameter in the drying process, as it leads to moisture removal from the product (Cheng & Langrish, 2023). The moisture content value also helps in analysing materials during the drying process, such as the drying rate, time required for water equilibration, and moisture content of the dried product. Figure 7 shows the relationship between moisture content and drying time of mango slices over two days of drying. The time required to reach a final moisture content of 15% (weight of material) is 12 hours. The figure also indicates that there is no constant-rate drying period, as the entire drying process occurs during the decreasing-rate period, confirming that diffusion is the dominant mechanism of moisture transfer. These results support the hypotheses of thin-film drying, which demonstrate that moisture removal from the product occurs only during the sunlight period and in the vertical direction. Liquid diffusion is the mechanism that regulates moisture transfer. Figure 7 shows the relationship between moisture content and drying time. It also confirms that moisture content decreases with increasing drying time. A common feature of this curve is its similarity to the typical curve for thinly packed dried fruit this result in line with (Rizki *et al.* 2025). Equation 8 explain that the two-term exponential model represents two simultaneous drying mechanisms: a fast surface diffusion and a slower internal diffusion. Each exponential term can be associated with Fick's second law, enabling the estimation of an equivalent effective moisture diffusivity as a weighted average of both phases.

Table 1. Moisture content and measured weight on wet basis and dry basis of Mango slices

Time (hr)	Weight (grams)	Moisture content	
		Wet basis %	Dry basis %
9:00	4.1	80	3.2324
10:00	3.5	75	2.7145
11:00	3.3	73.4	2.5431
12:00	3	65.33	1.7776
13:00	2.9	61	1.5475
2:00	2.4	57	1.3817
15:00	2.2	48.8	1.2311
16:00	1.7	36	.0.9834
17:00	1.5	33	0.5881
9:00	1.4	25	0.3489
10:00	1.3	15	0.19448
11:00	1.3	15	0.19448
12:00	1.3	15	0.19448

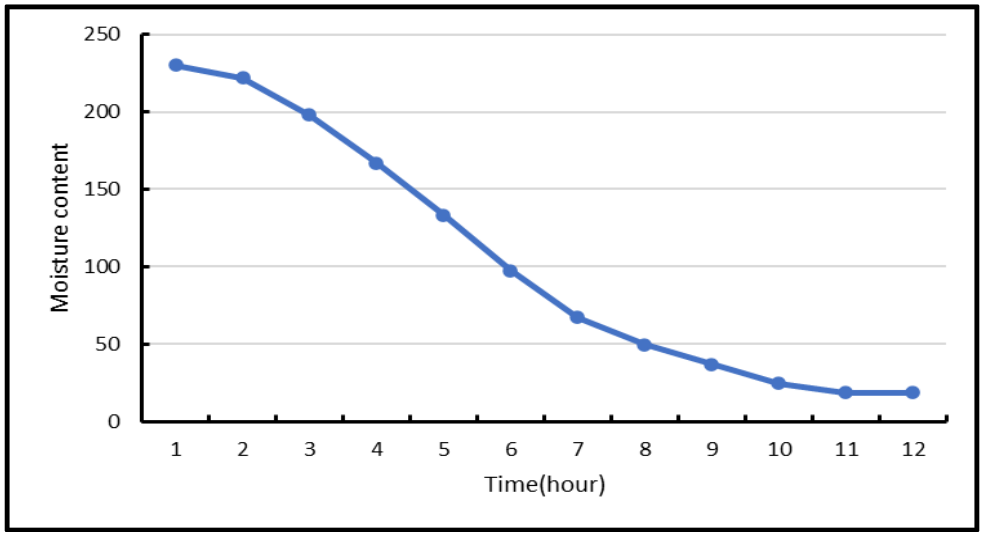
Figure 6. The relation between Drying rate and time during drying period



Source: Authors' own experimental data

Although this model provides a more detailed description of moisture transport in heterogeneous materials like mango, it is more complex and less widely used than the simpler Page model, which generally offers the best overall fit with fewer parameters. It gives a better description of moisture transport in materials with multiple porosities or layers (*e.g.*, mango, guava, potato). The effective moisture diffusion coefficient (D_{eff}) was calculated using Fick's second law and ranged from 3.31×10^{-10} to 9.77×10^{-10} m²/s, increasing with increasing air velocity and decreasing slice thickness.

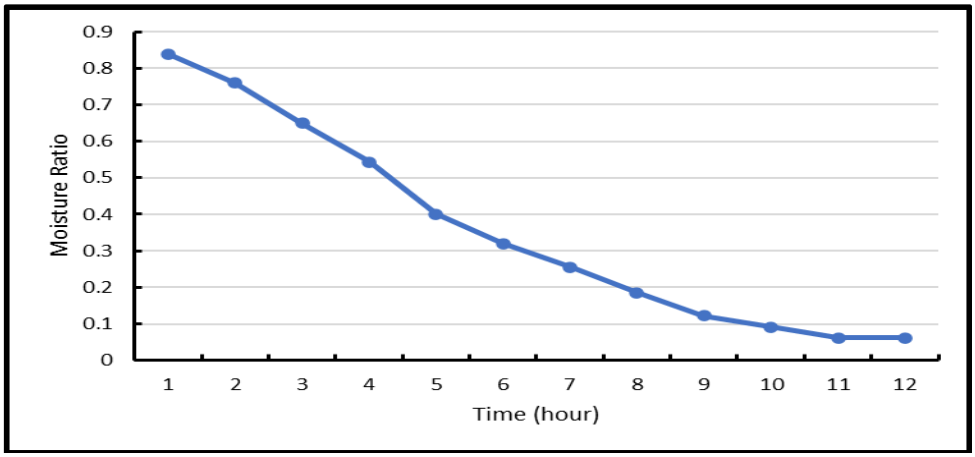
Figure 7. Variations of moisture content with drying time



Source: Authors' own experimental data

Figure 8 also shows the moisture content versus drying time. The figure shows that the moisture content gradually decreases with increasing drying time. A common feature of this curve is its similarity to the typical curve for thin-layer dried fruit.

Figure 8. Variations of moisture ratio with drying time



Source: Authors' own experimental data

Table. 2. Values of the drying constants and coefficients of three tested drying models

Models	R^2	X^2	SSE	RMSE	AAD	Models' constants & Coefficient
Lewis	0.996	0.027	0.004	0.030	0.168	K=0.2435
Page	0.997	0.087	0.003	0.001	0.029	K= 0.1401 n=1.234
Henderson & Pabis	0.995	0.031	0.019	0.003	0.146	K=0.267 a =1.2565

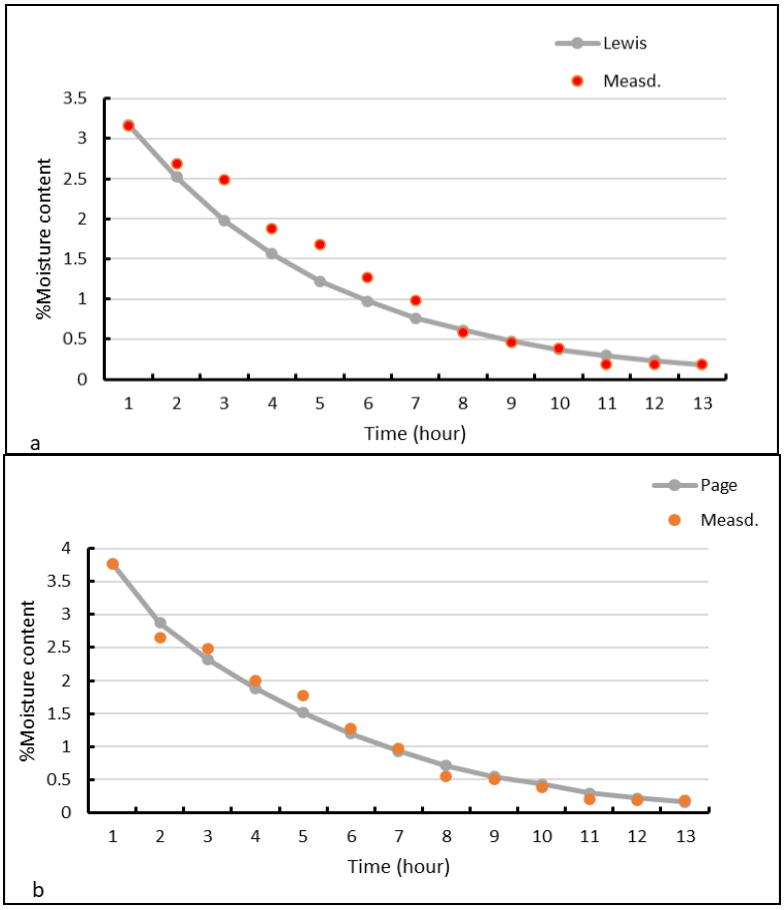
2.3 Selection of the Optimal Mathematical Model

Table (2) show the results of a linear regression analysis to fit the three tested drying models to the experimental data. This table shows the drying constants, drying coefficients, and coefficient of determination (R^2) values for the three tested drying models. The results show that the drying constant (K) is 0.2435, 0.1401, and 0.2671 for Lewis, Page, and Henderson and Pabis, respectively. The drying coefficient (n) for Page is 1.234, while the drying coefficient (a) for Henderson and Pabis is 1.2565. From the figures and table, the Page model is considered the best for representing the drying kinetics when compared to the other two models. This result is consistent with Raaf *et al.* (2022), who reached similar results in the drying of guava, according to Parmar *et al.*

(2025), the Lewis model is considered less accurate because it relies on initial drying conditions and neglects the final periods. The Henderson and Pabis model, according to Sadaka *et al.* (2022), was not suitable in his experiments on corn drying, for the first two hours of drying due to the large temperature difference between the grain and the air. Drying kinetic models are very important in determining ideal drying conditions, as they include basic criteria for design, equipment optimization, and product quality improvement (Getachew *et al.* 2025).

Figures 9 (a, b, c) show the measured and predicted moisture content (expressed as moisture content on a dry decimal basis) versus drying time. For comparison, the best kinetic drying model that could represent the drying of mango slices using a solar dryer was analysed. Five statistical error coefficients were used, and it was observed that R^2 was the highest, while the statistical values of X^2, SSE, MSE, RMSE and AAD were the smallest. However, when determining the optimal model, one basic error function is chosen for the solution, while the other error function is used as a comparator (Luke *et al.* 2021). The most important criterion is SSE, which measures the difference between the collected data and the constructed predictive model. SSE is frequently used as a research reference in determining optimal data. Ganesh *et al.* (2024) stated that a more accurate model should have a mean model error and mean absolute difference close to zero and a small standard error of estimate AAD for the best model Page model (0.0295). Therefore, it can be said that the three tested drying models adequately simulated the drying process of mango slices. However, Fig. (9) shows that the Page model is the most appropriate of the three tested drying models for simulating the drying process of mango slices. El-Mesery *et al.* (2023), obtained similar results for whole okra pods. As evident, the Page model provided the best fit to the experimental data under all conditions, registering the highest R^2 values (>0.997) and the lowest RMSE and χ^2 values. The equation 6 captures the interaction between the drying constant (k) and the dimensionless exponent (n), giving it the flexibility to accurately describe the drying curve (Kabeel *et al.* 2021).

Figure 9 (a, b, c). Measured and simulated moisture contents by Lewis, Page and Henderson and Pabis models



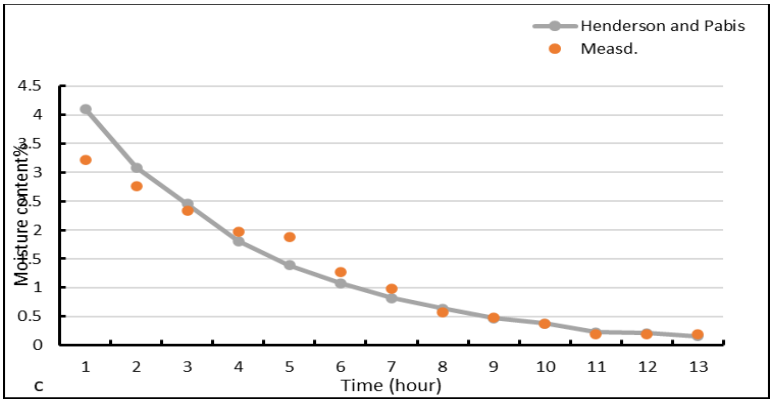


Table 3. Two-sample T-Test of the sample means of experimental and simulated moisture contents by the three tested drying models

Model name	95% confidence interval for $\mu_1 = \mu_2$	$\mu_1 = \mu_2$ vs $\mu_1 \neq \mu_2$			
		t_0	t_1	P	$d.f.$
Lewis	(-0.664, 0.952)	0.38	2.057	0.561	22
Page	(-0.833, 0.863)	0.03	2.067	0.981	22
Henderson & Pabis	(-0.952, 0.890)	-0.07	2.073	0.952	22

**(expressed as moisture content on dry basis, decimal)*

Table 3 shows a t-test to determine whether there is a difference in the sample means for the experimental and predicted moisture content for determining the moisture content of mango slices (expressed as moisture content on a dry decimal basis). From this table, it is concluded that the null hypothesis (H_0: $\mu_1 = \mu_2$) is true, i.e., $t_0 \leq t_1$, for the three tested drying models. There is insufficient evidence to reject the null hypothesis. In other words, based on the current data, there is no difference between the two methods with regard to determining the moisture content of mango slices. This confirms that the three tested drying models are successful in simulating the thin-layer drying process of mango slices (Mbaye *et al.* 2026).

Where: μ_1: population mean of the measured moisture content, decimal (d.b.). μ_2: population mean of the predicted moisture content, decimal (d.b.).t_o: calculated value of the test statistic (calculated t).t_1: tabulated value of the upper α/2 percentage point of the t-distribution (tabulated t). P: probability or percent risk of being wrong if the null hypothesis (H_o) is rejected. df: degrees of freedom.

The thin-layer drying models - Lewis, Page, Henderson and Pabis, and Logarithmic - are empirical or semi-theoretical equations that describe the drying behavior of agricultural materials. All these models are linked to Fick's second law of diffusion, which governs moisture transfer inside the material. The Lewis model assumes a simple exponential decay of moisture ratio, corresponding directly to a constant effective moisture diffusivity. The Henderson and Pabis model introduces a shape factor to better represent the initial drying phase. The Page model, a modified form of Lewis, adds an exponent n to time, allowing flexible curvature and thus fitting experimental data more accurately, particularly when the drying rate decreases non-linearly. Therefore, the Page model generally provides the best correlation (highest R^2) and yields more realistic estimates of effective moisture diffusivity, especially for fruits like guava with non-uniform internal structure and varying porosity (Nnamchi *et al.* 2025; Khaled *et al.* 2024).

2.4 Analysis of the Method of Drying Mangoes with a Solar Dryer

Various drying techniques are used in various studies, including oven drying, sun drying, and freeze drying. Each has distinct advantages and disadvantages in preserving the essential properties of the product. Therefore, choosing the appropriate drying method has a significant impact on product quality, the retention of bioactive compounds, and its energy efficiency. Some drying methods increase or increase the temperature, which affects product quality and the preservation of other properties. Sun drying is an ideal, cost-effective, and environmentally friendly alternative. However, there are some challenges regarding process control and drying efficiency. Although it preserves some bioactive compounds, such as beta-carotene, studies indicate that the

degradation of essential oils occurs due to prolonged exposure to ultraviolet radiation (Khaled *et al.* 2024). Solar drying, while energy efficient can be affected by climatic conditions because it relies on the sun for drying, requiring longer drying periods (Nnamchi *et al.* 2025). Based on the results of previous studies, solar drying remains a viable option in resource-limited environments, but precautions must be taken to prevent microbial contamination and degradation caused by ultraviolet radiation (Shrivastava & Gaur, 2026).

Conclusions and Further Research

This study demonstrated the characterization of the drying kinetics of mango slices using a solar dryer using a thin-layer method. Different thin-layer models were compared to determine the most appropriate mathematical representation of the drying process. Among the evaluated models (Lewis, Page, and Henderson & Pabis), the Page model showed the best fit with the highest correlation coefficient (R2 = 0.997) and the lowest error values, demonstrating its accuracy in predicting drying behavior. Furthermore, the designed dryer heated the drying air satisfactorily, which is optimal for drying mango slices. Furthermore, all mango slices were dried within the falling rate period, with diffusion being the dominant mechanism of moisture transport. Mathematical modelling can be used as a practical tool in simulating the drying of agricultural products. Using a solar dryer is less expensive and energy-intensive, making crop processing easier and reducing waste during the drying process. It is also a small-scale investment project that allows entrepreneurs and small farmers to increase their income. For future work, it is recommended to study the effect of air temperature more discretely, analyse the quality attributes (such as colour and vitamin C content) of the dried product, and integrate the model with IoT and learning machine and into a user-friendly interface to facilitate its use by engineers and farmers.

Declarations

Credit Authorship Contribution Statement:

Egbal Elmsaad: Writing, Original draft.
Omer Elmahi: Methodology, Supervision
Abdelnaser Omran: Editing, Plagiarism
Abda Emam: Supervision

Declaration of Conflict of Interest: The authors have no conflicts of interest to declare that are relevant to the content of this article.

Declaration of Use of Generative AI and AI-Aided Technologies: The authors declare that they did not use generative artificial intelligence.

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Marine Recreation Valuation: A Review

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Abstract: Marine and coastal ecosystems are main tourist attractions around the world. Being public goods, they are constantly become subjected to degradation. Estimation of economic values and proper appropriation of such values is a necessary requirement for their conservation and management. This study intends to review economic valuation studies on marine and coastal recreational areas with a view to identify trends and gaps and to formulate a research agenda towards sustainable management of the resource. Published literatures were explored with keywords such as marine, recreation and valuation using mainly google scholar and other search engines such as Science direct and individual journal web sites. The values of the studies were established in common currency unit of US$ and converted into 2026 prices using GDP deflator values.

Results indicate diverse valuation approaches adopted and the variety of types of values that have been estimated. Both local and global focus were common and conceptual frameworks of total economic value and ecosystem service concepts have been equally adopted. All major ecosystems and their components and variety of uses have been the focus of the valuation studies. The adoption of values in the policy context however was rarely sought. The diversity of the valuation studies was lesser among the developing countries. The upcoming global threats such as climate change and the common resource degradations issues have not been adequately understood by the valuation studies. Towards the future, the trade-offs between the different ecosystem services as well as the synergies need to be correctly identified in order to minimize the conflicts among different user groups of the marine resources. The essentially global nature of the marine resources has to be correctly established to avoid future climate change related grand depletion of the resource. The complex dynamics of the ocean resources and increasing anthropogenic threats have to be understood with more interdisciplinary research and at least all key ecosystems have to have their baseline values established in the face of the rapid degradation due to increasing incidence of marine oil spills and unprecedented levels of other anthropogenic threats.

Keywords: marine; recreation; valuation; GDP deflator; ecosystem services.

JEL Classification: Q26; Z32.

Introduction

Marine recreation is one of the main tourist attractions in coastal countries especially in the tropical region. Marine resources are often being neglected and subject to degradation owing to their public good nature. Regulations have been ineffective with poor enforcement has been difficult leading to further degradation. These reasons suggest the need for estimating the correct value of marine resources which could highlight the contribution of these resources to the national income and thus justify often neglected conservation efforts. Reviewing the existing literature will be an important first step towards the valuation exercise which will help to understand the status quo, gaps and policy linkages both in the local and global contexts.

This review is distinctive in its comprehensive synthesis of marine and coastal recreation valuation studies across diverse ecosystems, countries, and methodological approaches, standardized to 2026 US$ values for comparability. Unlike earlier reviews that focused narrowly on specific ecosystems or valuation techniques, this study integrates findings across wetlands, coral reefs, beaches, marine protected areas, and deep-sea environments, thereby offering a holistic perspective on global valuation trends. Its novelty lies in identifying critical gaps - such as the limited policy uptake of valuation results, the underrepresentation of developing countries, and the insufficient integration of climate change impacts - while simultaneously proposing a forward-looking research agenda. By establishing baseline values and emphasizing trade-offs and synergies among ecosystem services, this study provides an essential foundation for interdisciplinary approaches to sustainable marine resource management and strengthens the case for embedding economic valuation into national and international policy frameworks.

1. Ecosystem Services and Value of Conservation

Ecosystems offer numerous life support services that are essential to sustain the life of humans and other living beings. Ecosystems provide benefits known as ecosystem services (ES).

Based on the UN Millennium Ecosystem Assessment (2005), ES are classified under four major categories- provisioning or extractive services, regulating, supporting and cultural services which contribute to the various aspects of human wellbeing. Marine recreational areas offer all four major types of ES. Surrounding communities obtain benefits from these multiple ES, especially provisioning services, for their livelihoods on continuous basis.

Major provisioning services of these areas include extraction by local communities of edible and non-edible species to cater demand from local and foreign markets. Provisioning services generate market-based values and people extract them for short-run economic gains and are usually private in nature. As a result, there is a tendency for overexploitation of provisioning services that offer short-term economic values. Ecosystem services (ES) are interconnected and unsustainable use of provisioning services could lead to overall loss of flow of other ecosystem services. Especially, overexploitation of provisioning services often lead to compromise the ecosystems' capacity for offering supportive and regulating services, which are usually involved with indirect nonmarket values.

In contrast, regulating and supporting services are public goods that are usually non-market in nature. Despite the fact they do not offer cash benefits to private users, they play an important role in maintaining the sustainability of the system in the long-run. Without the support of regulating and supporting services, the long-term sustainability of even provisioning and cultural services could not be guaranteed. Hence, the conservation of regulating and supporting services are indispensable for maintaining the sustainability of ecosystems.

Recent rise in the variety of tourism and recreation activities related to marine ecosystems implies expanded profile of cultural services. Though the recreation services are non-extractive in nature, they could lead to degradation of the resource base due to congestion and exceeding the carrying capacity.

2. Need of Valuing Marine Recreation

Sustainable development goals have identified valuation of marine resources as a priority area (Goal 14). Therefore, need arises to value and inform the policy makers about their values to guide them towards prompt action. Economic value estimates for natural environment could guide both decision makers including environmental managers towards decisions that minimize costs maximize social benefits (Lew *et al.* 2010; Tuttle and Heintzelman 2015; Schuhmann and Mahon 2015) thus achieving social efficiency (Ruckelhaus *et al.* 2015). Information on values of marine resources including values of conservation and restoration efforts of species and habitats and direct benefits of humans (Camacho-Valdez *et al.* 2013) when presented in monetary values provides a useful guide in allocating resources of an economy given all other competing demands (Kaffashi *et al.* 2012). Economic values incorporated into national accounts provides a more correct picture of each sector in terms of their contribution to national wealth (Dharmaratne and Strand, 1999; Mwebaze and MacLeod 2013; Brander *et al.* 2013). In addition, values of nature help in understanding and resolving tradeoffs between marketed values and non-market values (Ressurreição *et al.* 2011; Ahtiainen and Vanhatalo 2012). Monetary values enable this comparison since alternative uses of natural resources create a range of impacts, which are usually not in comparable units (changes in fish stocks, water or air quality changes, or reef degradation) (Brander *et al.* 2006). Schuhmann and Mahon (2015), Hanley *et al.* (2015), Beaumont *et al.* (2008) have carried out reviews on marine recreation related studies.

The number of coastal and marine management settings where valuation researchers have attempted to make a contribution is rising fast. However, there is no equivalent increase in the application of values in managing marine resources (McVittie and Moran 2010) which lead to the question of lack of policy relevance of valuation

(Shivlani *et al.* 2003 and Hanley and Torres, 2017). However, Svensson *et al.* (2008) and Laurans et al, (2013) are on the view that valuation has helped in increasing awareness but in order to include such values in the policy context, there need to be inputs from multidisciplinary perspectives. Hanley *et al.* (2015) emphasize similar ideas with enhanced interaction between disciplines of political and social sciences "to communicate Ecosystem Services (ES) research more effectively and to improve understanding of the realities of policy makers to economists and marine and coastal scientists".

As stated by O'Garra, (2012) and Ruckelshaus *et al.* (2015) "the pace at which the theory of ES valuation is being incorporated into real decisions has been painstakingly slow, with disapprovingly few success stories". Park and Leeworthy (2002) and Laurans *et al.* (2013) argue that, despite the role of valuation in demonstrating values of sustainable management, the values are mostly used as just a source of information but have not been used in the technical sense to make decisions.

Economic values explain and quantify the necessary link between ecosystem services with wellbeing of the humans (Schuhmann and Mahon 2015). Proper valuation and communication of such values to decision makers would result in necessary improvements in the environmental management sector in coastal and marine management (Barr and Mourato 2009; Brander *et al.* 2012; Jobstvogt *et al.* 2014).

This paper is organized as follows: the next section outlines the methodology adopted which is followed by results, analysis of gaps, recommendations and conclusions.

3. Methodology

The literature sources were searched with keywords related to marine ecosystem and their use and management aspects including coastal, recreation, mangroves, lagoon, marsh, swamp, fishing, beach, corals, valuation, degradation, extinct, exploit and coral bleaching. Environmental valuation techniques such as choice experiment, contingent valuation, travel cost were also used as keywords within search engines such as Science direct and Google scholar and journals dedicated to marine valuation. From the search, 120 studies have been considered for the study with 4 review papers. The available values of each valuation study were converted to 2019 $ values using GDP deflator figures for easy comparison. The studies were then classified based on the ecosystem types and management areas. Eg: wetlands mangroves, Further, details were summarized according to application of various environmental valuation methods to value marine ecosystems. Studies were also tabulated based on specific focal areas such as water quality aspects and trends related to marine valuation research were identified.

4. Results on Valuation Literature

Table 1 presents ecosystem-based valuation summary. Specific ecosystem types were categorized under the main categories of coastal and marine ecosystems. Wetlands, Mangroves, Marshes and Samps were considered and under each geographical location are indicated.

Table 1. Ecosystem types and management areas

Specific Ecosystems	Country	No. of Papers	Reference
Coastal ecosystems			
Wetlands	Indonesia Mexico Iran France USA Sri Lanka Australia	11	Brander *et al.* (2012), Brander, *et al.* (2013), Camacho-Valdez *et al.* (2013) Kaffashi *et al.* (2012) Westerberg *et al.* (2010) Woodward *et al.* (2001), Shivlani *et al.* (2003) Rathnayake RMW Prayaga *et al.* (2017)
Mangroves	Ireland Tanzania Malaysia Indonesia Sri Lanka Colombia	7	Whitehead *et al.* (2008) Lange and Jidawi (2009) Pascoe *et al.* 2014 Brander *et al.* (2012), Brander, *et al.* (2013) Rathnayake (2016) Rojas *et al.* (2019)
Marshes	Indonesia Mexico	4	Brander *et al.* (2012), Brander *et al.* (2013), Camacho-Valdez *et al.* (2013), Barr and Mourato (2009)
Swamps	Indonesia Mexico Iran	3	Brander *et al.* (2012), Camacho-Valdez *et al.* (2013) Kaffashi *et al.* (2012)

Specific Ecosystems	Country	No. of Papers	Reference
Subtotal for wetlands		**25**	
Beaches	U.S.A China Sri Lanka Greece Australia	11	Beharry-Borg *et al.* (2010), Bhat (2003), Font (2000), Landry *et al.* (2020) Huang (*et al.* 2007) Rathnayake RMW, Sivakumar (2016), Sivakumar (2019) Kontogianni *et al.* (2014) Zhang (2015)
Subtotal for beach		**11**	
Coastal protected natural areas	Mexico U.S.A UK Sri Lanka Spain Italy China India	15	Barr & Mourato (2009), Camacho-Valdez *et al.* (2013), Almendarez *et al.* (2020) Beharry-Borg and Scarpa (2010), Brumbaugh *et al.* (2008) Ghermandi and Nunes (2013), Ghermandi (2015) Hanley *et al.* (2003) Balasuriya (2018), Jayasekara and Gunawardena (2019), Jayaratne *et al.* (2016) Jayaratne *et al.* (2019) Rodrigues *et al.* (2016) Tonin (2019), Bertram *et al.* (2020) Liu *et al.* (2019) Mukhopadhyay *et al.* (2020)
Capes	UK	1	Hanley et al, (2015)
Peninsulas	UK	1	Hynes *et al.* (2013)
Barrier islands	UK	1	Kline and Swallow (1998) etc
Subtotal for coastal area		**18**	
Rivers and streams	USA UK Philippines	5	Ojeda *et al.* (2010), Liu & Stern (2008) Lipton *et al.* 2014, Luisetti *et al.* (2011) Samonte-Tan *et al.* (2007)
canals,	USA	1	Ojeda *et al.* (2008)
Lakes	UK USA Ireland	4	Torres *et al.* (2017), Voke, *et al.* (2013) Wilson *et al.* (2005) Whitehead *et al.* (1993)
Reservoirs	UK USA Ireland	4	Hicks *et al.* (1999), Siderelis *et al.* (1995), Wilson *et al.* (2005) Whitehead *et al.* (1993)
Deltas, estuaries and catchments	USA, Spain	3	Ojeda *et al.* (2010), Duijndam (2020) Pouso *et al.* (2020)
Subtotal for river basin		**17**	
Bays	UK USA Sweden Iceland	8	Jobstvogt *et al.* (2014), Wattage *et al.* (2011) Barbier *et al.* (2011), Rönnbäck *et al.* (2007) Hasler (2016) Cook *et al.* (2020)
Gulfs	Sweden Ireland USA UK	4	Hasler (2016) Hynes *et al.* (2018) Huang *et al.* (2007) King (1995)
Sounds, Fiords	USA	1	Kaoru (1995)
Inland Seas and Sea Waters near the coast	Australia Sri Lanka	3	Liu and Stern (2008) Hettige *et al.* (2014), Prakash *et al.* (2019)
Subtotal for coastal water		**16**	

Specific Ecosystems	Country	No. of Papers	Reference
Marine ecosystems			
Coastal coral reef	Jamaica France New Caledonia Zanzibar USA Australia Indonesia UK Sweden Philippines Israel Thailand Japan	25	Cesar and Chong (2004), Cesar *et al.* (2000) Westerberg *et al.* (2010) Marre *et al.* (2015) Ngazy *et al.* (2004) Laurans *et al.* (2013) Prayaga (2017), Peachey (1998) Brander *et al.* (2012) Rees *et al.* (2015) Rönnbäck *et al.* (2007) Samonte-Tan *et al.* (2007) Wielgus, *et al.* (2002), Wielgus *et al.* (2003) Tapsuwan and Asafu-Adjaye (2008) Carlson (2015)
Subtotal for coral reef		**25**	
Deep sea	Zanzibar	1	Lange and Jiddawi (2009)
Open ocean (Including Cold-Water Corals)	UK	4	McVittie and Moran (2010) Wattage *et al.* (2011)
Subtotal for deep sea		**5**	
Marine conservation zones	Australia Seychelles Malaysia Vietnam USA Sri Lanka Japan	8	Carlsen and Wood (2004) Mwebaze and MacLeod (2013) Pascoe *et al.* (2014), Yacob *et al.* (2009) Svensson *et al.* (2008) Jeong and Haab (2004) Ranjan *et al.* (2017) Shah *et al.* (2019)
Subtotal for marine protected areas		8	
Marine Parks	Sweden Greece, USA Sri Lanka	4	Paulrud (2004) Remoundou *et al.* (2009) Rees *et al.* (2010) Jayaratne *et al.* (2017)
Subtotal for marine parks			
Marine Reserves	USA	1	Rees *et al.* (2015)
Subtotal for marine reserves		**1**	
Marine Sanctuaries and Marine Critical Habitat Units	USA, Sri Lanka	2	Chong and Cesar (2004) etc, Senarathne *et al.* 2015
Subtotal for marine sanctuaries and marine habitat		**2**	
Total		**132**	

According to the table, coral reefs and deep sea have received the most attention. Few studies have been done on inland and transitional waters and the researchers have been particularly interested in contributing to the management of wetlands, beaches, coastal waters and Marine Protected Areas (MPAs). Some researchers for example, Brander *et al.* (2012), Brander, *et al.* (2013) have carried out research in multiple countries and in multiple ecosystems.

The main focus of many MPA studies has been on coral reefs. Moreover, wetlands and coastal areas also have been under the focus and many valuation studies have positively contributed to management of such areas (Whitehead *et al.* 2008) and (Castaño-Isaza *et al.* 2015; Hanley *et al.* 2003; Loureiro *et al.* 2013 and Torres and Hanley, 2017). The main aim of many valuation studies was to provide inputs towards the management of marine resources. This publication pattern has also been found for studies that have valued services provided by inland and transitional waters, (Parsons *et al.* 2013; Miller *et al.* 2015). Majority of papers focusing on services offered by coastal waters, coral reefs and MPAs have been published during the last decade (Brander *et al.* 2012; Torres and Hanley, 2017). This is especially true for studies on deep-sea services, which have received attention by the scientists and economists recently. (Wielgus *et al.* 2009; Lange and Jiddawi 2009; Beharry-Borg and Scarpa 2010; Ghermandi *et al.* 2010).

4.1 Values of Coastal and Marine Ecosystem Services

In early research, value classifications had their focus on the concept of Total Economic Value (TEV) (Hanley *et al.* 2003). Majority of the recent studies have adopted the Ecosystem Services (ES) (Prayaga, 2017). The main focus has been on cultural services especially recreational values provided by coral reefs and coastal habitats (Söderberg et al, 2014 and Börger*et al.* 2014). Significantly high benefits have been reported along with correlations to the quality of the environment being valued (Onofri and Nunes 2013). The estimated use values provide sound justification for further protection of these areas and estimation and incorporation of non-use values of marine resources would provide additional justifications (Lange and Jiddawi 2009).

4.2 Diversity of Methods of Valuation

The results indicate a wide variety of valuation methods adopted by different studies. Among the 120 studies, 37 have used choice experiment, 30 have adopted contingent valuation method and 30 were based on travel cost method. Other methods included Combined Stated and Revealed Preference Approach, Hedonic Analysis, Productivity Change Method, Random Utility Models and Value Transfer Approaches. Values on number of studies done and mean value in US$ under each category are presented in Table 2. Many researches have estimated recreational values including both local and global values. The concepts of total economic value and the ecosystem service framework have been commonly used in the studies. Valuation focus was wide ranging including economic value of ecosystem services in the coastal regions, value of wetlands in supporting recreational fishing, benefits of coral ecosystems, indirect and existence value of coastal and marine biodiversity, recreation value of coastal lagoons and values of beach erosion control.

According to table 1, many studies have been done in developed countries (61%) compared to developing countries (39%). Table 2 illustrates a summary of valuation studies carried out in different countries for different ecosystem types. Many Asian countries have focused on valuing coral reefs since it is main tourist attraction which positively contribute to Gross Domestic Product (GDP) for developing countries (Asafu-Adjaye and Tapsuwan, 2008; Senarathne *et al.* 2015; Pascoe 2014) etc. Another way to classify valuation studies are based on single country vs. multiple countries. For example, some studies have covered several countries in the European region Ahtiainen and Vanhatalo (2012) while many studies have focused on individual countries. Certain valuation studies have focused on specific aspects of marine ecosystems such as eutrophication (Ahtiainen and Vanhatalo, 2012) or pollution, oil spills over exploitation issues etc.

Value of Ecosystem Services has been carried out in Sri Lanka for, Bar Reef Marine Sanctuary (Senarathne *et al.* 2015) and Pigeon Island National Park (Jayaratne *et al.* 2016). Marine ecosystem conservation has been valued by (Jayaratne *et al.* 2019) for Hikkaduwa National Park and recreational values also has been estimated for Hikkaduwa National Park (Jayasekara and Gunawardena, 2019). In Sri Lanka several studies have been done to protect certain species e.g.: (Rathnayake, 2016). Table 2 represents the valuation method and the number of studies conducted under each method and basic statistics related to estimated values.

According to the below table majority of studies have adopted choice experiment method (39). Maximum value under CE method is 113.23 and minimum value is 0.48. Whereas the standard deviation is 34.83 and the mean value is 32.35. There are 36 studies on travel cost method. Maximum consumer surplus is US$ 18075 billions and minimum is US$ 1.43. Standard deviation of the travel cost studies is US$ 361.43 and the mean value is US$ 648.97. Maximum value of the contingent valuation studies is US$ 3600 million per year and minimum value is US$ 1789 million per year. Standard deviation is US$ 1450 million per year and the mean is US$ 1754million per year.

Table 2. Application of various environmental valuation methods to value marine ecosystems

Method	No. of Studies	Unit US$	Maximum	Minimum	Standard Dev.	Mean
Contingent Valuation Method	33	Aggregated value Millions/year Per person	3600 120	1789 2.02	1450 48.58	1754 44.37
Choice Experiment Method	39	per person	113.23	0.48	34.83	32.35
Combined Stated and Revealed preference method	5	Billions per year	8200	125	3057	3732.6
Value Transfer approach	3	Billions per year	4748	1770	2353	3259
Travel Cost Method	36	Total consumer surplus (Billions)	18075	1.43	361.43	648.97
Decision Tree	2	Billions/year	142	114	22.62	128.45
Hedonic Analysis	5	Billions/year	32.45	12.23	14.29	47.65
Random Utility Models	5	Billions/year	42.65	2.53	28.36	38.54
Productivity Change Method	4	Billions/year	1.25	0.12	0.79	0.25

Table 3 provides a summary of travel cost studies done and the consumer surplus values. Accordingly highest Consumer surplus amounts to US$23 billion per year and the lowest consumer surplus amounts to US$1.63 (increased consumer surplus per trip).

Table 3. Summary of travel cost studies

Topic	Author	Value (2026)
Recreational value of Coastal and Marine Ecosystems in India a macro approach	Mukhopadhyay *et al.* (2020)	23 billion
Valuing coral reefs: a travel cost analysis of the Great Barrier Reef	Carr and Mendelsohn (2003)	1232 million to 2.82 billion
Estimating the potential impact of entry fees for marine parks on dive tourism in South East Asia	Pascoe *et al.* (2014)	6.07 billion per year
Monetary valuation of recreational fishing in a restored estuary and implications for future management measures	Pouso *et al.* (2020)	1.70 million per year
Management of a marine protected area for sustainability and conflict resolution: Lessons from Loreto Bay National Park (Baja California Sur, Mexico)	Stamieszkin *et al.* (2009)	434.7 million
Can people value protection against invasive marine species? Evidence from a joint TC–CV survey in the Netherlands	Nunes and van den Bergh (2004)	417
Divers' willingness to pay to visit marine sanctuaries: an exploratory study	Arin and Kramer (2002)	150.5
An economic assessment of marine recreational fishing in southern California	Wegge, *et al.* (1986)	159.6
Recreation demand and economic value: An application of travel cost method for Xiamen Island	Weiqi *et al.* (2004)	88.9

Topic	Author	Value (2026)
Travel cost analysis of recreation value in the Wet Tropics World Heritage Area	Driml (2002)	90.3
Studies on marine ecosystem services and valuation: a case of Nanji Archipelagos Natural Marine Reserve	Pan *et al.* (2009)	33.50
The efficiency of the environmental management charge in the cairns management area of the Great Barrier Reef Marine Park	Farr (2011)	26.40
Recreational Value of the Coral Surrounding the Hon Mun Islands in Vietnam: A Travel Cost and Contingent Valuation Study	Nam *et al.* (2004)	29.4
Fees for reefs: economic instruments to protect Mexico's marine natural areas.	Rivera and Muñoz (2005)	24.2
Incorporating users' perceptions of site quality in a recreation travel cost model	Siderelis *et al.* (2000)	25.1
The recreational value of Lake McKenzie, Fraser Island: An application of the travel cost method	Fleming and Cook (2008)	17.70
Travel cost methods for estimating the recreational use benefits of artificial marine habitat	Milon (1988)	32.6
An economic analysis of coral reefs in the Andaman Sea of Thailand	Seenprachawong (2016)	4.28
"Should 'ParaviwellaBeach'in Sri Lanka be Preserved for 'Sea Bathing'?": A ZTCM Approach.	Rathnayake (2015)	4.32
Economic valuation of the Hon Mun Marine Protected Area	Nama *et al.* (2005)	1.63

Table 4 provides a summary of travel cost studies done and the values are based on per person values. Accordingly highest value has been recorded as US$ 2358 and lowest value amounts to US$ 1.82 per person.

Table 4. Studies done based on travel cost method

Topic	Author	Values ($2026) per person US$
Economic valuation of sportfishing in the surroundings of Cerralvo Island, Baja California Sur, Mexico using the travel cost method	Almendarez *et al.* 2015	2358
The value of Tiger Shark diving within the Aliwal Shoal marine protected area: a travel cost analysis	Du Preez *et al.* (2012)	1420 (per tiger shark)
Recreational benefits from a marine protected area: A travel cost analysis of Lundy	Chae *et al.* (2012)	620 to 991
Economic evaluation of the recreational value of the coastal environment in a marine renewables deployment area	Voke *et al.* (2013)	178
The value of coastal lagoons: Case study of recreation at the Ria de Aveiro, Portugal in comparison to the Coorong, Australia.	Clara *et al.* (2018)	165 per day

Topic	Author	Values ($2026) per person US$
Contingent Behavior and Asymmetric Preferences for Baltic Sea Coastal Recreation	Bertram *et al.* (2020)	140 (Finnish sample) 296 (German sample) 56 (Latvian sample)
Access to marine parks: A comparative study in willingness to pay	Peters and Hawkins (2009)	137.53 per day
Valuing beach width for recreational use: Combining revealed and stated preference data	Parsons, *et al.* (2013)	113 overnight access value
Application of non-market valuation to the Florida Keys marine reserve management	Bhat (2003)	60
The recreational value of gold coast beaches, Australia an application of the travel cost method	Zhang *et al.* (2015)	24.34
Managing the marine environment: is the DPSIR framework holistic enough?	Atkins *et al.* (2011)	23
Valuing snorkeling visits to the Florida Keys with stated and revealed preference models	Park, *et al.* (2002)	2.99
British tourists' valuation of a Turkish beach using contingent valuation and travel cost methods.	Blakemore & Williams (2008)	1.82

Table 5 and 6 provides a summary of contingent valuation studies. Based on the 30 studies recorded, some studies have provided per person values and some studies have provided aggregated WTP values. Highest value has been recorded as US$ 4577 million per year. Lowest value has been recorded as US$ 0.43 per person as an entrance fee.

Table 5. Summary of contingent valuation studies

Study	Author	Value $ (2026)	Unit
International public preferences and provision of public goods: assessment of passive use values in large oil spills	Loureiro and Loomis (2013)	Spain 179.47, UK 116.65, Australia 128.53	Per household
User fees as sustainable financing mechanisms for marine protected areas: An application to the Bonaire National Marine Park	Steven (2010)	78 to 170	Per person
Valuing marine turtle conservation: A cross-country study in Asian cities	Jin *et al.* (2010)	1.83 (Beijing),1.56 (Davavo) 1.40 (Bangkok) 1.22 Ho Chi Minh	Per person
Contingent valuation of marine protected areas: Southern California Rocky intertidal ecosystems	Hall, *et al.* (2002)	208.49	Per household
Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs)	Jobstvog *et al.* (2014)	152.56	Per person
Divers' willingness to pay to visit marine sanctuaries: an exploratory study	Arin and Kramer (2002)	133.49	Per person
Economic valuation for the conservation of marine biodiversity	Beaumont *et al.* (2008)	122.05	Per person per year

Study	Author	Value $ (2026)	Unit
Recreational diver preferences for reef fish attributes: economic implications of future change	David *et al.* (2015)	80.09	Per person
Economic valuation of beach quality improvements: comparing incremental attribute values estimated from two stated preference valuation methods	Loomis and Santiago (2013)	68.65	per visitor day
Valuation of natural marine ecosystems: an economic perspective	Remoundou *et al.* (2009)	35.6	Per person
A contingent valuation study of scuba diving benefits: Case study in Mu KoSimilan Marine National Park, Thailand	Asafu and Tapsuwan (2008)	34.33	per person per year
Valuing multi-attribute marine water quality	Eggert and Olsson (2009)	27	Per person
Hotel managed marine reserves: A willingness to pay survey	Svensson *et al.* (2008)	12.2	Per room per night
Economic evaluation of the recreational value of the coastal environment in a marine renewables deployment area	Voke *et al.* (2013)	11.82	Per person
Marginal WTP and distance decay: the role of 'protest 'and 'true zero 'responses in the economic valuation of recreational water quality	Söderberg and Barton (2014)	9.53	Per person
Economic valuation of environmental services sustained by water flows in the Yaqui River Delta	Ojeda *et al.* (2008)	4.84	Household per month
Collective versus voluntary payment in contingent valuation for the conservation of marine biodiversity: an exploratory study from Zakynthos, Greece."	Stithou, *et al.* (2012)	3.83	Per person
Contingent valuation of ecotourism in Marine Parks, Malaysia: implication for sustainable Marine Park revenue and ecotourism management	Mohd *et al.* (2009)	3.26	Per visit
Willingness to pay as an economic instrument for coastal tourism management: Cases from Mersin, Turkey	Birdir *et al.* (2013)	3.23	Per adult beach visit

Study	Author	Value $ (2026)	Unit
Estimating the value of marine resources: a marine recreation case	King, (1995)	2.57	Per person
A contingent valuation study of marine parks eco-tourism: The Case of PulauPayar and PulauRedang in Malaysia	Yacob *et al.* (2009)	2.40	Per local visitor
Valuing marine parks in a developing country: a case study of the Seychelles	Mathieu *et al.* (2003)	0.43	Entrance fee
Economic Values of Coastal Erosion Management: Joint Estimation of use and existence values with recreation demand and CVM data	Landry *et al.* (2020)	27.97	Per household per year
Evaluation of the non-use value of beach tourism resources: A case study of Quingdao coastal scenic area China	Liu *et al.* 2019	12.71	Per year

Table 6. Summary of contingent valuation studies (aggregated values)

Study	Author	Value $ (2026)	Unit
Charging for nature: marine park fees and management from a user perspective	Uyarra *et al.* 2010	4577	millions Per year
Benefits of meeting nutrient reduction targets for the Baltic Sea - a contingent valuation study in the nine coastal states	Ahtiainen et al. (2014)	4189	Millions aggregated WTP
Valuing marine and coastal ecosystem services: an integrated participatory framework	Mathieu and Videira (2013)	3313	Millions aggregated WTP
Access to marine parks: A comparative study in willingness to pay	Peters and Hawkins (2009)	2275	Millions aggregated WTP
Can people value protection against invasive marine species? Evidence from a joint TC - CV survey in the Netherlands	Nunes *et al.* (2004)	414	Millions per year
A contingent valuation approach to estimating the recreational value of commercial whale watching - the case of Faxafloi Bay Iceland	Cook *et al.* 2020	1.25	Millions per year
The recreational benefits of coral reefs: A case study of PulauPayar Marine Park, Kedah, Malaysia	Yeo (2004)	644,900	Recreational value of the reefs in the park
Valuing recreational benefits of coral reefs: The case of Mombasa Marine National Park and Reserve, Kenya.	Ransom and Mangi (2010)	492,000	aggregated WTP
Estimating the use and preservation values of national parks	Lee and Han (2002)	605,000	aggregated WTP

Table 7 gives a summary of choice experiment studies. Based on the recorded studies highest value recorded amounts to US$ 253.4 (per year). Lowest value that has been recorded amounts to US$ 0.20 for an increase of fish catch by 10%.

Table 7. Summary of choice experiment studies

Study	Author	Value $ 2026	Unit
Valuing a Caribbean coastal lagoon using the choice experiment method: The case of Simpson Bay Lagoon, Saint Martin	Duijndam *et al.* (2020)	14.95 Mn	Per year
Valuing marine ecosystem service damage caused by land reclamation: Insights from a deliberative choice experiment in Jiaozhou Bay China	Shan *et al.* (2020)	253.4	Per year
Public willingness to pay for recovering and down listing threatened and endangered marine species	Wallmo and Lew (2012)	53.8 & 98.3	Per household for Chinook salmon & Per household for north pacific right whale
Valuing marine and coastal ecosystem service benefits: Case study of St Vincent and the Grenadines' proposed marine protected area	Christie *et al.* (2015)	13.9 & 34.1 US$	Locals per household per year and Tourists per household per year
'Turtle watching': A strategy for endangered marine turtle conservation through community participation in Sri Lanka	Rathnayake (2016)	0.94 for locals & 19.3 for foreigners	Per visit
Economic valuation of the non-use attributes of a south-western coastal wetland in Bangladesh	Ghosh and Mondal (2013)	0.64 million	Per year
Impact of a local, coastal community-based management regime when defining marine protected areas: Empirical results from a study in Okinawa, Japan	Shah *et al.* 2019	0.20, 0.80,0.64	for a 10% increase in the number of fish catch, for 10% increase in the extent of coral coverage
Economic Valuation of sport fishing in Sweden	Paulrud and Anton (2004)	187.3	net value per day
Economic valuation of beach quality improvements: comparing incremental attribute values estimated from two stated preference valuation methods	Loomis and Santiago (2013)	130	per visitor day
A boating choice model for the valuation of lake access	Siderelis *et al.* 1995	189	Per household per annum
Valuing the benefits of improved marine environmental quality under multiple stressors	Tuhkanen *et al.* (2016)	103	per household per year
Economic valuation of recreational fishing in Western Australia:	Raguragavan *et al.* (2013)	93	per person
Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application	Brander *et al.* (2012)	86.5	per ha per year
Conservation of maritime cultural heritage: A discrete choice experiment in a European Atlantic Region	Durán *et al.* (2015).	78.7	per year
Economic valuation and conservation: Do people vote for better preservation of Shadegan International Wetland?	Kaffashi *et al.* (2012)	79.6	per person
Economic evaluation of the recreational value of the coastal environment in a marine renewables deployment area	Voke *et al.* (2013)	72	per person
Estimating indigenous cultural values of freshwater: A choice experiment approach to Māori values in New Zealand	Miller *et al.* (2015)	53	per year
Non-market use and non-use values for preserving ecosystem services over time A choice experiment	Baptiste *et al.* (2015),	32.8	per visitor

Study	Author	Value $ 2026	Unit
application to coral reef ecosystems in New Caledonia.			
Conservation of maritime cultural heritage: A discrete choice experiment in a European Atlantic Region	Duran *et al.* (2015)	31.5	Per person
Valuing multi-attribute marine water quality.	Eggert and Olsson (2009)	21.28	Annual tax
Cultural bequest values for ecosystem service flows among indigenous fishers: A discrete choice experiment validated with mixed methods	Oleson *et al.* (2015)	30.8	Per person per year
Valuing conservation benefits of an offshore marine protected area	Borger *et al.* 2014	25.1	Per visitor
Valuing public goods: the purchase of moral satisfaction	Kahneman and Knetsch (1992)	27.5	Per person
Evaluation of the non-use value of beach tourism resources: A case study of Qingdao coastal scenic area, China	Liu *et al.* (2019)	12.8	Per visitor per year
Valuing climate change mitigation: A choice experiment on a coastal and marine ecosystem	Remoundou *et al.* (2015)	8.3	Per person per year
Public and expert preference divergence: evidence from a choice experiment of marine reserves in Australia	Rogers (2013)	6.0	Per person per month
Consumers' willingness to pay for the color of salmon: a choice experiment with real economic incentives	Alfnes, *et al.* (2006)	5.7	Per kilogram of fish
Social welfare and marine reserves: Is willingness to pay for conservation dependent on management process? A discrete choice experiment of the Ningaloo Marine Park in Australia	Rogers (2013)	4.6	Per month per 10% increase in live coral cover
Valuation of environmental improvements in a specially protected marine area: A choice experiment approach in Göcek Bay, Turkey	Can and Alp (2012)	4.25	per person per visit
Recreational SCUBA divers' willingness to pay for marine biodiversity in Barbados	Schuhmann *et al.* (2013)	4.15	per person per year
Conservation values and management preferences for the Ningaloo Marine Park: a discrete choice experiment	Rogers (2012)	3.9	Per person per month
Valuing enhancements to endangered species protection under alternative baseline futures: the case of the Steller sea lion	Lew. *et al.* (2010)	4.1	per person
Effects of coral reef attribute damage on recreational welfare	Wielgus *et al.* (2003)	4.0	per dive
Economic valuation of regulating services provided by wetlands in agricultural landscapes: A meta-analysis	Brander *et al.* (2013)	2.0	per ha per year
Economic value of conserving deep-sea corals in Irish waters: a choice experiment study on marine protected areas	Wattage *et al.* (2011)	1.56	per year
Ecosystem benefits from coastal habitats - A three-country choice experiment	Kosenius *et al.* (2015)	1.06	As annual tax
Valuing improvements to coastal waters using choice experiments: An application to revisions of the EU Bathing Water Directive	Hynes *et al.* (2013)	0.64	annual tax
Recreational diver preferences for reef fish attributes: economic implications of future change.	Gill *et al.* (2015)	0.63	Per dive
Preferences for Coral Reef and Fishery Management in Okinawa, Japan.	Carlson (2015)	0.60	per month for 10% increase in biodiversity

4.3 Role of Environmental Valuation (EV): in Developing Country Settings

Coastal and marine resources have significant contribution to livelihood of the surrounding communities especially in the low-income countries (Oleson et.al 2015). These resources play an additional role in reducing income disparities and valuation exercises are important in highlighting such contributions (Lange and Jiddawi 2009; Loomis *et al.* 2013 and Voke *et al.* 2013). Valuation studies have played an important role in highlighting cultural service values over other direct and indirect uses (Ngazy *et al.* 2004). According to studies done in India (Atkins *et al.* 2007), Madagascar (Oleson *et al.* 2015), Southeast Asia (Brander *et al.* 2012), Seychelles Mathieu *et al.* (2003) and Tunisia (Westerberg *et al.* 2010) bequest values have provided foundation to cultural, social and ecological sustainability in the long run. According to studies done in Mexico by Barr and Mourato (2009), payments for ecosystem services could be used as mechanisms to address poverty issues (Czajkowsk *et al.* 2015, Castaño-Isaza *et al.* 2015 and Ojea *et al.* 2010).

In developing countries like Sri Lanka, policies have rarely paid attention to incorporate values of environment. The challenge is to make use of economic values to design appropriate management and policy strategies so that the value expressed by respective user categories of these recreational resources are captured to ensure the long-term sustainability of these valuable natural assets. The findings call for the need of taking appropriate measures for minimizing the activities which cause environmental degradation. Applications in green accounting can be used to incorporate the economic values more effectively. Further policy instruments can be used in fisheries management and coastal area development. A suitable institutional mechanism would be required in order to avoid congestion and resultant overexploitation of ES. Also, existing governance structure has to be strengthened appropriately to ensure the sustainability of the ecosystem.

Table 8 provides a summary of marine ecosystem valuation studies done in Sri Lanka. The most commonly adopted methods are CVM and TCM.

Table 8. Marine ecosystems valuation studies done in Sri Lanka

Author	Method used	Value Range US$ (2026)	Value focus
Senarathne *et al.* (2015)	CVM	0.38 million per year	Bar reef Marine Sanctuary
Jayaratne *et al.* (2016)	CVM	Visitors 0.42 million per year Households 11,230 per year	Pigeon Island National Park
Jayasekara *et al.* (2019)	TCM	8.75 per local visitor	Local recreational value
Rathnayake (2016)	CVM	Mean WTP for local visitor 0.93 and 1.43 (for two scenarios) foreigners 19.16 and 24.27	Two different management scenarios for turtle conservation
Rathnayake (2015)	TCM	$0.046 million (consumer surplus)	Local recreational value

Table 9 provides a summary of recreational and environmental quality aspects of marine/coastal areas of Sri Lanka. According to Buultjens *et al.* (2016) and Prakash *et al.* (2019), there has been several attempts towards proper management of whale watching. Properly executed valuation method may help in attaching a price tag based on visitor's willingness to pay for whale watching and such values are helpful for the policy makers to make informed decisions.

Hettige *et al.* (2014) has attempted assessment of coastal water quality along the Western Province coastal line and recommended means of mitigating the pollution. Calculation of cost of such pollution could guide the decision makers on improving the quality of water. Replacement cost approach could be used to measure the cost incurred in converting the water to the usable quality.

Table 9. Recreational and Environmental quality aspects of marine/coastal areas of Sri Lanka

Author	Topic
Balasuriya (2018)	Coastal Area Management: Biodiversity and Ecological Sustainability in Sri Lankan Perspective.
Buultjens *et al.* (2016)	Whale watching in Sri Lanka: Perceptions of sustainability
Hettige (2014)	Water Pollution in Selected Coastal Areas in Western Province, Sri Lanka: A Baseline Survey
Prakash *et al.* (2019)	Current perceptions and the need for a strategic plan for the whale watching industry in Mirissa, Sri Lanka
Ranjan *et al.* (2017)	Service Quality and Its Impact on the Level of Tourist Satisfaction in Marine Based Recreation

Sivakumar (2019)	Assessment of marine water quality and its suitability for recreational activities in Pasikudah beach
Sivakumar (2016)	Preliminary assessment of marine water quality in bathing, surfing and fishery areas of arugam bay
Wilhelmsson, D (2002)	Monitoring the trends of marine ornamental fish collection in Sri Lanka

Sivakumar (2016 and 2019) based on scientific evidence (such as dissolved oxygen level, nitrate and phosphate values) established suitability of Pasikudah beach for recreation and Arugam Bay. Economic value can be estimated for these beaches to inform the policy makers about the importance of these areas.

4.4 Valuation Studies with Special Focus on Environmental Aspects

Some other studies have focused on individual species (Aanesen *et al.* 2015; Brumbaugh *et al.* 2008; Lew *et al.* 2010; Rathnayake 2016) while some research have focused on pollution, water quality aspects oil spills and similar overexploitation issues. The following table represents the studies based on water quality aspects.

Table 10. Studies based on water quality aspects

Topic in brief	Country	Mean value US$ (2026)	Reference
Water quality improvements	Denmark	6.33	Atkins *et al.* (2007)
Valuing quality changes in Carrabin coastal waters	Tobago	2.93 on average to visit a beach with up to 2 boats near the coastline.	Beharry-Borg and Scarpa (2010)
Benefits of coastal water quality improvement	UK	12.63 per person	Hanley *et al.* (2003)
EU Bathing water directive (valuing improvements to)	Europe	9.93	Hynes *et al.* 2013
European water framework directive	Europe	67.70	Kataria. et.al. (2012)
Measuring the recreational benefits of water quality improvement	Japan		Kaoru, Y. (1995).
Economic valuation of recreational water quality	Norway		Söderberg et al, 2014
Hedonic analysis of lake water quality	USA	4529 (marginal value of a loon)	Tuttle and Heintzelman (2015)

Evidence shows that assessment of water quality has been mainly established in developed countries. Developing countries like Sri Lanka has not attempted such studies. Studies such as Tuttle and Heintzelman (2015) indicates how property values are affected by water quality. Such results illustrate the influence of water quality on various sectors of the economy.

4.5 Trends in Marine Valuation Research

CVM has been applied in a wide range of empirical context in the last two decades. Different valuation methods are shown to produce widely different values.

King (1995) has used open ended WTP method and used multiple linear regression method to arrive at the value of the ecosystem using contingent valuation method. Recreational values of coral reefs have been mainly assessed by the CVM. Different coral reef valuation studies have estimated a variety of welfare measures (Beaumont *et al.* 2008). Arin and Kramer (2002) have estimated willingness to pay of divers for marine sanctuaries. Hall *et al.* (2002) have used the CVM approach to estimate benefits from better management of MPA that could avoid depletion of coastal ecosystems.

Benefits of scuba diving in Thailand Mu Ko Similan Marine National Park has been estimated by Asafu-Adjaye, and Tapsuwan (2008) using CVM. They have calculated the present value of these aggregate benefits (ranges between US$31 and US$71 million), using a social discount rate of 3%. Yacob *et al.* (2009) have applied dichotomous choice survey design-CVM to investigate empirically the willingness to pay (WTP) of the visitors for ecotourism resources in two selected marine parks in Peninsular Malaysia. It has used Logit and Probit models to estimate the visitor's WTP responses for conservation the marine parks for ecotourism. Liu *et al.* (2008) have analyzed 39 contingent valuation papers with 120 observations to conduct the first meta-analysis of the ecosystem service values provided by the coastal and near shore marine systems. Their results show that over three quarters

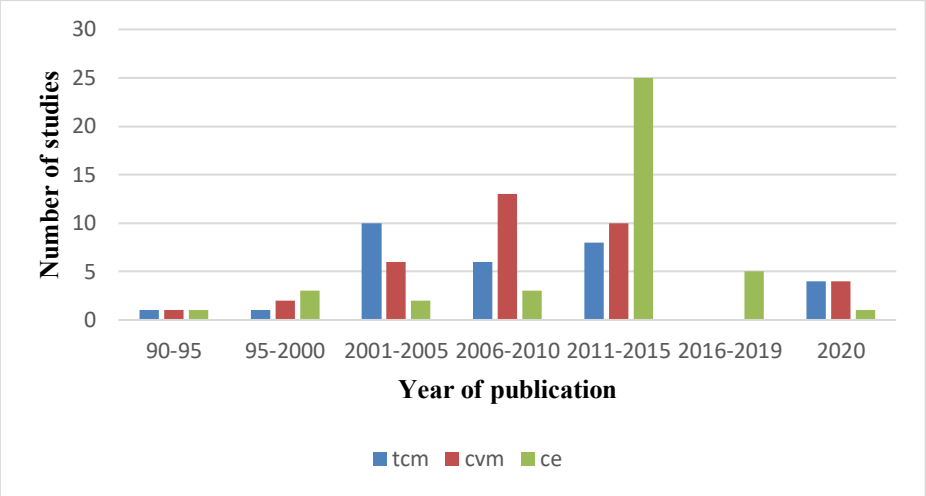
of the variation in Willingness to Pay (WTP) for coastal ecosystem services could be explained by variables in commodity, methodology, and study quality.

Travel cost method (TCM) which has been most commonly used to value marine resources has been criticized for its inability to capture non use values of unique marine habitats. According to Aanesen *et al.* (2015) stated preference methods need lot of effort to capture the knowledge. Therefore, choice experiment method has evolved.

The theoretical background behind choice modelling (CM) was developed by economists and mathematical psychologists. The method is based on the Here, the individual decision making process is modelled in a specific context. CM is the common method that has been applied in the recent years. It is a non-market valuation method and is widely used in guiding ecosystem conservation. In recent research by Shah *et al.* (2019) choice experiment method has been used to derive to assess the substitutability between man-made and natural capital for MPAs.

Below mentioned graph illustrates the trends of marine valuation studies carried out over the years. From 1990 to 1995 only a few studies have been done and with the passage of time number of research done has been increased. Initially, studies have adopted mainly CVM and travel cost methods and at the latter stages more studies have adopted choice experiment method.

Figure 1. Trend of research done over the years



Source: compiled by the author

5. Gaps in Current Research

In the global context, there is a significant volume of coastal and marine valuation (Menzel *et al.* 2013). However, this has not yielded equivalent rise in the adoption of economic values in the policy context or in management decision making. Economic values have only been a source of information (Font, 2000, Marre *et al.* 2015 and Laurans *et al.* 2013). It is important to overcome the limitations of valuation and according to Hanley *et al.* (2013 and 2015) mainly focus on the limitations of Economic Valuation and emphasize that "the need to communicate ES research more effectively and to improve understanding of the realities of policy makers to economist and marine and coastal scientist". Collaboration between economist and natural scientist is also lacking at present. Sustainable ecosystem management requires integration of natural and social science disciplines.

In the Asian region, the main marine attraction are coral reefs and it is urgently required correct information that are useful in park management tasks. In Sri Lankan context, many marine MPAs have demonstrated failures in achieving their conservation objectives-(Wattage, *et al.* 2011 and Perera and Vos, 1997). Main problems faced by developing countries like Sri Lanka are lack of economic instruments, economic values often not been estimated and not recognized, non-incorporation of potential climate change impacts on coastal and marine ecosystems within the policy context. Further, lack of economic values applications and marine resource related comprehensive reviews is also an issue in Sri Lanka.

6. A Marine Recreational Research Agenda for the Future

A deeper look into the available research indicates that much of the ecological complexities of the marine ecosystems have not been in the center of many studies. There is only little attention paid towards complex

dynamism that underpins the flow of marine recreational services. Therefore, there is a need for novel approaches that combine underlying sensitivities of the ecosystems and sustainable flow of resources and the economic values.

Individual marine ecosystems are under constant influence from the rest of the large ocean governed by global currents and other climatic variables which are subjected to the variations brought by the climate change. Marine resources are therefore having characteristics of public goods that it is constantly been subjected to degradation from activities taken place in immediate proximity and from distant locations. It is therefore important to establish baseline resource valuations due to the uncertainty that surrounds on the short and long term and proximate and distant changes that might impact the resource in question. Developing countries face inequities from two directions: Their ocean resources are being depleted by the major greenhouse gas–emitting nations. At the same time, in order to earn much-needed foreign exchange through tourism, they often sacrifice short-term provisioning services for their own populations and instead prioritize cultural services for foreign visitors. As a result, both immediate provisioning services and the potential cultural services that could benefit the majority when they achieve higher income levels are compromised. These countries remain victims of climate change impacts caused by polluters, despite having little or no role in generating those emissions.

The demand for key ocean and coastal based provisional services in developing nations are arising from two main sources: firstly, the declining productivities and increasing costs of the land based agriculture implies higher demand for food from ocean and secondly, increasing income of the population implies upward demand for food from oceans.

Quality of recreational resources will not be affected from the direct threats as traditionally understood. Many threats are unknown and unseen. Threats to marine organisms from chemicals and land based pollution is also high. Therefore, valuation of the baseline is important with attention paid towards potential threats. Pollution from micro plastics is one such issue that can bring long lasting impacts on the coastal resources. Maritime accidents pose another significant threat and Sri Lanka is currently facing one of the worst chemical accidents in the world maritime history. Sea level rise will also bring a significant threat and therefore valuing marine resources and the associated potential losses would be important which can be added to the cost side of the climate change and to justify the implementation of the adaptation measures. Land expansions towards the seaside are also on the rise. Coastal stability largely depends on sand supply from the land side. Lack of understanding on such dynamics can lead to excessive erosion in the coast leading to multiple losses. The burden of such activities will be on the already stressed recreational activities and supporting natural infrastructure.

When the incomes of the developing country are on the rise, there is a tendency that they seek for avenues that increase quality of life and therefore more recreational resources. The novelty of the resources and the variety of experiences have to be maintained in order to cater for the ever-increasing demands for recreation. This is especially true for tropical coastal states and developing countries.

7. The Need for Global Regional Cooperation with Respect to Sustainable Development Goals

Focusing only on sustainable development goals 14 and 15 is not enough there is a need for a long term all-encompassing global authority that could govern and ensure health of the coastal and marine ecosystems. The links between marine resources and the main economic activities need to be identified without delay.

A learned focus on synergies between different ecosystem services is worth attention. Many intact cultural services implies proper flow of provisioning services. Properly functioning intact coral ecosystem means fishery resources are abundant. Similarly, intact mangroves is a source of recreational values as well as it enriches the fish productivity. Fisheries sector and recreational sector are therefore synergistic as long as the sustainability of the service flows are guaranteed.

Understanding this ground reality is important in the valuation context. Extractive values such as fishing should not damage the coral structure (or any other intact ecosystem) and coral viewing should not damage the coral itself (case of glass bottom boats) and the associated fish need to be protected. Valuation exercises need to emphasize / highlight such jointly feasible /synergies more often than tradeoff stories.

Functional relationships have to be established among resources such as mangroves and fish productivity, mangroves and coastal stability, mangroves and coastal scenery etc.

Nonuse values have always given a lesser emphasis within the valuation literature since coastal resources are more of ‘used ‘resources than ‘non-used’ resources. When the focus is on non uses, the recreation and infrastructure will become irrelevant. However, the resources have to be maintained to the maximum extent possible. Yet, the relationships between status of conservation and nonuse values is a little understood subject. Future research may be designed to address such gaps.

The carrying capacity aspect of marine recreational resources has largely been understudied. It is important to combine carrying capacity studies with the valuation studies. Coupling of valuation with crowding will enable to plan the resources properly (Rathnayake and Gunawardena, 2014). For example, visitor management strategies need to be coupled with the recreational clusters which provide similar level of recreational opportunities. Preferences towards such recreational resource clusters could be estimated before designating them as clusters. Currently these are missing in the valuation literature.

The phenomenon of crowding suggests that many environmentally responsible uses of resources are displaced by non-use values. The central challenge, therefore, is how to elevate these concerns to the forefront of the research agenda. In particular, the problem of free-riding highlights the need for institutional mechanisms that safeguard resources on behalf of non-users. One possible approach is the formal designation of certain resources as strict conservation areas, thereby ensuring that the preferences and concerns of non-users are adequately represented in policy and practice.

In summary, valuation has to be focused on establishment of baseline valuation studies with potential degradation issues in mind especially, climate change related land-based overexploitation related, ship accident related, conversion to other uses related, crowding related etc. Decision making tools such as cost benefit analysis need to be applied more rigorously in these areas to arrive at more informed decisions. Provisioning and cultural services nexus – sustainable limits of provisioning services are both very important to be in the top priority in the marine valuation agenda. Valuations on costs of exceeding sustainable capacities are not available - future research agenda need encompass all these. In addition, more coordinated efforts have to be in place among neighbouring countries to get a more complete overview of the various facets of the total value of the marine recreational resources.

Another area of concern is where the local communities are constrained by income and their valuations may not reflect the true preferences. In addition, when the local communities are unfamiliar on the hypothetical market structures, there may be errors in the estimated values. The valuation methods can be designed to reflect such concerns in further research. (Kataria *et al.* 2012, Schuhmann and Mahon 2015).

8. Discussion: Implications for Education, Culture, and Public Policy

The findings of this review not only highlight methodological diversity and ecosystem-specific valuation trends but also underscore broader implications for education, culture, and public policy. From an educational perspective, the synthesis of valuation approaches provides a valuable resource for curricula in environmental economics, marine science, and sustainability studies. By incorporating case studies and valuation outcomes into teaching materials, universities and training institutions can cultivate a new generation of professionals equipped to apply economic valuation in practical conservation and management contexts.

Culturally, the recognition of recreational and non-market values associated with marine ecosystems reinforces the importance of these resources as part of community identity and heritage. Valuation studies that capture cultural services - such as recreation, aesthetic appreciation, and spiritual connections - help articulate the intangible benefits that coastal and marine ecosystems provide to societies. This strengthens arguments for conservation not only on economic grounds but also in terms of preserving cultural continuity and social wellbeing.

In terms of public policy, the review reveals a persistent gap between valuation research and its application in decision-making. Bridging this gap requires institutional reforms that integrate valuation outcomes into national accounts, coastal zone management plans, and climate adaptation strategies. Policymakers can use valuation evidence to justify investments in marine protected areas, restoration projects, and sustainable tourism initiatives. Furthermore, embedding valuation into policy frameworks enhances transparency in resource allocation and ensures that trade-offs between competing uses of marine ecosystems are addressed systematically. Ultimately, the integration of valuation into education, cultural discourse, and policy processes can foster a more holistic and sustainable approach to marine resource governance, aligning conservation priorities with societal values and long-term economic resilience.

Conclusion

Correct estimation and appropriation of economic values of marine and recreational resources can provide essential information for the day-to-day management as well as long term planning of these resources with correct level of resource allocation. There are various threats that could bring significant degradation of these resources and establishment of baseline values are important especially in the case of climate vulnerable coastal states with high population that are located in heavy maritime traffic areas.

Valuation experts need to think ahead to plan the valuation studies that can cater for the local and global needs with long term sustainability of these resources in mind. Each country needs to prepare their research agendas considering the needs of policy makers, conservationists, local managers, local communities, users, non-users and future generations in mind.

Declarations

Credit Authorship Contribution Statement:

Full Name of Author 1: write the contribution of first author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Project administration, Software, Formal analysis, Writing – original draft, Supervision, Data curation, Validation, Writing – review and editing, Visualization, Funding acquisition);

Full Name of Author 2: write the contribution of the second author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Project administration, Software, Formal analysis, Writing – original draft, Supervision, Data curation, Validation, Writing – review and editing, Visualization, Funding acquisition);

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Declaration of Use of Generative AI and AI-Assisted Technologies: The authors declare that they have not used generative AI and AI-assisted technologies during the preparation of this work.

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Determinants of Tourism Growth in India: Analysing Economic and Environmental Factors Influencing Inbound and Domestic Tourism (2022–2023)

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Abstract: This research paper focuses on the tourism industry as a vital sector that plays a significant role in driving economic growth, generating employment opportunities, preserving cultural heritage, and strengthening international relationships. The study further explores the economic and environmental determinants that shape both inbound and domestic tourism in India. The research incorporates Pearson Correlation Matrix, Factor Analysis, and Multiple Linear Regression to analyse data sourced from government reports and articles for the year 2022. The top three countries from which India received the highest number of tourists in 2022 were the U.S.A, Bangladesh, and the U.K. Factor analysis revealed that 83.31% of total variance in tourism growth is explained by three major components, strongly linked to economic and disaster-related factors. The Kaiser-Meyer-Olkin (KMO) value was 0.668, confirming sampling adequacy, and Bartlett's Test of Sphericity was significant ($p = 0.000$), validating the use of factor analysis. Pearson correlation results show a strong relationship between Inbound Tourism and State GDP ($r = .772$), and similarly between Domestic Tourism and State GDP ($r = .767$). Regression analysis revealed a strong predictive model with an R value of 0.84 for inbound tourism and 0.799 for domestic tourism. The study concludes that economic factors such as GDP growth and effective utilization of sanctioned tourism funds are vital drivers for tourism development in India, alongside the need for effective disaster management strategies.

Keywords: inbound tourism; domestic tourism; disaster impact; tourism growth factors.

JEL Classification: O44; Z30; Z32

Introduction

This study primarily focuses on the growth of tourism in India following the impact of the COVID-19 pandemic. Tourism was one of the most severely affected industries globally during and after the health crisis. According to the United Nations World Tourism Organization, India welcomed approximately 17.91 million international tourists in 2019. However, this number sharply declined to 6.34 million in 2020 and 7.00 million in 2021 due to pandemic-related restrictions. It was only in 2022 that the sector began to recover, recording a rebound with 14.33 million foreign tourist arrivals. Globally, several countries that heavily rely on tourism - such as the Maldives, Seychelles, Aruba, Macau, Fiji, Thailand, the Bahamas, Saint Lucia, Grenada, Jordan, and Croatia - faced severe economic setbacks during 2020 and 2021. These nations experienced significant losses in GDP and employment, highlighting the vulnerability of tourism-dependent economies in times of global crises. However, by 2022, many of these countries began to regain stability as inbound tourism started to recover. (Jagdale and Ganatra 2021) Due to the impact of COVID-19, all tourism destinations in India experienced a 30% decline in domestic tourism. Additionally, the tourism industry witnessed a significant rise in unemployment, increasing from 10% to 20% (Jagdale and Ganatra 2021). Tourism plays a crucial role in enhancing the economy of many countries. With proper government

planning and investment, a healthy environment can be created for both tourists and industries associated with tourism. (Sun *et al.* 2021)

India is a country rich in culture, home to diverse languages, ancient heritage sites, and unique architectural marvels - all of which continue to attract foreign tourists. Following the COVID-19 pandemic, which caused a major disruption in global travel, the Indian government implemented several recovery measures to revitalize the tourism sector. Key actions included the launch of the Dekho Apna Desh campaign to promote domestic tourism, providing financial support to tour operators and travel agencies, extending e-Visa services to more countries, and implementing strict safety and hygiene protocols to restore traveller confidence. Additionally, initiatives like the Swadesh Darshan Scheme (Ministry of Tourism, and Government of India, "Developing Sustainable and Responsible Destinations.," Swadesh Darshan 2.0 Scheme Guidelines, 2022) and PRASHAD Scheme (Ministry of Tourism and Government of India. "PRASHAD 15th Finance Commission Scheme Guidelines.," Ministry of Tourism, Government of India., 2023) were strengthened to improve tourism infrastructure and promote spiritual and heritage tourism. After covid 19 these above schemes and helped the Indian tourism industry and began its recovery in 2022 (India records, 2023).

Inbound Tourism in India

Inbound tourism refers to visitors from other countries exploring India's diverse tourist destinations. It significantly boosts the nation's economy, culture, heritage, and natural beauty while creating employment, encouraging research, and building international relationships. Countries like Russia, with its 26 world-class destinations, and Malaysia, which promotes business, health, and food tourism, show how inbound tourism supports economic growth and job creation (Okhrimenko and Timakova 2021, Rupam, Vinayaraj and Jeetesh 2016, Jingjing and Peter 2018). Globally, inbound tourism also fosters regional development through R&D, innovation, and FDI, highlighting the importance of infrastructure and heritage-based events to attract international visitors (Okhrimenko and Timakova 2021, Alluri and Venkateswarlu 2023).

In India, 10.93 million Foreign Tourist Arrivals (FTA) and 17.91 million International Tourism Arrivals (ITA) were recorded in 2019, including 6.98 million NRIs, 5.7 lakh diaspora tourists, 3.3 lakh medical tourists, 1.8 lakh business travellers, 1.2 lakh holiday visitors (Sengupta and Chandni, 2020) and, the Government launched schemes like the Swadesh Darshan Scheme (2014–15), targeting eco, wildlife, tribal, and heritage tourism with thematic circuits To boost inbound tourism in India. By 2015–16, over ₹3,000 crore was spent under the scheme, with ₹160 crore for the Northeast, ₹78 crore for eco-tourism, and ₹68 crore for tribal circuits (Mishra, Sen and Ojha 2016). The PRASHAD Scheme further strengthened regional pilgrimage tourism, funding destinations like Velankannai, Kanchipuram, Puri, and Varanasi in multiple instalments (Karthilingam and Kannan 2020). It also focused on enhancing tourist amenities - ATM access, green energy, Wi-Fi, walkways, and water transportation - with major allocations in 2020 (*e.g.*, ₹129 crore for Uttar Pradesh and ₹69 crore for Punjab) (Ministry of Tourism, "Final Report on Study, Analysis and Development of Action Plan based on World Economic Forum Ranking System for Travel & Tourism Competitiveness for India," 2019) which help in the recovery of covid 19 crisis.

The Ministry of Tourism (2019) outlined five pillars for tourism development: business facilitation, safety, health, human resources, and infrastructure. These five pillars play a major role in upbringing the inbound tourist to India (Modi and Shah 2024). Economic analyses show a positive relationship between tourism and national income: there is a relationship between hotel transport and trade with forging exchange earnings and foreign tourist arrival revealed in R^2 of 99% using regression model (Sagar and Retheesh 2020). This was further supported by a correlation coefficient of 0.995, showing a near-perfect relationship between inbound tourism and foreign exchange earnings (Jayswal and Jaiswal 2016) increase in the number of inbound tourist paves way to foreign exchange earnings to India.

The introduction of the E-Visa led to a massive jump in foreign tourist inflow - from 39,000 in 2014 to 4.45 lakh in 2015, with particularly high arrivals in December (Abdull, Albahadili and Noori 2019). In total, 1,690 tourists from 42 countries used the E-Visa facility, including 465 from the USA and 300 from the UK hence after covid 19 E-visa helped the arrival of foreign travellers to visit India (Iyer and Thomas 2019) India's UDAN Scheme aimed at affordable regional connectivity through flights capped at ₹2,500, benefiting over 60 lakh passengers (Kumar *et al.* 2021) Pre-UDAN, Gujarat had seven airports; post-UDAN, states like Uttar Pradesh, Maharashtra, and Tamil Nadu saw expansions. The number of states with 4–7 airports grew from 7 to 13, while those with just 3–4 fell from 15 to 10, with new airports built in Himachal Pradesh and Haryana (Thoma, Handuj and Iyer 2020). A Mann-Whitney U test showed Indian travelers were significantly more satisfied than foreign travelers with the scheme at a 1% level, and eight routes including Shimla–Delhi and Salem–Chennai scored 100% efficiency (Singla and Singh 2023).

To further enhance tourist experience, Indian Railways introduced luxury trains and "tourist-friendly stations" with modern amenities, alongside inclusive tourism packages (Kumar and Komaraiah 2014). Railways contributed

27% to tourism growth in 2017–18, though it declined to 12.96% in 2019–20. Over 52.3% of young travellers reported satisfaction with improvements in services, and 90% praised food hygiene and overall service quality (Kumar 2016; Poongavanam *et al.* 2021). The Sagarmala Project, launched by the Ministry of Shipping, invested ₹8 lakh crore across 400 projects to modernize port infrastructure and promote cruise tourism in states like Kerala, Goa, Maharashtra, and Tamil Nadu. A one-way ANOVA test confirmed that factors like age, employment, and expenses were closely linked to cruise satisfaction (Ministry of Tourism, "Cruise Tourism – Potential & Strategy Study" 2005). While ocean, river, and luxury day cruises were launched, further promotional strategies and FDI are needed. Ports in Chennai, Kochi, Goa, Mumbai, Mangalore, and Tuticorin have been prioritized, with Kochi hosting over 25 cruise ships in 2016 alone (Chawla 2017).

Domestic Tourism in India

Domestic tourism refers to people traveling within their own country. It plays a vital role in bridging the gap left by international tourists, especially in lesser-known destinations. This form of tourism generates substantial revenue and contributes significantly to the national economy. Being one of the oldest and simplest modes of travel, it usually requires no formal documentation. Most domestic travelers use cost-effective surface transport like trains, buses, cars, or bikes, making it affordable. Moreover, it is inclusive and accessible to people from all economic backgrounds, enabling unrestricted travel across the country. Many people believe that domestic tourism is more cost-effective compared to outbound tourism. It offers easier access to destinations within the country and eliminates the need for travel documents, making it a more convenient option for many travelers (Nurul *et al.* 2020). Tourists often prefer domestic food over unfamiliar international cuisine and avoid the difficulties associated with currency exchange (Nurul *et al.* 2020). Additionally, online media platforms have played a significant role in spreading awareness and providing real-time updates on transportation and travel options, further supporting the growth of domestic tourism (Melese 2022). Technological advancements have enhanced the overall experience and accessibility of domestic travel. In contrast, the complex documentation and regulations required for international travel often discourage people from exploring other countries. However, developing countries like Ethiopia still face challenges in fully developing their domestic tourism sector (Bayih and Singh 2020). Despite this, domestic tourism holds great potential to strengthen a nation's economy and cultural identity. Through awareness programs, event organization, and proper employee training, attitudes toward domestic destinations are gradually changing for the better (Bayih and Singh 2020). Tourists increasingly seek opportunities to interact with local communities and participate in cultural activities. Hence, it is essential that tourism workers are trained to provide comprehensive information about local culture and destinations to enrich the visitor experience (Chebli, Kadri and Said 2022).

From 1997 to 2012, domestic tourism in India saw steady growth, rising from 160 million to 1036 million visitors. Notably, in 2004 and 2009, there was an 18% increase compared to the previous years (Malik, and Nusrath 2016). People primarily preferred domestic tourism for a change in climate, while marketing practices significantly influenced destination choice; however, pricing had minimal impact on their decision-making (Radhika and Jayalakshmy 2016). The growth of domestic tourism in India is driven by a safe and clean environment, rising incomes, changing lifestyles, and better infrastructure. Government initiatives, such as promotional campaigns and organized events, have further supported this trend (Chougle 2014). Post-COVID-19, the increasing population has notably impacted destination demand, with many people making weekend domestic trips a regular habit (Shyju *et al.* 2024).

The steady increase in India's GDP - from an average growth of 3.6% (1950-1955) to 6.6% (2000-2004) - has contributed significantly to the rise of domestic tourism. Economic growth has enhanced people's income and travel capacity, boosting tourism demand (Basu and Maerten 2007). The sustainable economic growth in India is driven by financial development, people's saving and investment habits, a robust financial system, impactful new policies, and industrialization. These factors have also supported the expansion of domestic tourism by increasing economic stability and spending power (Dogga, Kuruva and Kashyap 2023). Increased earning capacity raises people's income, where income influences consumption more than wealth. Past consumption patterns also help determine the country's disposable income, which boosts domestic tourism demand (Khari 2023). In India, most people prioritize spending on education over health, while the government supports the poor through insurance schemes and allocated ₹1.38 lakh crore for the health sector. Improved social welfare and government support contribute indirectly to the growth of domestic tourism by enhancing overall wellbeing (Sinha and Adhikary 2020). By 2025, the spending capacity of the middle and upper-middle classes in India is expected to rise, with urban middle-class populations growing significantly. Since the 1991 reforms, poverty has decreased due to this growth, which in turn boosts domestic tourism demand (Beinhocker, Farrell and Zainulbhai 2007). The lower and new middle-class populations in India grew from 23.6% and 28.9% (1999-2000) to 30.1% and 50.3% (2011-2012),

respectively. This expansion has positively influenced domestic tourism by increasing the number of potential travelers (Krishnan and Hatekar 2017).

India ranks third globally in internet usage, with over 20 crore users annually and 8.33% of global internet share. A study found that 95.33% of respondents were familiar with computers, reflecting strong digital adaptation that supports domestic tourism through online access to travel information and services (Sing 2012). India's younger generation is increasingly adopting a Western lifestyle, leading to greater comfort and reliance on digital devices like mobiles, computers, and tablets. This shift has significantly influenced consumer behavior, including how people plan and engage in domestic tourism (Joseph and Singh 2013). The Indian government allocated $105 billion for highways, civil aviation, and irrigation, and $361 billion for ports, railways, telecom, and electricity. Policies like the Road, Railway, Airport, and Port policies were introduced to strengthen infrastructure, which indirectly supports domestic tourism growth (Mishra 2012). The Tourism Policy of 1982 encouraged private sector participation and volunteer involvement to strengthen the tourism sector. The National Action Plan for Tourism (1992) aimed to boost domestic and international tourism, enhance destination services, and generate employment opportunities (Alpesh and Shri 2022).

Role of GDP in Tourism Development

Tourism plays a vital role in increasing a country's GDP, as growth in both domestic and inbound tourism greatly influences economic development (Vedapradha *et al.* 2017). Several key factors determine GDP growth through their impact on tourism. Government policies and regulations that support the tourism sector encourage investment and sustainable development (Mishra 2012). Infrastructure development, such as transportation networks and hospitality facilities, improves accessibility and the overall tourist experience (Prajapati and Parikh 2022). Natural resources, including scenic landscapes and cultural heritage sites, attract visitors and generate revenue (Nayak and Hanagodimath 2024). Technological advancements facilitate better marketing, booking systems, and service delivery within the tourism industry (Ukpabi and Karjaluoto 2017). Additionally, growth in the labor force, especially a skilled workforce in tourism-related sectors, enhances the quality and capacity of services, further boosting the contribution of tourism to GDP (Patra *et al.* 2017).

India is known for its vast cultural diversity and unique tourist destinations, often referred to as the "subcontinent of the world." Visitors can experience a wide array of people, languages, customs, religions, heritage sites, and cultures. Ancient temples and traditional artwork continue to attract foreign tourists, making tourism a significant contributor to India's GDP (Shekhar 2025; Kumar 2025). With 26 states, each possessing distinct languages and cultural practices, India also promotes strong domestic tourism. Inter-state travel allows people to explore and admire diverse traditions and lifestyles, thereby bolstering domestic tourism - a crucial component of economic development (Shekhar 2025; Simpson 2024). Several industries are closely connected to tourism - including hotels, restaurants, transportation, food & beverage, retail, banking, and financial services. These allied sectors substantially contribute to the GDP by supporting and enriching the tourism experience (Simpson 2024).

Tourism significantly contributes to a country's GDP, acting both as a driver and a beneficiary of economic growth. In India, the tourism industry rebounded to contribute approximately 5% of GDP in FY 2022–23, driven primarily by strong domestic tourism, which exceeded pre-pandemic spending levels and helped the sector reach ₹19.13 trillion. Employment in the sector also rose by 10% over 2019 levels (Bastian, Bastian and Rabitz 2019; Sreyesh and Vamshidhar 2024). Globally, the travel and tourism industry accounted for around 9–10% of GDP before the pandemic, with its total contribution - including indirect and induced effects - projected to reach $11.1 trillion (about 10% of global GDP) in 2024, supporting nearly 348 million jobs worldwide (Goretti et al., 2021).

Empirical analyses using cointegration and causality models confirm that in India, both government tourism expenditure and private investment significantly promote GDP growth, reinforcing the tourism-led growth hypothesis. Moreover, strong correlations have been observed between tourism turnover, employment, foreign exchange earnings, and GDP growth, underscoring tourism's dual role as both a contributor to and a reflection of economic development (Singh and Alam 2024, Sreyesh and Vamshidhar 2024).

Disaster and Its Impact

The global human population has crossed 8.2 billion, with people spread across diverse regions of the world. Some countries have extremely high populations, such as India with 1.43 billion, China with 1.41 billion, the United States with 335 million, and Indonesia with 278 million. In contrast, some countries have very small populations, including Vatican City with around 800 people, Tuvalu with 11,500, Nauru with 12,300, and Palau with 18,000 (World Population Review 2025, United Nations Department of Economic and Social A, India Population 2025). People live in a wide variety of environments, including hill stations, coastal areas, desert regions, river valleys, forests,

plateaus, polar regions, and islands. Regardless of the location, people strive for a peaceful life. However, this peace is often disrupted by natural and man-made disasters.

In areas with high population density, man-made disasters are more common and more impactful. These include industrial accidents, building collapses, urban fires, and transport accidents (Kumar 2024). Coastal populations are especially vulnerable to natural disasters such as cyclones, hurricanes, typhoons, tsunamis, rising sea levels, and coastal erosion (Haran *et al.* 2020). Similarly, people living in hill stations are at risk from landslides, earthquakes, flash floods, forest fires, avalanches, cold waves, and heavy rainfall (Praveen and Rajesh 2021). Different regions experience different types of disasters, and the impact of these disasters is usually classified as either high impact or low impact. When a disaster occurs in a densely populated area, the consequences are severe - this is considered a high-impact disaster. On the other hand, if a disaster strikes an area with little or no human presence, the damage and loss are minimal, and it is termed a low-impact disaster. Therefore, the level of disaster impact is often determined by the density of the human population in the affected area (Choo and Yoon 2024).

Global climate change is leading to an increase in various natural disasters worldwide, including earthquakes, cyclones, floods, and extreme temperature events (Maarten *et al.* 2008). These escalating hazards underscore the significant environmental impacts and growing challenges faced globally, profoundly affecting human populations and national development. For instance, natural disasters have affected an estimated 68 million people worldwide and reduced country development after such events (González *et al.* 2021). The May 1960 Chilean earthquake, the world's largest at Richter 9.5, affected a 300-mile area (Steinbrugge and Clough). This devastating event resulted in over 3,000 deaths and left millions homeless. Deadly cyclones, formed by low pressure at sea, cause immense global devastation, exemplified by a Typhoon with 305 km/h winds that left over 20,000 homeless in Japan, caused extensive landslides, and led to over $50 million in industrial losses (Breaton, *et al.* 2023). These disasters critically impact vulnerable communities, with many fishermen losing lives and livelihoods due to destroyed boats and high sea waves (Sea *et al.* 2021). Flooding, triggered by heavy rainfall, snowmelt, or cyclones, submerges land, severely impacting national economies, especially where drainage is poor. Besides destroying infrastructure, floods degrade the environment, harm agriculture and wildlife, contaminate groundwater (Aldardasawi and Beytullah 2021), and spread diseases, leading to fatalities, homelessness, joblessness, and compromised drinking water supplies (Husain, Trak and Meshram 2018). Climatic shifts profoundly affect daily life, with cold waves (temperatures below 10°C) impacting Indian regions like Himachal Pradesh and Delhi, affecting agriculture, transportation, and causing over 1100 reported deaths, primarily between October and January (Nair 2023, Bhatla *et al.* 2016).

Among man-made disasters, war devastates economies, infrastructure, and health systems, leading to mass casualties (*e.g.*, 100,000 deaths, including women and children) and widespread mental distress (Mohsen 2008, Ventevogel 2015). Uncontrolled fires, often due to human carelessness (*e.g.*, kitchen accidents, electrical faults), destroy forests and lives, frequently originating from industrial and transport settings (Planas, Montiel, and Casal 1997). Terrorism, a significant global threat, involves violent acts like bombings and kidnappings, costing the world economy billions and severely impacting regions like Iraq and Afghanistan (Greenbaum, Dugan and LaFree 2007, Bardwell and Iqbal 2020). Finally, despite its economic benefits, railway transportation faces increasing accidents, with India reporting 3151 incidents from 2000-2016, mainly from human error, equipment failures, or sabotage (Aher and D. Tiwari 2017).

1. Literature Review

Disaster and its Impact on tourism Industries

This research primarily focuses on the key factors that influenced Indian tourism following the impact of COVID-19. The Indian tourism industry experienced a significant decline during the pandemic, and it was only in 2022 that the sector began to recover, gradually attracting all categories of tourists once again.

Previous studies have primarily focused on key areas such as the impact of natural disasters on Indian tourism, internal political conflicts, the global significance of inbound tourism, central government funding for tourism development, and investments aimed at increasing foreign tourist arrivals. Additionally, considerable attention has been given to the effects of the COVID-19 pandemic on the Indian tourism sector between 2019 and 2021, (Barbhuiya and Chatterjee 2020, Acheampong, *et al.* 2025, Singh and Alam 2024, Galiano Martínez *et al.* 2025). In 2016, the tourism industry directly generated approximately 25 million jobs. By 2019, it had become the second-largest employment-generating industry worldwide, employing around 4,00,37,000 people (Amutha 2016). Tourism has emerged as an indirect yet powerful driver of economic growth, enabling several developing nations to transition into more developed economies. In India, tourism is among the fastest-growing industries. Foreign exchange earnings from tourism increased significantly - from USD 1,861 million in 1991 to USD 21,071 million in 2015 (Saqib and Satar 2018).

The tourism industry is one of the most dynamic and rapidly growing sectors worldwide, significantly contributing to national economies, employment, and cultural exchange. However, it is also highly vulnerable to crises and disruptions. The COVID-19 pandemic, which struck globally in early 2020, had an unprecedented impact on tourism, leading to a near-total shutdown of travel activities across countries. According to the World Tourism Organization (UNWTO), global international tourist arrivals dropped by 74% in 2020, while India witnessed a 75% decline in Foreign Tourist Arrivals (FTA) and a drastic dip in Domestic Tourist Visits (DTV) as per the Ministry of Tourism reports. The ripple effect was felt across hospitality, transportation, and allied sectors, particularly in developing nations like India, where tourism contributes significantly to state GDP and employment (Ministry of Tourism., "India tourism statistics 2021," Government of India., 2021).

The necessity for adaptive resilience strategies in tourism to cope with future shocks. The research indicated that while international travel took longer to rebound, domestic tourism presented opportunities for quicker recovery, driven by local exploration and fewer restrictions (Gossling *et al.* 2021). Similarly, domestic tourism emerged as a focal point in post-pandemic recovery strategies due to its relatively low risk and strong potential for revenue regeneration (Kaushal and Srivastava 2021). Moreover, government policies, regional economic strength, and investment in tourism infrastructure played vital roles in the speed and strength of the tourism recovery process. Several states in India with higher GDP and well-developed tourism facilities reportedly experienced quicker rebounds in domestic travel, while those more severely affected by natural or man-made disasters lagged behind (Sharma and Nicolau 2022).

From an institutional perspective, the Ministry of Tourism launched the "Dekho Apna Desh" initiative to revive domestic travel, while also increasing sanctioned funds for tourism development across states. Data trends from 2022 suggest a noticeable uptick in DTVs, attributed to eased travel restrictions, improved infrastructure, and greater tourist confidence However, at the same time, the impact of natural and man-made disasters - such as floods, landslides, and industrial accidents - cannot be overlooked, especially in tourism-dependent regions (Ritchie and Y. Jiang 2019, Balakrishnan Nair 2020). The Research's highlighted that areas frequently hit by disasters tend to see prolonged declines in tourism inflows unless countered by effective crisis communication and recovery marketing strategies (Rosselló, Becken and Santana-Gallego 2020, Meher 2024, Pal, *et al.* 2016).

Disaster Impact

Air travel plays a significant role in spreading infectious diseases globally, as seen during the SARS outbreak, which was widely transmitted by international travellers (Baker 2015). Natural disasters such as tsunamis and cyclones have a more profound impact on tourists than heatwaves or avalanches, while terrorism and crime also decrease tourism arrivals (PARK and Y. Reisinger 2008). The global tourism sector suffered immense losses during the COVID-19 pandemic, with millions of jobs affected and top tourism-dependent countries like France, Spain, and the USA seeing sharp declines (Sultana, Islam and Islam 2020).

Economic perception and destination image significantly influence traveler decisions, especially among middle-income groups who avoid disaster-affected areas (Genc 2018). During the pandemic, countries with strong tourism sectors faced major losses, with income drops and a complete halt in travel during April–May 2020 (Salehnia, Zabihi and Safarzaei2020). Quantitative analyses of disasters like earthquakes and floods show variations in death tolls and economic losses across countries (Rossello, Becken and Santana-Gallego 2020).

Stakeholders such as hotels, transport, and tourism operators faced systemic challenges during the COVID-19 crisis, highlighting the need for resilient policies (Sigala 2020). Recovery management consists of six key stages that guide the response before, during, and after a disaster (Muskat, Nakanishi and Blackman 2014). In Nepal, the 2015 earthquake caused a drastic drop in tourism, but recovery followed with strong GDP growth and increased tourism receipts (Min *et al.* 2020). Effective risk and crisis management planning help reduce tourism-related losses during disasters (Ghimire *et al.* 2015).

In Indonesia, the "spillover effect" was observed when tourists shifted from disaster-hit areas to safer destinations, reflecting redistribution in tourism flows (Rindrasih *et al.* 2019). In Zhejiang, China, where COVID-19 originated, tourist behavior shifted toward safer, more isolated lodging options, especially among younger demographics (Hong *et al.* 2020). In addition to global and national studies, localized disaster impact assessments reveal the vulnerabilities at the household and regional levels. Patankar (2019) studied Mumbai, Chennai, and Puri and noted that floods caused damage to homes and essential appliances, while uninsured small businesses faced huge losses. Similarly, Madhanarekha (2015) documented the 2015 Chennai floods, highlighting the combined efforts of the government and volunteers during rescue operations and the inadequacy of compensation post-disaster. Goodnews Israel Oshiogbele (March 2021) emphasized the lack of awareness and communication during floods, recommending the inclusion of disaster education in school curricula and improved NGO-private sector involvement. Patil (2012) outlined India's disaster management framework post-1999, categorized into five disaster

types and managed through a network of national-level committees, including the Central Relief Commission and National Crisis Management Committee.

Studies like Pillai *et al.* (2021) explored landslide vulnerability in Ranni, Kerala, where slope, soil type, and poor drainage infrastructure contributed to disaster risk. Gupta *et al.* (2021) analyzed cyclone impacts in West Bengal, stressing the importance of IMD's early warning system and coordinated post-disaster efforts from government and NGOs. In Assam, Ali *et al.* (2021) detailed the health-oriented disaster management during COVID-19, where the state employed "Three T" (Test, Treat, Transport) and "Three S" (Surveillance, Segregate, Save) strategies, covering 30,000 villages with effective response mechanisms. Agarwal *et al.* (2021) focused on a major man-made disaster - the Deepwater Horizon oil spill in the Gulf of Mexico - which caused significant ecological damage across five US states. Lastly, Khatu *et al.* (2021) proposed cyclone shelters designed using REVIT software and manual testing to withstand structural loads, guided by Government of India and UNDP protocols. These shelters are crucial for future disaster resilience, particularly in cyclone- and tsunami-prone regions.

Tourism

A study in the Nilgiris region highlighted that destination attractiveness and support services such as transport are crucial for increasing tourist inflow, with natural beauty and climate being the major pull factors (Govindarajan 2002). Research from Zimbabwe confirmed that cultural and nature-based attractions, combined with safety, clean water, and communication services, significantly enhance destination appeal (Vengesayi, Mavondo and Reisinger 2009). In the United States, a study applying the 4Es model - Education, Entertainment, Esthetics, and Escapism - showed that esthetics strongly influenced tourists' memories, which positively affected satisfaction and destination loyalty (Quadri-Felitti and Fiore 2013). Analysis of Tamil Nadu's international tourism trends between 2001–2012 revealed a consistent 13–14% growth due to cultural heritage and coastal attractions (Kumar, Bhavani and Karthik 2014). Tourism has been defined in many ways, but studies now emphasize its pleasure-driven nature, though research in the field remains limited due to lack of historical academic interest (Butler 2015). Typology-based research confirmed that pre-visit expectations and post-visit experiences are critical in determining tourist satisfaction and likelihood of return (Żegleń and Grzywacz 2016). In Malaysia, business, medical, and gastronomic tourism were explored, with medical tourism showing the strongest association with tourist motivation and promotion (Konar, Mothiravally and Kumar 2016). A study in Malawi identified infrastructure deficits, lack of security systems, and poor hospitality education as barriers to tourism growth (Jackson 2017). Research in Tamil Nadu found that young tourists preferred the area for its environment and affordability, with recommendations to improve parking and preserve nature (Jayaprakash and Mythili 2017). In Madurai, domestic tourists valued the cultural experience and found the destination safe, with guides playing a key role in satisfaction (Ketharaj and Anitha 2018). Tourists in Tamil Nadu appreciated climate and safety but faced issues like traffic and infrastructure; they ranked local foods like homemade chocolates" highly (Sumina 2019). In Kodaikanal, tourists were attracted to scenery and climate, although high transport costs and limited guidance created dissatisfaction (Amarjothi and Kumar 2020). An analysis of ten top global tourist cities found that their advanced e-marketing and updated websites enhanced destination promotion, although cultural and sports opportunities needed improvement (Basarangil 2021). Gastronomy tourism emerged as a growing trend, with tourist food-related spending increasing from 18% to 24% between 2004–2014, highlighting the role of food in memory creation and destination value (Cetin 2021). A generational study from Turkey indicated that post-COVID, Generation X prioritizes safety while Generations Y and Z are more open to travel, though safety measures can further motivate all groups (Buzlukcu and Sahin 2021). Api tourism, involving beekeeping, honey production, and bee museums, was proposed as a unique, memory-based tourism model for rural development (Cesur 2021). Digital technology has transformed tourism promotion, making destinations more accessible through tools like websites, Google Maps, and translation apps, though it also brings risks such as fake reviews and misinformation (Onat and Karakus 2021). Historical data on tourism development confirmed that geography alone does not determine success; supporting infrastructure, trained staff, and varied cultural activities are equally vital (Aleksanyan 2021). The impact of COVID-19 on tourism in Tamil Nadu saw a major drop in tourist inflow, with recommendations to improve online booking, safety protocols, and medical tourism (Martin 2022). Tourists increasingly prefer self-guided travel using digital platforms, finding satisfaction in safety, food quality, and flexibility (Vidhyalakshmi, and Nannore 2023). The Nilgiris Mountain Railway continues to attract visitors due to its scenic views, heritage value, and affordability, contributing over 20% to Tamil Nadu's tourist inflow (Sathish and Vasanthi 2023).

Despite these valuable contributions, most of the literature has either focused on international tourism recovery or broader tourism policy changes, with limited studies offering a quantitative, state-wise analysis of domestic tourism recovery in India specifically during the year 2022, which is a crucial period marking the shift from

pandemic disruption to sectoral revival. Further, although some studies mention the importance of disasters, few have systematically included disaster-related deaths (both natural and man-made) as predictors affecting tourism trends.

2. Research Gap

Based on the reviewed literature, it is evident that prior research on tourism and disasters can be broadly grouped into three major areas. The first set of studies has focused on the development of tourism and its significant contribution to national economies, particularly in terms of GDP growth, employment generation, and foreign exchange earnings. These works often emphasize the role of government policies, funding, and infrastructure in boosting the tourism sector. The second group of studies has concentrated on the impact of natural and man-made disasters - such as floods, earthquakes, cyclones, industrial accidents, and especially the COVID-19 pandemic - on the tourism industry. These studies primarily discuss how disasters disrupt tourism, damage destination image, affect visitor behavior, and highlight the need for crisis management, resilience strategies, and emergency responses. The third strand of literature explores what makes a destination attractive to tourists. Factors such as safety, infrastructure, digital tools, cultural heritage, affordability, tourist expectations, and overall experience have been identified as crucial in drawing and retaining visitors.

However, a significant research gap remains. While the existing literature has extensively discussed tourism development, the impacts of disasters, and destination attractiveness, there is a lack of focus on how tourism recovers and develops after a disaster, particularly in the context of post-pandemic recovery. Most studies have either examined the damage caused by disasters or proposed general crisis management measures, but few have systematically analyzed the factors that influence the revival of the tourism industry after a major disruption. In the case of India, there is limited state-wise, quantitative research on how different regions have recovered since the COVID-19 pandemic and what specific factors - such as regional GDP, infrastructure quality, domestic tourism trends, or government initiatives - have contributed to this recovery. Therefore, this study aims to address the following research gap: What are the key factors that influence the revival of the tourism industry in India after a major disaster such as COVID-19, and how have different regions responded to this recovery challenge? This investigation is crucial because tourism plays a vital role in economic development, and understanding post-disaster recovery dynamics can guide future policy and planning efforts.

3. Research Methodology

This study adopts a quantitative research design to examine the factors influencing both Domestic Tourist Visits (DTV) and Foreign Tourist Arrivals (FTAs) across the 28 Indian states and 8 union territories during the year 2022. This year is significant, as it marks a turning point when India and many other countries began recovering from the COVID-19 pandemic. Tourism activities, especially domestic travel, began to rebound during this phase, while international travel also showed early signs of recovery. The dual focus on domestic and foreign tourism enables a more comprehensive understanding of the tourism sector's revival and its relationship with economic indicators, government policies, and disaster-related factors.

The objectives of this study are:

1. To analyze the relationship between state-level economic performance, tourism investments, and the volume of both domestic and foreign tourist visits in 2022.
2. To examine how natural and man-made disaster occurrences influence DTV and FTAs across Indian states.
3. To assess the role of government funding and service sector contributions in shaping tourism inflows post-pandemic.

The significance of this research lies in its attempt to fill a key gap in the existing literature by focusing on post-disaster recovery patterns in both domestic and international tourism. Most prior studies have separately examined domestic or foreign tourism or have only explored tourism disruptions during disasters. This study, however, uses updated data from 2022 to evaluate not just the impact of disasters but also the role of economic and infrastructural factors in the revival of both tourist categories.

The scope of the study includes all states and union territories of India, analyzing tourism activity at the state level. It concentrates solely on the year 2022, a critical period of post-COVID recovery, and limits its analysis to the selected economic and disaster-related indicators. The study does not include qualitative perceptions of tourists or longitudinal trends across multiple years.

Data Collection: Secondary data were sourced from reputable government and institutional databases, including the Ministry of Tourism, National Disaster Management Authority, and the Reserve Bank of India. The variables considered encompass:

- State GDP (2022): Reflecting the economic strength of each state.
- Contribution of Trade, Repair, Hotels & Restaurants Sector: Indicative of the state's service sector vitality.
- Sanctioned Tourism Funds (2014–2022): Representing government investment in tourism infrastructure.
- Natural Disaster Deaths (2022): Highlighting the impact of unforeseen natural calamities.
- Man-Made Disaster Deaths (2022): Accounting for incidents like accidents or conflicts affecting tourism.

Analytical Tools: Multiple Linear Regression analysis was conducted using SPSS software to determine the relationship between DTV and the selected independent variables. The model's validity was assessed through R-squared values, F-tests, and significance levels.

Study Area and Period: The area of the study encompasses all 28 states and 8 union territories of India, providing a comprehensive national-level analysis of both Domestic Tourist Visits (DTV) and Foreign Tourist Arrivals (FTAs) during the year 2022. This wide geographical coverage ensures that the research captures regional disparities in tourism trends, disaster impacts, and economic conditions across India. Each state and union territory serves as an individual observation unit, allowing for a comparative evaluation of how various factors - including state GDP, service sector performance, sanctioned tourism funds, and disaster-related fatalities - affect tourism inflows. The selection of India as the study area is especially relevant given the country's diverse tourism potential, vulnerability to both natural and man-made disasters, and its evolving post-pandemic recovery strategies.

The hypotheses for this study are as follows:

- **H1:** State GDP has a significant positive relationship with both Domestic Tourist Visits and Foreign Tourist Arrivals.
- **H2:** The contribution of the Trade, Repair, Hotels & Restaurants sector significantly influences DTV and FTAs.
- **H3:** Sanctioned tourism funds between 2014 and 2022 positively affect tourism activity in 2022.
- **H4:** Natural disaster deaths negatively impact DTV and FTAs.
- **H5:** Man-made disaster deaths have a significant influence on tourism inflows, particularly on FTAs.

The limitations of the study arise from its reliance on secondary data sources, which may not fully reflect local socio-cultural contexts or behavioural patterns of tourists. Additionally, the impact of marketing efforts, media coverage, or travel advisories has not been considered, and some variables that influence tourism (like visa regulations or global travel sentiment) are outside the study's scope.

4. Results and Discussion

This chapter presents an in-depth analysis of the data collected across various Indian states and union territories, focusing on the interconnected factors influencing foreign and domestic tourist inflows in the year 2022. The findings are organized to explore not only tourism volumes but also the socio-economic, infrastructural, and disaster-related variables that potentially affect tourism dynamics.

The analysis is based on a comprehensive table that includes metrics such as the nearest major international airports, foreign and domestic tourist arrivals, state GDP, sectoral contributions from trade, hotels, and restaurants, sanctioned tourism development funds (2014–2022), and natural and man-made disaster mortality rates. This multifaceted approach enables a holistic understanding of how different factors - ranging from economic strength and infrastructure to environmental safety and funding support - influence tourism at the regional level.

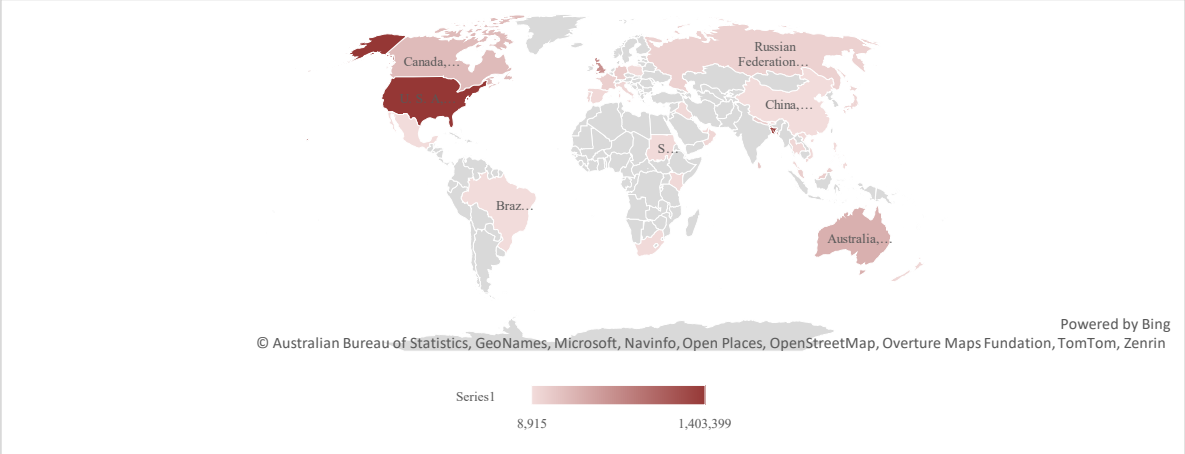
The discussion aims to interpret these figures to identify patterns and correlations, such as the relationship between airport connectivity and FTAs, economic development and tourism volume, or disaster vulnerability and its deterrent effect on tourism. Furthermore, states with high FTAs (*e.g.*, Delhi, Maharashtra, West Bengal, Gujarat) are compared with those showing low international tourist activity, despite having considerable domestic tourist visits or economic potential.

This chapter also critically examines how government support through sanctioned tourism funds aligns with the tourism performance of states, and how disaster events - both natural and man-made - impact tourist perception and safety considerations. Through this integrated discussion, the chapter offers insights that are vital for stakeholders and policymakers in planning for sustainable and resilient tourism growth in India.

Table 1. Country-wise Foreign Tourist Arrivals to India from Top Source Nations – 2022
(Breakdown by Major Western, Asian, Gulf, and Neighboring Countries)

Canada	2,89,259	Singapore	1,32,668
U. S. A	14,03,399	Thailand	54,367
France	1,20,282	Japan	64,196
Germany	1,41,425	Rep. of Korea	49,423
U.K.	6,41,051	Australia	376,898
Brazil	12,301	New Zealand	54,974
Poland	18,025	Mexico	8,915
Russian Fed.	97,911	Portugal	69,522
Kenya	35,743	Italy	62,226
South Africa	25,860	Nether lands	55,019
Sudan	24,930	Spain	39,658
Oman	56,474	Mauritius	24,743
U.A.E	43,702	Iraq	36,277
Israel	36,418	Maldives	71,707
Bangladesh	12,77,557	Bhutan	20,772
Nepal	1,38,203	Vietnam	37,232
Sri Lanka	1,83,459	Philippines	28,379
Malaysia	1,26,192	China	11,762

Figure 1. Country-wise Foreign Tourist Arrivals to India from Top Source Nations – 2022



The reasons behind visiting India can broadly be classified into two major factors: economic growth in the tourists' home countries (GDP growth) and the cost of travelling to India. Among these, GDP growth in the tourists' countries plays a crucial role. When a country experiences economic growth, it increases the disposable income of its residents. As people have more surplus income beyond their basic needs, they tend to spend more on leisure activities such as international travel. Higher GDP growth improves living standards, enhances purchasing power, and encourages individuals to explore foreign destinations for recreation, cultural exposure, and relaxation. As a result, countries with stronger economic performance often contribute a higher number of outbound tourists, including those travelling to India.

The second important factor influencing inbound tourism is the cost of travel and services in India. India is considered a cost-effective destination compared to many other international tourist locations. When the quality of tourism services - such as accommodation, transportation, food, and hospitality - is high and the overall cost remains relatively low, it becomes more attractive to foreign tourists. Affordable travel expenses combined with

diverse cultural experiences, heritage sites, and natural attractions significantly increase India's appeal as a preferred destination for international travellers.

The table presents data on inbound tourist arrivals to India during 2022–2023 from various countries around the world. It highlights the number of foreign tourists arriving from each country, reflecting the importance of international tourism in supporting India's economy, generating foreign exchange earnings, and promoting cultural exchange between India and the global community.

In 2022, India experienced a substantial rise in international tourist arrivals, with the United States emerging as the top source country. A total of 14,03,399 American tourists visited India that year, averaging approximately 1,16,950 visitors per month.

The primary motivations for their travel included a deep interest in India's spiritual heritage, architectural marvels like ancient temples, and unique shopping experiences. A major factor influencing their decision was India's cost-effectiveness; compared to Western countries, India offers a much more budget-friendly travel experience (MediaBird Magazine, "10 things that attract Americans to travel India."). While many Americans travel globally, their most frequently visited countries include Mexico, Canada, the United Kingdom, France, and Italy - primarily due to geographical proximity, ease of access, and cultural appeal.

The United Kingdom followed the United States in contributing to India's foreign tourist arrivals in 2022, with 6,41,051 British tourists, averaging approximately 53,421 visitors per month. Several factors make India an appealing destination for travelers from the U.K. A strong historical connection dating back to the colonial era has fostered sustained interest in India's cultural and architectural heritage (Anand, "Why is UK an important source market for Indian tourism? Discuss the profile of British tourists visiting India." 2024). Tourists from the U.K. are often drawn to India's UNESCO World Heritage Sites, such as the Taj Mahal, Qutub Minar, and the Ajanta and Ellora Caves, as well as spiritual destinations like Varanasi, Bodh Gaya, and Rishikesh (Singh 2024).

In addition to spiritual and cultural tourism, India's vast geographical diversity supports a wide range of travel experiences - from Himalayan treks and wildlife safaris in national parks to relaxing holidays on Goa's beaches and Kerala's backwaters. India's vibrant nightlife in metropolitan cities like Mumbai, Bangalore, and Delhi offers cosmopolitan appeal, while its affordable accommodations, food, and transportation make it a cost-effective option for long-term travel (Travel and Tour World, "India Tourism Showcases its Culture and Heritage to Allure European and UK Tourists at World Travel Market London," 2024.) Business travelers also find India attractive due to its growing economy, startup ecosystem, and expanding trade relations with the U.K. Moreover, the availability of e-visas, the promotion of India through tourism campaigns like 'Incredible India', and improved air connectivity have made travel more accessible. These diverse offerings, combined with a welcoming environment, make India a multifaceted and compelling destination for British tourists (Fida *et al.* 2023).

In 2022, India welcomed 1,277,557 tourists from Bangladesh, drawn by strong linguistic and cultural ties, medical tourism, religious and cultural interests, educational opportunities, and family or social visits. Cross-border travel to cities like Kolkata is made seamless through shared language (Bengali), cultural affinities, and close proximity - many even travel by bus or train. A significant portion of Bangladeshi visitors come for medical treatment - drawn by India's high-quality, cost-effective healthcare infrastructure, shorter wait times, and access to advanced procedures unavailable in Bangladesh. One study focusing on Kolkata hospitals found that these "demand-pull" medical tourism factors were a major motivation for more than 200 Bangladeshi patients interviewed (Choudhury *et al.* 2023). Another investigation highlighted the role of aligned procedural and interpersonal justice perceptions in prompting Bangladeshi patients to seek care in India (Nabi *et al.* 2023). Education and cultural tourism also play a role, supported by family ties and religious visits, while travel costs remain affordable, with typical 5–9 day trips costing around USD 115 - often relying on public transport (Sinha and Sharma 2020).

From the above data, it is observed that the countries with the least number of tourists visiting India in 2022 were Mexico (8,915 tourists), China (11,762 tourists), and Brazil (12,301 tourists). The lower tourist arrivals from Mexico, China, and Brazil can be attributed to factors such as long geographical distance, limited direct connectivity, and higher travel costs. In China's case, post-pandemic restrictions also affected travel. Moreover, low cultural familiarity and limited promotion of Indian tourism in these regions contributed to the reduced tourist flow.

Table 2. State-wise Overview of Tourism, Economic Indicators, and Disaster Impact in India – 2022
(Including Foreign and Domestic Tourist Visits, GDP Contribution, Sanctioned Tourism Funds, and Disaster-related Deaths)

Nearest Major International Airport Handling Foreign Tourists	State/UT	Foreign Tourists (FTAs in Thousands) – 2022	Domestic Tourist Visits (DTV in thousands) 2022	State GDP 2022	Trade, Repair, Hotels & Restaurants Contribution	Sanctioned Tourism Funds 2014 to 2022	Sanctioned Fund Years	Natural Disaster Deaths (2022)	Man-Made Disaster Deaths (2022)
Delhi Airport	Chandigarh	28,000	3,027,000	2638390000	246930000	-	–	0	0
Delhi Airport	Delhi	8,16,000	27,186,000	5488260000	989250000	-	–	0	1653
Delhi Airport	Haryana	2,000	2,108,000	5191350000	978690000	495200	2019–20	5	5705
Delhi Airport	Himachal Pradesh	29,000	15,071,000	1126330000	96100000	-	–	133	150
Delhi Airport	Jammu & Kashmir	20,000	18,499,000	1002860000	165980000	404600	2016–17	263	550
Delhi Airport	Ladakh	21,000	510,000	-	-	-	–	5	0
Amritsar Airport	Punjab	3,29,000	26,089,000	3995640000	495260000	315700	2021–22	5	53
Delhi Airport + Jaipur Airport	Rajasthan	3,97,000	108,328,000	6851050000	1410190000	326400	2015–16	22	0
Delhi Airport + Lucknow Airport	Uttar Pradesh	6,49,000	317,914,000	11160110000	1487440000	1303900	2014–15 to 2018–19	51	23
Delhi Airport	Uttarakhand	62,000	54,643,000	1732800000	403630000	1452600	2015–16 to 2021–22	66	0
Chennai/Kolkata Airport	Andaman & Nicobar	4,000	235,000	69250000	-	-	–	Nil	Nil
Gaya Airport	Bihar	87,000	25,330,000	3768230000	892110000	415400	2015–16	106	169
Kolkata Airport	Jharkhand	1,92,000	38,284,000	2392360000	364720000	391300	2018–19	131	5
Kolkata Airport	Odisha	22,000	7,868,000	4162000000	496080000	500000	2014–15	3129	459
Kolkata Airport	West Bengal	10,37,000	84,542,000	7350490000	2228490000	300300	2016–17	15	72
Assam (Guwahati domestic hub)	Arunachal Pradesh	1,000	222,000	159960000	9420000	378800	2020–21	18	0
Kolkata Airport (nearest international hub)	Assam	9,000	8,382,000	2447880000	514890000	298000	2015–16	180	200
Kolkata/Delhi	Manipur	4,000	140,000	193190000	-	-	–	58	0
Kolkata/Delhi	Meghalaya	8,000	937,000	235470000	82030000	293200	2020–21	52	0
Kolkata/Delhi	Mizoram	3,000	218,000	72640000	-	-	–	12	12
Kolkata/Delhi	Nagaland	3,000	97,000	170740000	30280000	252600	2018–19	15	2
Kolkata/Bagdogra	Sikkim	69,000	1,626,000	187380000	19130000	333200	2020–21	1	0

Kolkata/Agartala (limited international)	Tripura	8,000	236,000	377520000	57060000	378000	2020–21	0	0
Nagpur/Raipur (limited connectivity)	Chhattisgarh	0	23,636,000	299430000	156920000	433300	2020–21	5	459
Dabolim + MOPA Airport	Goa	1,75,000	7,012,000	463620000	59630000	-	–	2	5
Ahmedabad Airport	Gujarat	17,77,000	135,811,000	12946460000	1864450000	1555300	2016–17 to 2021–22	54	15934
Delhi/Nagpur	Madhya Pradesh	2,04,000	35,849,000	5460050000	1119250000	948200	2017–18 to 2020–21	311	5427
Mumbai Airport	Maharashtra	15,12,000	111,298,000	19358420000	1758890000	529200	2017–18	363	25
Mumbai	Dadra & Nagar Haveli	2,000	800,000	-	-	-	–	0	22
Chennai/Vizag	Andhra Pradesh	1,66,000	192,717,000	6724550000	819910000	708500	2015–16 to 2017–18	0	0
Bengaluru Airport	Karnataka	1,29,000	182,413,000	11875570000	1946290000	-	–	22	0
Cochin + Trivandrum + Calicut	Kerala	3,46,000	18,867,000	5459900000	1409860000	461400	2016–17	32	4317
Cochin	Lakshadweep	0	23,000	-	-	-	–	0	0
Chennai Airport	Puducherry	1,000	1,760,000	226550000	38540000	-	–	0	0
Chennai + Coimbatore + Trichy + Madurai	Tamil Nadu	4,07,000	218,585,000	12788310000	2231900000	188500	2016–17	4	0
Hyderabad Airport	Telangana	68,000	60,748,000	6435280000	2042240000	367300	2020–21	44	0

Figure 2. Sanctioned Tourism Funds 2014 to 2022

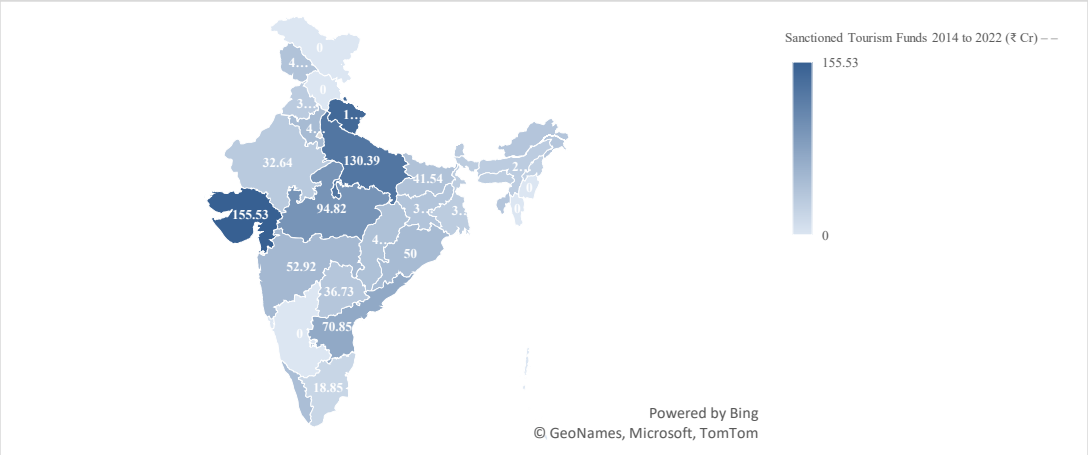


Figure 3. State GDP 2022

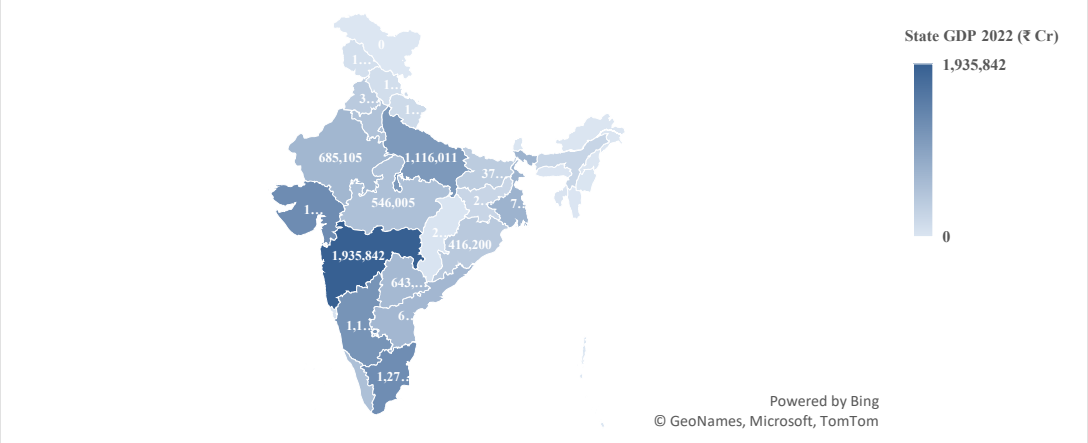
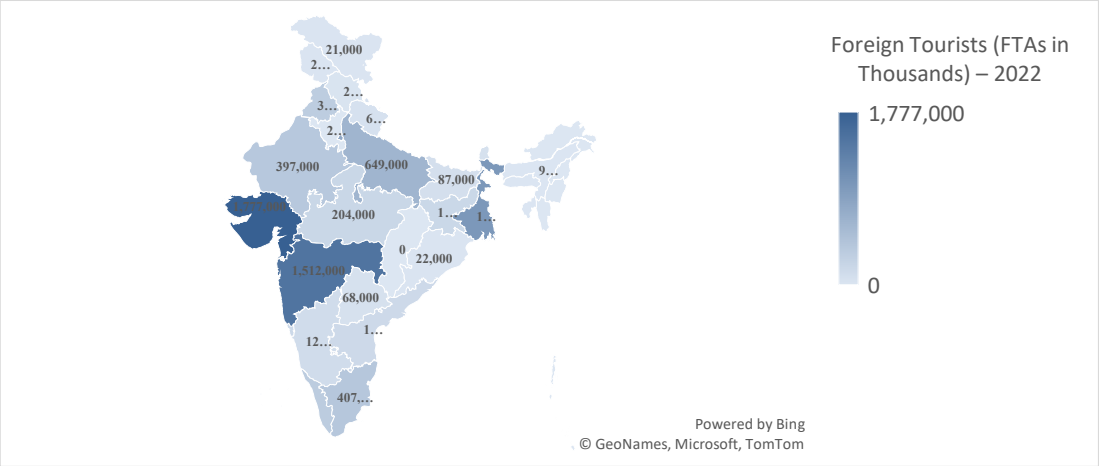


Figure 4. Foreign Tourists (FTAs in Thousands) – 2022.



4.1 Foreign Tourists (FTAs in Thousands) – 2022

In 2022, the top three Indian states that received the highest number of foreign tourists were Gujarat (17,77,000), Maharashtra (15,12,000), and West Bengal (10,37,000). These states stood out due to their excellent international connectivity, vibrant business environments, and rich cultural and heritage offerings. Gujarat is widely recognized for its diverse tourism experiences, including the Gir National Park - the only home of the Asiatic lion, the White Rann of Kutch with its iconic Rann Utsav, heritage sites like Rani Ki Vav, and spiritual destinations such as Dwarka and Somnath (Dhawan 2013, Sarkar 2024). Maharashtra, home to the financial capital Mumbai, offers a cosmopolitan experience through landmarks such as the Gateway of India, Chhatrapati Shivaji Maharaj Terminus, and a vibrant film and nightlife culture. It also houses UNESCO World Heritage sites

like the Ajanta and Ellora Caves, along with popular hill stations like Lonavala and Mahabaleshwar (Jacob *et al.* 2021). West Bengal attracts international tourists with its colonial charm and cultural vibrancy in Kolkata, the scenic beauty of Darjeeling, the unique biodiversity of the Sundarbans, and the terracotta temples of Bishnupur. The state's cultural depth and artistic heritage make it a key destination for both leisure and academic travelers (Mondal, n.d.) (Mondal 2016). Together, these three states reflect India's ability to offer a combination of nature, spirituality, history, and modern urban experiences that continue to appeal strongly to foreign tourists.

In 2022, the Union Territory of Ladakh attracted only 21,000 foreign tourists, while the northeastern states of Nagaland and Mizoram each recorded just 3,000 international arrivals. Chhattisgarh saw no foreign visitors during the year. This discrepancy primarily stems from inadequate international flight connections - for example, Ladakh's Kushok Bakula Rimpochee Airport has limited routes, and Mizoram's Lengpui Airport serves mainly domestic traffic. The challenging terrain and weak infrastructure further limit accessibility in these regions. Additionally, there is limited international promotion, though Nagaland has begun cultural promotion through events like the Hornbill Festival. These areas also cover relatively small land masses with low populations - Ladakh spans 59,146 km² with 274,000 residents, Nagaland 16,579 km², and Mizoram 21,081 km² - making large-scale tourism economically impractical (Wikipedia). Despite infrastructure enhancements such as the Atal Tunnel improving year-round access, Ladakh's tourism, which exceeded 500,000 visitors in 2022, is causing significant ecological strain - highlighting both its growing potential and the urgent need for sustainable tourism management (Yen 2025).

4.2 Domestic Tourist Visits (DTV in Thousands) – 2022

In 2022, the Indian states that received the highest number of domestic tourists were Uttar Pradesh (317.9 million), Tamil Nadu (218.6 million), and Andhra Pradesh (192.7 million). These states consistently top the charts due to their rich blend of religious, cultural, and natural attractions that appeal strongly to Indian travelers. Uttar Pradesh leads in domestic tourism primarily because of its deeply spiritual and historical destinations such as Varanasi, Ayodhya, Mathura-Vrindavan, Prayagraj, Agra, and Sarnath. The state government's promotion of the "Heritage Arc" connecting Agra, Lucknow, and Varanasi has further strengthened its tourism appeal. According to a study religious tourism in cities like Kashi and Ayodhya significantly boosts employment and local economic development. Tamil Nadu, known as the "Land of Temples," attracts visitors to iconic temples such as Meenakshi Amman in Madurai, Ramanathaswamy in Rameswaram, and the Brihadeeswarar Temple in Thanjavur (Pandey 2024). In addition, scenic destinations like Ooty, Kodaikanal, and Marina Beach in Chennai enhance the state's appeal for nature and leisure tourism. pilgrimage, coastal tourism, and government initiatives are major contributors to Tamil Nadu's tourism growth (Radhakrishnan 2015). Meanwhile, Andhra Pradesh sees the highest tourist concentration in Tirupati, home to the Sri Venkateswara Temple, one of the most visited spiritual centers in the country. Andhra Pradesh became the top domestic tourism state largely due to Tirupati's appeal, alongside growing interest in eco-tourism spots like Araku Valley and the coastal city of Visakhapatnam (Dhawan 2013). These three states effectively combine cultural depth, religious heritage, and tourism infrastructure, making them top choices for Indian travelers.

In 2022, the Union Territory of Lakshadweep (23,000 visits) and the northeastern states of Manipur (140,000 visits) and Arunachal Pradesh (222,000 visits) recorded the lowest numbers of domestic tourists in India. All three are geographically small and sparsely populated - Lakshadweep spans roughly 32 km² with about 64,000 inhabitants, Manipur covers 22,327 km² housing around 2.7 million, and Arunachal Pradesh stretches over 83,743 km² with close to 1.5 million residents - factors that limit large-scale tourism development. Their geographic isolation - Lakshadweep as a remote archipelago only accessible via Agatti Island airport and limited ferries (Salahudheen 2024). Manipur traversed through difficult terrain despite a single airport, and Arunachal constrained by sparse highway connectivity - coupled with limited infrastructure and promotion, have hindered tourist inflow (Laskar and Debnath 2024). Additionally, bureaucratic restrictions like protected-area permits in the Northeast further deter many potential domestic travelers . Although these regions possess significant tourism potential - Lakshadweep's unmatched coral reefs, Manipur's Loktak Lake (a Ramsar site), and Arunachal's scenic landscapes and cultural festivals - current visitation remains low due to accessibility and promotional challenges.

4.3 State GDP – 2022

In 2022, Maharashtra (₹19,35,842 crore), Gujarat (₹12,94,646 crore), and Tamil Nadu (₹12,78,831 crore) were the top three contributors to India's state GDP, driven by robust industrial, services, and tourism sectors. In Maharashtra, tourism plays a pivotal role in the economy - accounting for approximately 20–22 % of the state's GDP in the travel, trade, hotels, and restaurants sector, supporting thousands of jobs and regional development. Tourism is a major thrust area, contributing significantly to employment and complementing the industrial base (Malay 2025). Gujarat's tourism industry contributes around 10.2 % of the state's GDP, adding substantial

revenue through visitor spending. Research on Gujarat tourism indicates that strategic infrastructure investments and heritage promotion (*e.g.*, Rann Utsav, Gir National Park) have bolstered its economic impact (Rinkeshkumar and Mahida 2023). Lastly, in Tamil Nadu, tourism is one of the most dynamic service sectors, contributing directly and indirectly to nearly 8–8.5 % of the state GDP. The National Council of Applied Economic Research reports that tourism supports about 15 % of total employment, underlining its role in socio-economic development (Ministry of Tourism and Government of India, "Regional Tourism Satellite Account – Tamil Nadu," 2014).

Despite their rich natural resources, the northeastern states of Mizoram (₹7,264 crore), Arunachal Pradesh (₹15,996 crore), and Nagaland (₹17,074 crore) recorded the lowest GDP figures in 2022, reflecting their smaller economic base and limited diversification. Mizoram remains constrained by a predominantly agrarian economy - over 60% of its population depends on agriculture, yet industrial and service sectors are underdeveloped due to geographic isolation, poor connectivity, and limited infrastructure (Lalengkima 2022). Although the state shows high GSDP growth rates (~11.6%), this growth stems from small-scale sectors and lacks broader industrial momentum (Peter 2018). Arunachal Pradesh, with its vast yet remote terrain, continues its reliance on agriculture, forestry, and hydropower, but struggles due to deficient physical infrastructure, scant industrial activity, and fragile governance - barriers highlighted in studies like "Challenges in Economic Diversification – Arunachal Pradesh. Similarly, Nagaland depends heavily on agriculture and has minimal secondary industry; while the tertiary sector - including tourism - contributes around 58% of GSDP, this remains inadequate without substantial structural support (Kumar and Shobana 2023). A comparative study of northeastern tourism reveals that despite rich cultural and natural assets, all three states suffer from low investment, poor connectivity, lack of tourism infrastructure, and limited private-sector engagement, which collectively hinder tourism's capacity to drive GDP growth.

4.4 Trade, Repair, Hotels & Restaurants Contribution

In 2022, West Bengal recorded a total contribution of ₹22,28,490 lakh from the combined trade, repair, hotels, and restaurants sector. While trade and repair activities primarily support local commerce and services, it is the hotels and restaurants segment that directly reflects the strength of West Bengal's tourism industry. According to a recent study by Proshanta Dey (2024), tourism in West Bengal has experienced consistent growth driven by its rich cultural heritage, diverse heritage tourism sites, and improved transport infrastructure. Popular destinations such as Kolkata, Darjeeling, the Sundarbans, Digha, and Shantiniketan continue to attract both domestic and international tourists, boosting economic activities in accommodation and hospitality services. The study highlights that West Bengal's targeted tourism policies, promotional campaigns, and enhanced connectivity - such as upgraded railways and international airports - have been vital in generating employment and increasing revenue within the hospitality sector. This underscores how tourism, primarily through hotels and restaurants, acts as a key driver of the state's service-led economic development (Dey, 2024). In 2022, Gujarat recorded a combined contribution of ₹18,64,450 lakh from the trade, repair, hotels, and restaurants sector. While trade and repair primarily support the general economy and local consumption, it is the hotels and restaurants component that directly reflects the strength of Gujarat's tourism industry. According to a study by Patel and Mehta (2012), Gujarat has strategically leveraged its diverse cultural and natural assets - including the Rann of Kutch, Gir National Park, Dwarka, Somnath, and the heritage city of Ahmedabad - to expand its hospitality sector. The state has focused on infrastructure development, event tourism (like the Rann Utsav), and heritage promotion to attract both domestic and international tourists. These efforts have significantly boosted occupancy in hotels and growth in food services, both of which are integral to tourism's GDP contribution. Thus, while not all elements of the sector are tourism-driven, the hotel and restaurant sub-sector plays a vital role in Gujarat's service economy and its growing tourism profile (Viramgami and Patel 2012). In 2022, Maharashtra reported a combined contribution of ₹17,58,890 lakh from the trade, repair, hotels, and restaurants sector. While trade and repair services support general commerce, the hotels and restaurants sub-sector directly reflects the impact of tourism. According to an analytical study on Maharashtra's tourism growth, hotels and restaurants accounted for approximately 20–22% of the gross state domestic product, also contributing around 3.5% to total state employment (Meshram 2022). Another assessment highlighted that tourism - attractions like the Ajanta and Ellora Caves, Mumbai's heritage and nightlife, hill stations like Lonavala and Mahabaleshwar, religious sites such as Shirdi, and Konkan beaches - acts as a significant driver for infrastructure development and hospitality services in the state (Japan International Cooperation Agency., "Ajanta Ellora Conservation and Tourism Development Project (1) 2007). Studies show that even a moderate investment of ₹10 lakh in the hotel and restaurant industry creates up to 89 jobs, compared to 44.7 in agriculture and just 12.6 in manufacturing, demonstrating tourism's high employment multiplier effect. (Vernekar and Shukla 2021). These findings indicate that tourism through the hotels and restaurants sub-sector plays a vital role in Maharashtra's service-led economic development, contributing significantly to GDP growth, job creation, and overall regional prosperity. In 2022, Arunachal Pradesh (₹942 lakh), Sikkim (₹1,913 lakh), and

Nagaland (₹3,028 lakh) recorded the lowest contributions to their economies from the hotels and restaurants sub-sector - indicating that tourism-related services form a relatively small portion of their Gross State Domestic Product (GSDP). A detailed 2016 report by North Eastern Development Finance Corporation (NEDFi) estimates that tourism (hospitality) contributed just 6.24% to Arunachal Pradesh's GSDP in 2009–10 - a marginal share compared to other northeastern states (Bardhan and Halder 2013, North Eastern Development Finance Corporation 2016). Similarly, although Sikkim has steadily seen rising tourist numbers (1.6 million domestic visitors in 2022), its service-based GDP contribution from tourism remains modest at roughly 2–3%. In Nagaland, tourism is still in its nascent stage: a 2019 study highlights that tourism infrastructure and services are underdeveloped, limiting the industry's capacity to contribute significantly to the state's GSDP despite growing cultural tourism initiatives like the Hornbill Festival

4.5 Sanctioned Tourism Funds (2014–2022)

According to official data released by the Ministry of Tourism, Government of India, under centrally sponsored tourism development schemes, states like Uttar Pradesh, Madhya Pradesh, and Tamil Nadu have received the highest sanctioned funds for tourism infrastructure projects. Among these, Uttar Pradesh tops the list with ₹13,03,900 lakh, followed by Madhya Pradesh with ₹9,48,200 lakh, and Tamil Nadu with ₹1,88,500 lakh (Ministry of Tourism, and Government of India 2022). These allocations reflect the government's focused strategy to improve tourism-related infrastructure such as roads, sanitation, amenities at tourist sites, and the promotion of heritage circuits under schemes like Swadesh Darshan, PRASHAD (Mishra, Sen and Ojha 2016), and Assistance to Central Agencies. Academic research supports this, with Suraj V. Ayyappan et al. employing network analysis in Varanasi, Lucknow, Ayodhya, and Prayagraj to demonstrate the strong correlation between tourism facilities - such as transport, wastewater treatment, and accommodation - and increased tourist demand (Munshi *et al.* 2022). Additionally, the Farm Tourism Development Model (FTDM) suggests a holistic framework for rural infrastructure, integrating ecotourism and local community involvement in Uttar Pradesh (Yaduvanshi *et al.* 2025). In Tamil Nadu, literature underscores how the state tourism development authority and Public-Private Partnerships have fostered infrastructure build-out - such as festivals, eco-tourism circuits, and accommodation - enhancing both capacity and local socioeconomic uplift (Subramaniyan and Anuradha 2023). Similarly, in Madhya Pradesh, resource-development case studies outline the pivotal role of tourism as a catalyst for infrastructure growth and economic development in communities (Pandey *et al.* 2014).

4.6 Sanctioned Fund Years

The top states with consistent or multi-year fund sanctions were Uttar Pradesh (2014–15 to 2018–19), Tamil Nadu (2016–17), and Gujarat (2016–17 to 2021–22). These timelines show continuous tourism development efforts. In contrast, Ladakh, Lakshadweep, and Mizoram had no mentioned years for fund allocation, possibly indicating a lack of focused tourism investment over the years.

4.7 Natural Disaster Deaths (2022)

Odisha (3,129 deaths), In 2022, Odisha recorded the highest number of natural disaster-related deaths among Indian states, with 2,445 fatalities, stemming from events such as floods, sunstroke, cyclones, lightning, and landslides (u/Huehue_BR, "Death by forces of nature – accidental deaths in India in 2022," Reddit, 2024). Madhya Pradesh (311 deaths), and Bihar (106 deaths) were the top three states with the highest natural disaster-related fatalities in 2022 Research from the Internal Displacement Monitoring Centre (IDMC) highlights that from 2011–2021, states such as Madhya Pradesh and Bihar ranked among the highest in lives lost to natural disasters, while Delhi and Chandigarh reported zero such fatalities, indicating their vulnerability to floods, storms, and other calamities (Dakua *et al.* 2023). On the other end, Lakshadweep, Tripura, and Delhi reported zero natural disaster deaths, showcasing either resilience or lesser impact zones.

4.8 Man-Made Disaster Deaths (2022)

The highest man-made disaster deaths occurred in Gujarat (15,934 deaths) A research article on man-made disasters in Gujarat highlights industrial accidents, fire outbreaks, and infrastructure failures as the leading causes of fatalities. The Rajkot game zone fire (2024) is one notable example of such disasters (Kumar 2024). News reports from NDTV confirm this fire as a significant man-made disaster incident in Gujarat (Press Trust of India, "Rajkot game zone fire that killed 27 is man-made disaster," Gujarat High Court., 2024), Madhya Pradesh (5,427 deaths) State-level reports and parliamentary data indicate Madhya Pradesh has experienced numerous fatalities from man-made disasters, predominantly traffic accidents and industrial mishaps. These are documented in the Ministry of Home Affairs' annual disaster reports and supported by academic studies on regional disaster vulnerability (National Crime Records Bureau, "Accidental Deaths & Suicides in India 2022," 2022), Haryana

(5,705 deaths) Haryana's high fatality numbers have been attributed mainly to road accidents and industrial accidents (National Crime Records Bureau, "Accidental Deaths & Suicides in India 2022," 2022), as reported in NCRB statistics and regional news outlets, reflecting industrial accidents, road mishaps, or other such events. In contrast, Uttarakhand, Tamil Nadu, and Arunachal Pradesh had zero deaths reported from man-made disasters, indicating relatively better safety or lower exposure to such risks.

Table 3. Pearson Correlation Matrix between Tourism Indicators, Economic Factors, and Disaster Deaths

Correlations		Foreign Tourists (FTAs in Thousands)	Domestic Tourist Visits (DTV in thousands) 2022	State GDP 2022	Trade, Repair, Hotels & Restaurants Contribution	Sanctioned Tourism Funds 2014 to 2022	Natural Disaster Deaths (2022)	Man-Made Disaster Deaths (2022)
Foreign Tourists (FTAs in Thousands)	Pearson Correlation	1	.485**	.772**	.654**	.447**	-.040	.551**
	Sig. (2-tailed)		.003	.000	.000	.006	.815	.001
	N	36	36	36	36	36	36	36
Domestic Tourist Visits (DTV in thousands) 2022	Pearson Correlation	.485**	1	.767**	.702**	.471**	-.083	.110
	Sig. (2-tailed)	.003		.000	.000	.004	.630	.524
	N	36	36	36	36	36	36	36
State GDP 2022	Pearson Correlation	.772**	.767**	1	.880**	.413*	.065	.336*
	Sig. (2-tailed)	.000	.000		.000	.012	.708	.045
	N	36	36	36	36	36	36	36
Trade, Repair, Hotels & Restaurants Contribution	Pearson Correlation	.654**	.702**	.880**	1	.363*	-.012	.335*
	Sig. (2-tailed)	.000	.000	.000		.030	.945	.045
	N	36	36	36	36	36	36	36
Sanctioned Tourism Funds 2014 to 2022	Pearson Correlation	.447**	.471**	.413*	.363*	1	.107	.550**
	Sig. (2-tailed)	.006	.004	.012	.030		.536	.001
	N	36	36	36	36	36	36	36
Natural Disaster Deaths (2022)	Pearson Correlation	-.040	-.083	.065	-.012	.107	1	-.011
	Sig. (2-tailed)	.815	.630	.708	.945	.536		.947
	N	36	36	36	36	36	36	36
Man-Made Disaster Deaths (2022)	Pearson Correlation	.551**	.110	.336*	.335*	.550**	-.011	1
	Sig. (2-tailed)	.001	.524	.045	.045	.001	.947	
	N	36	36	36	36	36	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.9 Foreign Tourists (FTAs in Thousands)

The number of foreign tourist arrivals shows a strong and statistically significant correlation with several key economic indicators. It is highly correlated with State GDP ($r = 0.772$, $p < 0.01$), indicating that states with higher economic output tend to attract more foreign tourists. This might be due to better infrastructure, global connectivity, or promotional efforts. Similarly, there's a strong positive correlation with Trade, Repair, Hotels & Restaurants contribution ($r = 0.654$, $p < 0.01$), showing that the tourism ecosystem supports and attracts

international visitors. A moderate positive correlation exists with Sanctioned Tourism Funds (r = 0.447, p < 0.01), which implies that states receiving more tourism funding may invest in foreign tourist facilities and experiences. There's no significant correlation with Natural Disaster Deaths (r = -0.040, p = 0.815), suggesting that foreign tourists may not be heavily deterred by such risks. Interestingly, there is a moderate positive correlation with Man-Made Disaster Deaths (r = 0.551, p < 0.01), which may indicate foreign visits are concentrated in economically active states that are also prone to such events (*e.g.*, industrialized states).

4.10 Domestic Tourist Visits (DTV in Thousands)

Domestic tourism also exhibits strong positive correlations with economic strength and infrastructure. The correlation with State GDP is very high (r = 0.767, p < 0.01), showing that states with larger economies attract more internal tourists, possibly due to better transport, cultural appeal, and amenities. It also correlates highly with the Trade, Repair, Hotels & Restaurants sector (r = 0.702, p < 0.01), indicating the importance of service industries in encouraging local travel. There is a moderate positive correlation with Sanctioned Tourism Funds (r = 0.471, p < 0.01), suggesting that financial support from the government may improve facilities and attract more domestic tourists. However, no significant relationship was found with Natural Disaster Deaths (r = -0.083, p = 0.630), showing that domestic tourists are either undeterred or quick to adapt to disaster-affected areas. The correlation with Man-Made Disaster Deaths is also insignificant (r = 0.110, p = 0.524), indicating minimal impact on domestic travel decisions.

Table 4. KMO and Bartlett's Test of Sampling Adequacy

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.668
Bartlett's Test of Sphericity	Approx. Chi-Square	148.927
	df	21
	Sig.	.000

To assess the suitability of the data for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity were examined. The KMO value was 0.668, indicating a moderate level of adequacy, suggesting that the dataset is appropriate for factor analysis. Bartlett's Test was highly significant (Chi-Square = 148.927, df = 21, p < 0.001), confirming that correlations exist among the variables and that factor analysis is a valid technique for this dataset.

Table 5. Communalities

Variable	Extraction
Foreign Tourists (FTAs in Thousands)	.738
Domestic Tourist Visits (DTV in thousands) 2022	.792
State GDP 2022	.932
Trade, Repair, Hotels & Restaurants Contribution	.842
Sanctioned Tourism Funds 2014 to 2022	.654
Natural Disaster Deaths (2022)	.987
Man-Made Disaster Deaths (2022)	.887

The communalities of the variables ranged from 0.654 to 0.987, indicating that a substantial amount of variance for each variable is explained by the extracted components. State GDP (0.932), Natural Disaster Deaths (0.987), and Man-Made Disaster Deaths (0.887) exhibited particularly high communalities, while Sanctioned Tourism Funds (0.654) had the lowest, though still acceptable. This supports the robustness of the factor extraction process.

Table 6.Total Variance Explained

Component	Rotation Sums of Squared Loadings			
	Total	Total	% of Variance	Cumulative %

1	3.684	2.951	42.161	42.161
2	1.143	1.853	26.470	68.631
3	1.005	1.027	14.676	83.306
	Total		83.31%	

The total variance explained by the analysis revealed that three components together accounted for 83.31% of the total variance in the data. Component 1 contributed 42.16%, Component 2 explained 26.47%, and Component 3 accounted for 14.68%. This high cumulative variance demonstrates that these three components adequately capture the underlying structure of the dataset.

Table 7. Rotated Component Matrix (Varimax Rotation)

Variable	Component 1	Component 2	Component 3
Foreign Tourists (FTAs in Thousands)	.643	.564	-
Domestic Tourist Visits (DTV in thousands) 2022	.887	-	-
State GDP 2022	.927	.262	-
Trade, Repair, Hotels & Restaurants Contribution	.889	.226	-
Sanctioned Tourism Funds 2014 to 2022	.311	.729	.158
Natural Disaster Deaths (2022)	-	-	.993
Man-Made Disaster Deaths (2022)	-	.937	-

The rotated component matrix using Varimax rotation provided clearer interpretation. Component 1 was strongly associated with Domestic Tourist Visits (0.887), State GDP (0.927), Trade, Hotels & Restaurants (0.889), and Foreign Tourists (0.643), indicating that this factor represents economic strength and tourism volume. Component 2 was associated with Sanctioned Tourism Funds (0.729) and Man-Made Disaster Deaths (0.937), suggesting a policy-driven and human-activity-related dimension. Component 3 was uniquely defined by Natural Disaster Deaths (0.993), representing the distinct influence of natural calamities on the studied variables.

Figure 5. Scree Plot – Number of Factors to Retain

The scree plot further supported the retention of three components, as the graph showed a clear inflection point after the third factor, indicating that additional components would contribute minimally to explaining the variance. Overall, the factor analysis highlighted three meaningful and interpretable dimensions that collectively describe the interrelationships between tourism indicators, economic factors, and disaster impacts in Indian states.

H2: There is a significant relationship between inbound foreign tourist arrivals (FTA) and factors such as State GDP, Trade-Repair-Hotel-Restaurant sector contribution, natural disaster deaths (2022), and man-made disaster deaths (2022).

- Foreign Tourists (FTA) $Y_1 = \beta_0 + \beta_1$ State GDP + β_2 16-25 Trade, Repair, Hotels & Restaurants Contribution + β_3 Natural Disaster Deaths (2022) + β_4 Man-Made Disaster Deaths (2022) + e

Table 8. Log-Linear Multiple Regression Output Summary (Inbound Tourism Prediction Model)
Regression Statistics

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
FTA	.736[a]	.542	.466	1.57597

To test Hypothesis (H2), a multiple regression analysis using log-transformed variables was carried out. The Model Summary indicates a strong relationship between the dependent variable, foreign tourist arrivals (LN_FTA), and the set of independent variables, with an R value of 0.736. The R^2 value of 0.542 reveals that approximately 54.2 percent of the variation in foreign tourist arrivals is explained by State GDP, Trade, Repair, Hotels and Restaurants contribution, natural disaster deaths, and man-made disaster deaths. This suggests that the model provides a moderately good fit to the data.

The adjusted R^2 value of 0.466, which accounts for the number of predictors included in the model, confirms that the explanatory power remains reasonable after adjustment. The standard error of the estimate is 1.576, indicating an acceptable average deviation between the observed and predicted values of foreign tourist arrivals in logarithmic terms. Overall, the model demonstrates adequate explanatory strength and supports the suitability of the selected variables for examining the influence on foreign tourist arrivals.

Table 9. Anova Analysis

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	70.566	4	17.641	7.103	.001[b]
	Residual	59.609	24	2.484		
	Total	130.174	28			
a. Dependent Variable: LN_FTA						
b. Predictors: (Constant), LN_MDdeath, LN_GDP, LN_NDdeath, LN_THR						

The ANOVA results reveal that the log–log regression model is statistically significant, with an F value of 7.103 and a significance level of 0.001. This confirms that the independent variables, when considered together, have a significant influence on foreign tourist arrivals. Hence, the null hypothesis that the predictors have no joint effect on foreign tourist arrivals is rejected, validating the overall suitability of the model for further interpretation.

From the regression results, the intercept value is −12.493, which implies that when all independent variables are held at zero, the predicted value of foreign tourist arrivals in logarithmic form would be negative. This outcome has no practical interpretation, as variables such as GDP and disaster-related deaths cannot realistically take a value of zero. Hence, the intercept serves only as a scaling constant in the log–log model.

The coefficient for State GDP is positive (β = 1.189), indicating a strong positive elasticity between economic growth and foreign tourist arrivals. This suggests that a one percent increase in State GDP is associated with an estimated 1.189 percent increase in foreign tourist arrivals, holding other factors constant. Although this relationship aligns with theoretical expectations - where stronger economic performance enhances infrastructure, accessibility, and tourism facilities - the effect is not statistically significant in this model, possibly due to multicollinearity with other economic variables.

Table 10. Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF

1	(Constant)	-12.493	5.005		-2.496	.020		
	LN_GDP	1.189	.793	.821	1.500	.147	.064	15.694
	LN_THR	-.090	.733	-.067	-.122	.904	.063	15.761
	LN_ND death	-.082	.154	-.081	-.533	.599	.827	1.209
	LN_MD death	-.006	.103	-.010	-.062	.951	.754	1.327
a. Dependent Variable: LN_FTA								

Y_1= -12.493 + 1.189X_1 + -0.090 X_2 + -0.082 X_3+-0.006X_4

The coefficient for the Trade, Repair, Hotels and Restaurants sector contribution is negative (β = −0.090) and statistically insignificant. This indicates that a one percent increase in the contribution of this sector leads to a marginal decline of 0.09 percent in foreign tourist arrivals. The insignificant effect suggests that the sector's contribution alone does not directly influence inbound tourism, which may be due to overlapping effects with GDP or uneven quality and distribution of tourism-related services across states.

Natural disaster deaths exhibit a negative elasticity (β = −0.082), implying that a one percent increase in deaths caused by natural disasters results in a 0.082 percent decrease in foreign tourist arrivals. Although this effect is not statistically significant, the negative sign indicates that natural disasters tend to discourage inbound tourism. This supports the argument that natural disasters, especially when associated with loss of life and international media coverage, may negatively influence the perceptions and travel decisions of foreign tourists.

Similarly, man-made disaster deaths also show a negative elasticity (β = −0.006), suggesting a very small decline in foreign tourist arrivals with an increase in such incidents. However, the effect is statistically insignificant and economically negligible. This indicates that foreign tourists may not perceive man-made disasters as a major deterrent to travel, particularly when such events are localized and do not disrupt overall tourism infrastructure. As a result, man-made disasters appear to have a limited influence on inbound tourism during the study period.

Overall, the findings indicate that economic growth has a positive association with foreign tourist arrivals, while disaster-related variables show a weak and statistically insignificant impact. This suggests that foreign tourists may place greater emphasis on economic conditions and destination readiness rather than short-term disaster-related incidents when making travel decisions.

Table 10. Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	LN_GDP	LN_THR	LN_NDdeath	LN_MDdeath
1	1	4.355	1.000	.00	.00	.00	.01	.01
	2	.432	3.174	.00	.00	.00	.02	.67
	3	.209	4.564	.00	.00	.00	.97	.23
	4	.003	36.955	.68	.01	.03	.01	.09
	5	.000	159.966	.32	.99	.97	.00	.00
a. Dependent Variable: LN_FTA								

The collinearity diagnostics reveal the presence of multicollinearity among the explanatory variables, particularly State GDP and the Trade, Repair, Hotels and Restaurants sector contribution. This is evidenced by the very high condition index values in the higher dimensions, especially the maximum condition index of 139.706, along with the large variance proportions associated with State GDP and the Trade, Repair, Hotels and Restaurants sector in the same dimension.

Such multicollinearity can inflate standard errors and weaken the statistical significance of individual regression coefficients, even when the overall model remains statistically significant. Therefore, caution must be exercised while interpreting the individual effects of economic variables on domestic tourist visits, as their combined influence may be more meaningful than their separate effects

Conclusions and Further

The analysis reveals that economic factors, such as State GDP and government investment in tourism infrastructure, positively influence Domestic Tourist Visits. Conversely, both natural and man-made disasters have a detrimental impact on tourism, highlighting the sector's sensitivity to unforeseen events. The findings emphasize the need for robust disaster management and strategic planning to ensure the sustainable growth of the tourism industry.

Suggestions

Based on the study's findings, the following recommendations are proposed:

1. Enhanced Investment: Increased allocation of funds towards tourism infrastructure to attract more domestic tourists.
2. Disaster Preparedness: Development of comprehensive disaster management plans to mitigate the adverse effects of unforeseen events on tourism.
3. Promotion of Domestic Tourism: Initiatives to encourage domestic travel, such as promotional campaigns and incentives.
4. Data-Driven Strategies: Utilization of data analytics to monitor tourism trends and make informed policy decisions.

Scope for Future Research

Future studies could explore:

- Longitudinal Analysis: Examining tourism trends over multiple years to assess long-term recovery patterns.
- Impact of Specific Policies: Evaluating the effectiveness of government initiatives aimed at reviving the tourism sector.
- Tourist Behavior: Investigating changes in tourist preferences and behaviors in the post-pandemic era.
- Comparative Studies: Comparing India's tourism recovery with other countries to identify best practices and areas for improvement.

Declarations

Credit Authorship Contribution Statement:

Praveen M.: Conceptualization, Writing – original draft, Data collection, Formal analysis.
Ranjitha R.: Data curation, Investigation, Validation.
Tamil Selvi R.: Methodology, Supervision, Review & editing.
Dayana Jevalin R.: Visualization, Resources, Proofreading, Project administration.

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Assessing The Impact of Tourism Ban on Ecosystem Recovery in Saint Martin Marine Protected Area, Bangladesh

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Abstract: Situated in the north-eastern Bay of Bengal, Saint Martin's Island is a small sedimentary island. It hosts the only coral ecosystem in Bangladesh and is popularly (but wrongly) called 'coral island'. Since 2004, uncontrolled tourism and unsustainable practices, along with global warming and marine pollution have considerably degraded island's ecosystems and threatened its very existence. To mitigate this substantial threat, in January 2022, Bangladesh Government declared Saint Martin Marine Protected Area and in October 2024, imposed strict tourism regulations including a 'nine months' tourism ban' on the island, generating mixed reactions. Amid opposing demands from environmental and hospitality stakeholders, the first-ever 'tourism ban' (February to October 2025) has come to an end, providing a unique opportunity to assess the health status of the marine ecosystem and eventual recovery. For this purpose, temperature, salinity, pH, dissolved oxygen, total dissolved solids and turbidity were measured from November 2022 to October 2025, using multi-parameter oceanographic instruments. While the assessment of temperature and salinity showed distinct seasonal variability, the comparison of other bio-geochemical parameters, before and during the 'nine months' tourism ban', demonstrated considerable ecological improvement (DO improved from 6.0-6.6 to 7.1-7.4 mg/L and pH improved from 7.0-8.14 to 8.13-8.21). As one of the first in-situ assessments in the Bay of Bengal region, linking 'tourism ban' with ecosystem recovery, this research has the potential to generate valuable insights for sustainable development in Saint Martin's Island and similar places across the globe.

Keywords: anthropogenic stressors; biodiversity; coral ecosystem; ecological recovery; marine protected area.

JEL Classification: Q57; Z32; Q28.

Introduction

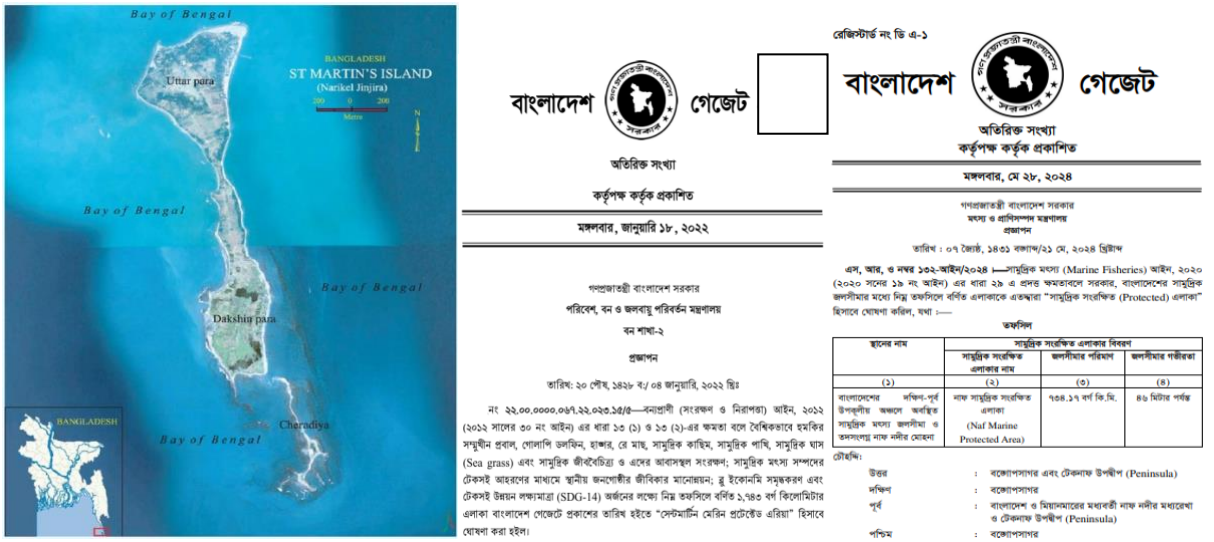
Bangladesh is part of the Bay of Bengal Large Marine Ecosystem (one of the largest ecosystems in the world), endowed with mangroves, coral reefs, estuaries, marine animals and fish breeding areas (Bay of Bengal Large Marine Ecosystem, 2015). Situated at the north-eastern Bay of Bengal, Saint Martin's Island (SMI) is the only island in Bangladesh that sustains coral ecosystem, one of the country's most biologically diverse and ecologically sensitive marine environments. To preserve its unique biodiversity, in 1999, Bangladesh's Department of Environment (DoE) declared the island an Ecologically Critical Area (ECA) (Ahmed, 2025).

Since 2004, tourist ferries from mainland started transporting regularly, making SMI the preferred domestic tourist destination (Saif, 2010). During winter season, roughly 3,000-8,000 tourists were recorded every day to visit the island, generating considerable economic activities for its 7,000 residents (Rahman, 2024). As SMI's estimated carrying capacity is 500-900 visitors/day, such mass tourism was beyond the hosting capacity of this 8 km² tiny island (SMI Master Plan, 2025). The growing number of tourist ferries/boats with associated water, air

and sound pollution posed considerable challenges for SMI's marine ecosystems (IUCN, 2010). Furthermore, repeated coral breakage from anchoring of tourist ships/boats and increasing oil spill, along with sewage discharge have been threatening the survival of SMI's coral ecosystem (Chowdhury *et al.*, 2021).

Corals are animals and host symbiotic zooxanthellae algae for food and color. Due to the slow process of reef generation, corals are unable to adapt in rapidly changing marine environment. Marine pollution, destructive fishing, disease, predation along with global warming, ocean acidification and natural calamities are globally degrading the health of coral ecosystems, threatening millions of species they host and half a billion people they feed (National Geographic, 2017). Considering the threats to fragile coral colonies and endangered wildlife, in January 2022, Bangladesh Forest Department declared 1,743 km² area around the island, as Saint Martin Marine Protected Area (MPA) and in May 2024, Bangladesh's Department of Fisheries declared 734 km² adjacent area as Naf MPA (MoEF, 2024). Though Bangladesh Navy and Coast Guard have been conducting regular patrols for compliance of declared MPA, the degradation of marine biodiversity could not be slowed down (Haque & Karim, 2022). Uncontrolled tourism and tourism-related unsustainable practices have not only endangered the coral reef-based ecosystem, but also island's very existence (Rahman, 2024).

Figure 1. Saint Martin's Island and Official Gazette Notification for Marine Protected Areas



Source: Bangladesh Legislative & Parliamentary Affairs Division, 2025

Realising this emerging threat, in October 2024, Bangladesh's Ministry of Environment, Forest & Climate Change (MoEF) banned single-use plastic and imposed compulsory pre-registration before tourists' arrival on SMI with the following temporal restriction to their access on the island: maximum 2,000 tourists/day; no overnight stay in November; possibility to stay overnight in December-January; no tourists allowed during February-October. These strict tourism regulations were aimed to facilitate natural regeneration of SMI's coral colonies and preservation of fragile biodiversity. Although a complete 'tourism ban' for the protection of coral ecosystem is something rare, localized restrictions on tourism activities for protection of globally endangered species have several precedents. In 2018, Thailand indefinitely banned tourists in Phuket's popular Maya Bay for coral regeneration; which was later reopened only for strictly monitored ecotourism in 2021. Ras Mohamed National Park in Egypt, Quintana Roo in Mexico and Boracay Bay in the Philippines have similar examples of 'tourism ban' for ecological recovery (Andaman, 2025).

Banning all sorts of tourism on SMI for nine months generated mixed reactions across Bangladesh (MoEF, 2024). Amid such contrasting opinions among environmental and hospitality stakeholders, this 'first-year's tourism ban' (February to October 2025) came to an end, providing a unique opportunity to analyze the changes in bio-geochemical parameters and assess the expected marine ecosystem recovery. Several researches have been conducted on the degradation of SMI's coral reefs, highlighting the adverse impact of anthropogenic stressors (Tomascik *et al.* 2021, Gazi et al. 2020). In addition, Norway's Research Vessel (RV) Fridtjof Nansen and USA's Research Vessel Thomas G. Thompson conducted oceanographic survey off SMI in 2025. However, decades of studies and concerns could do little to protect SMI's marine ecosystems (Doropoulos *et al.* 2025).

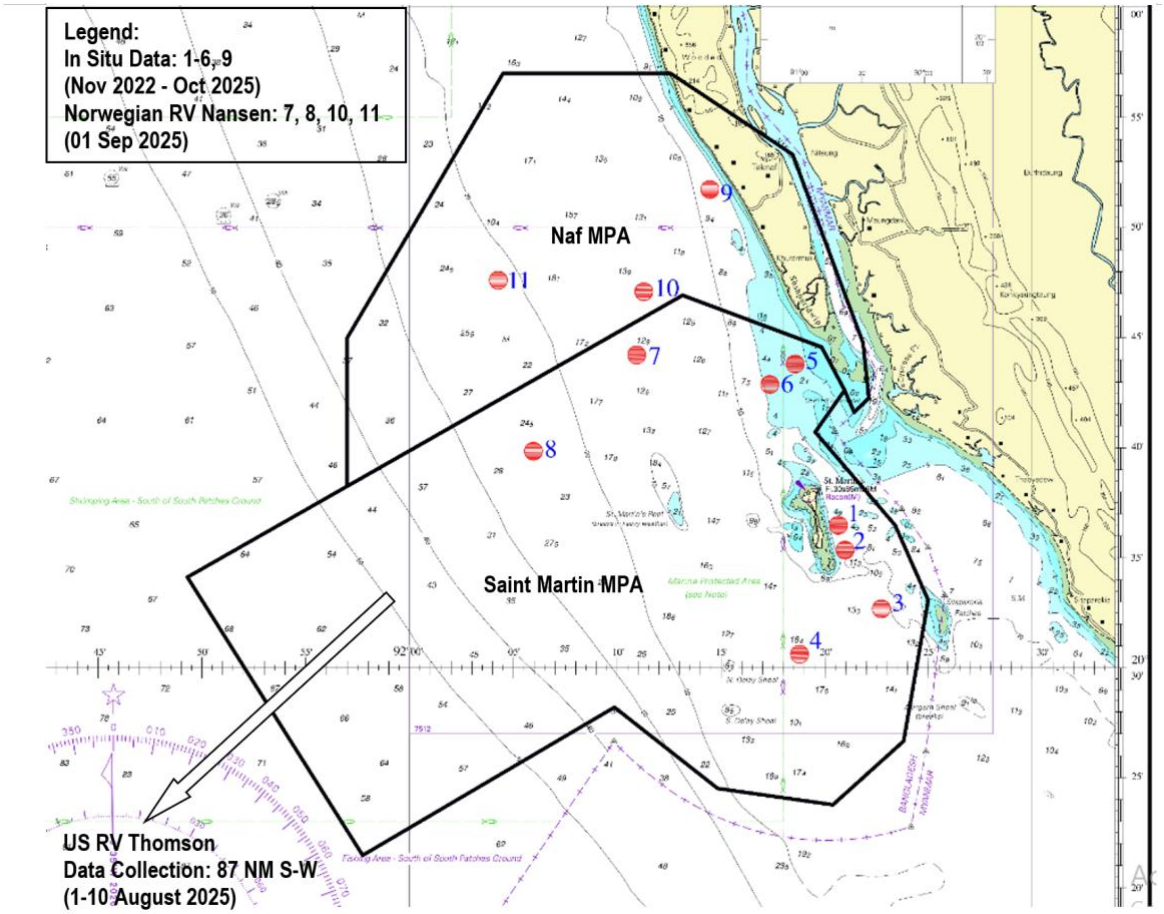
Though temperature (T), salinity (S), potential of hydrogen (pH), dissolved oxygen (DO), total dissolved solids (TDS) and turbidity are essential indicators of coral, plankton, fish productivity (Ahmed *et al.* 2020), their in-situ measurement has never been previously conducted in order to assess the health of SMI's coral ecosystem.

To statistically corroborate the results obtained from the analysis of in-situ data, 'the compliance of nine months' tourism ban did not have significant impact on ecosystem recovery of Saint Martin MPA' was considered as the null hypothesis (H_0) and 'the compliance of nine months' tourism ban had significant impact on ecosystem recovery of Saint Martin MPA' was considered as alternative hypothesis (H_1). Being the first scientific effort of in-situ assessments in the Bay of Bengal region, this research highlights the findings of the baseline study conducted to measure key ecosystem parameters in Saint Martin MPA before and during 'tourism ban' and assess its impact on coral ecosystem recovery. By proposing nature-based solutions, this research has the potential to generate valuable insights for sustainable development options to balance between conservation and livelihood needs of Saint Martin's Island and similar places across the globe.

1. Study Area

For the purpose of this research, Saint Martin MPA has been considered as the main study area and the recently declared Naf MPA has also been studied for broader understanding of ecosystem dynamics.

Figure 2. Ecosystem Parameter Collection Points in Saint Martin and Naf MPA



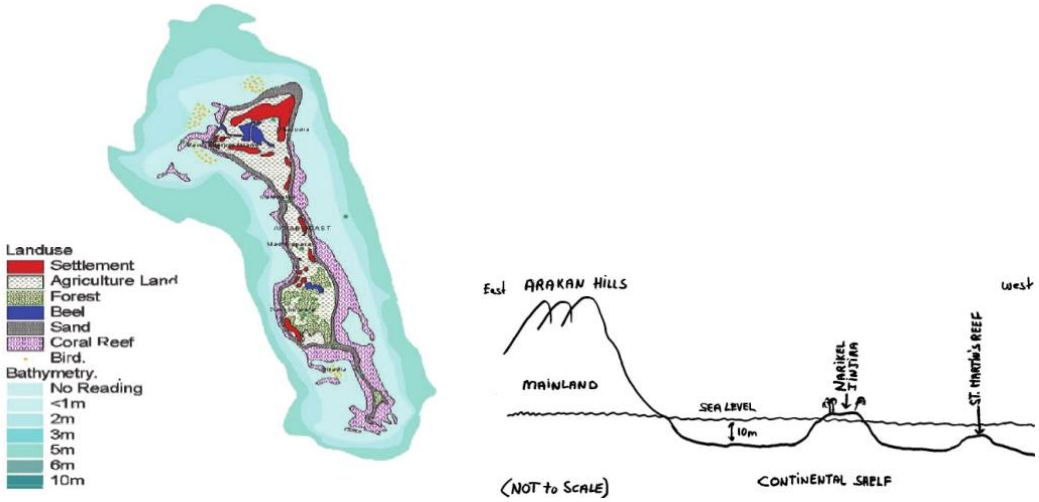
Source: Author's Construct from Bangladesh Navy Chart 30002

Being a small sedimentary island and hosting the only coral ecosystem in Bangladesh, SMI is popularly (though wrongly) called 'the coral island'. In 1997, detailed underwater survey found the island to be surrounded by rocky reefs, instead of corals, consisting of moderately hard/soft sandstones and covered by conglomerate boulders, calcareous concretions that provide a suitable substrate for coral settlement (Tomascik, 1997). This particular sedimentary geology facilitates the availability of highly selective coral larvae to attach and thrive (Ruano *et al.* 2025).

According to a national environmental survey, SMI hosts various ecologically sensitive and environmentally critical species (corals: 68, marine fish: 234, algae: 151, reptiles: 20, dolphins: 5, amphibians: 4, crabs: 40, mollusks: 191, etc.) (DoE, 2021). SMI had an abundance of forest which had gradually been cleared to meet the growing demands of cultivable land and tourism activities. Keya trees are prevalent along its eastern coast and limited mangrove patch may still be found in the south-western coast (Rahman, 2024). However,

uncontrolled tourism and unsustainable practices have threatened the very existence for many of these species. The destruction of biodiversity-rich coral ecosystem has particularly alarmed not only the environmentalists, but also the general population across the country (Tazvir, 2021).

Figure 3. Saint Martin's Island is sedimentary (not coral) island



Source: Tomascik, 1997

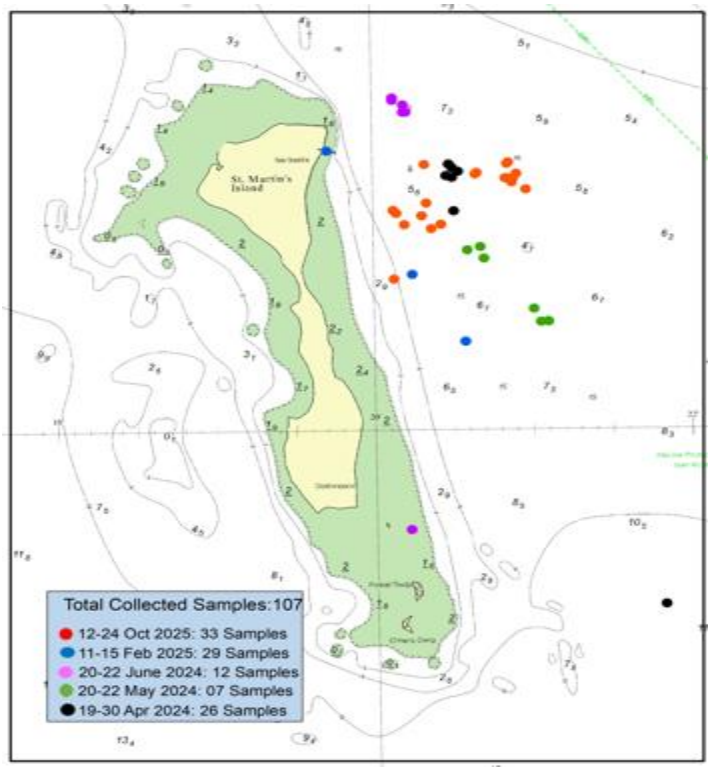
Figure 4. Revival of Saint Martin's biodiversity after 'nine months' tourism ban'

2. Materials and Methods

To assess the impact of 'nine months' tourism ban' on SMI's ecosystem recovery, the bio-geochemical parameters were collected from 107 sampling points before (November 2022 to June 2024) and during (February to October 2025) 'tourism ban'. Considering the limited accessibility, in-situ data (T, S, pH, DO, TDS, turbidity) have been collected primarily from SMI's eastern portion and during winter season. As offshore in-situ data samples were limited, secondary offshore data were collected from the National Oceanic & Atmospheric Administration (NOAA), Norwegian Research Vessel Nansen, and US Research Vessel Thomson for broader oceanographic understanding and cross-checking of the results.

Data were collected by portable multi-parameter oceanographic instruments (Hanna Instruments HI98494), Conductivity, Temperature, Depth (Ocean Seven 310) and Sound Velocity Profiler (Valeport MIDAS SVX2). These sensors were checked and calibrated before every deployment. To compare statistical significance, single-factor Analysis of Variance (ANOVA) across two temporal groups was used: pre-ban period and during-ban period. The analysis quantified the 'variance within groups' and 'variance between groups' at 95% confidence level (α=0.05). Following extreme heatwave and heavy rainfall, occasional localized spikes in the upper layers' ocean temperature, salinity and turbidity were identified. However, these natural variability and seasonal monsoon effects could not be quantified separately from impact of 'tourism ban', due to their complex interaction and lack of sufficient, relevant datasets.

Figure 5. Ecosystem Parameter Collection Points near Saint Martin's Island



Source: Author's Construct from Bangladesh Navy Chart 3501

3. Analysis of Collected Data

3.1. Sea Surface Temperature (SST)

SST refers to the temperature of ocean's upper layer. Satellite measurements typically refer to top few millimeters from sea surface, drifting buoys 0.2-1.5 m and ships 0-10 m depths. In this study, SST was measured at 0-2 m depth. Reef-building corals thrive in 23°-29°C water temperature (NOAA, 2022). The persistent temperature of 30° and above is likely to stress coral colonies.

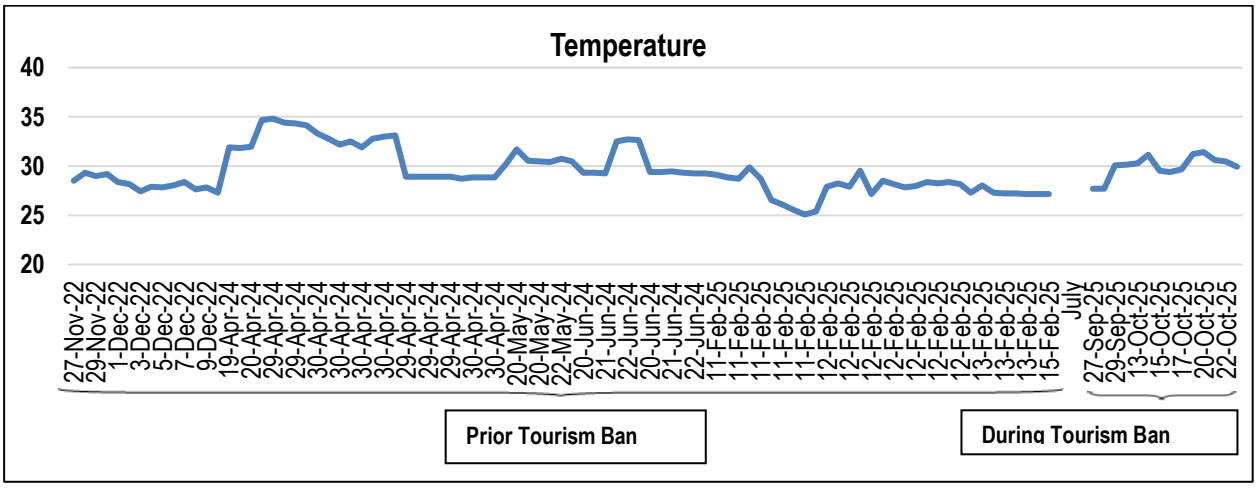
- **February**: SST ranged 25.07-29.85°C, representing the lowest values due to relatively colder winter and reduced incoming solar radiation, currents, etc.
- **April**: SST ranged 27.29-34.81°C due to hot and dry spring. The upper value (34.81°C) was very unusual, but likely due to severe record-breaking heatwaves across Bangladesh, occurred in April 2024 (NOAA, 2024).
- **May**: SST ranged 30.21-31.69°C, probably due to pre-monsoon weather pattern.
- **June**: SST varied between 29.28 and 32.48°C. This high range of temperature was threatening the entire ecosystem.
- **September**: SST varied 27.14-30.47°C. The onset of increased cloud cover and rainfall gradually moderated SST.
- **October 2025**: After 'nine months' tourism ban', SST ranged 29.10-31.48°C. Strong solar radiation under clear sky, calm sea and reduced mixing caused surface water to be quickly warmed up.

Table 1. Measured Sea Surface Temperature near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min (°C)	Max (°C)	Average
Secondary Data	**Optimum for Coral Ecosystem**	**26**	**29**	**27.5**
	NOAA ERSSTv5 (1975-2025)	25.5	31.2	28.3
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	29.06	29.29	29.18
	US RV Thomas Thompson (1-10 Aug 2025)	28	30.06	28.84
Prior Tourism Ban	**27-30 Nov 2022**	28.5	29.3	28.9
	01-09 Dec 2022	27.4	28.4	27.9
	19-30 Apr 2024	27.29	34.81	**31.41**
	20-22 May 2024	30.21	31.69	**30.64**
	20-22 Jun 2024	29.28	32.48	**30.15**
During Tourism Ban	**11-15 Feb 2025**	25.07	29.85	27.69
	27-30 Sep 2025	27.14	30.47	28.81
	13-18 Oct 2025	29.38	31.48	30.43
	20-23 Oct 2025	29.1	30.58	29.84

Figure 6: Measured Sea Surface Temperature near Saint Martin's Island



3.2. Sea Surface Salinity

Coral reefs generally thrive in salinity ranging 32-36 parts per thousand (ppt) and can tolerate 28-40 ppt (Kleypas *et al.* 2006). Maintaining stable salinity is vital for sustaining coral ecosystem. In this study, surface salinity was measured at 2-5 m depth. Freshwater influx from nearby Naf River caused seasonal variation with damage and decline of SMI's coral reef.

- **February**: Salinity ranged 30-38 ppt, due to lack of precipitation, low freshwater discharge from Naf River and high evaporation rate.
- **April**: Salinity ranged 30-34 ppt, due to increased temperature, evaporation and reduced freshwater discharge from Naf River.

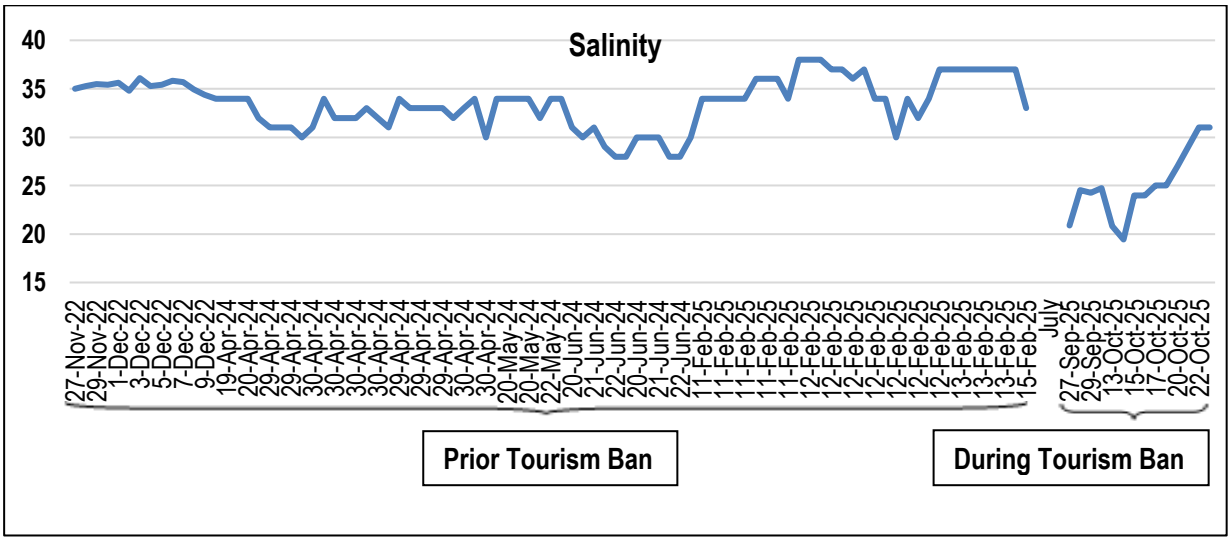
- **May**: Salinity ranged optimally 32-34 ppt, suggesting a balance between temperature, evaporation and freshwater discharge from Naf River.
- **June**: Salinity reduced to 28-31 ppt, reflecting the rainfall and freshwater runoff effects from Naf River.
- **September**: Salinity drastically diluted to 24-25.81 ppt, due to increased rainfall with substantial freshwater influx.
- **October 2025:** After 'nine months' tourism ban', salinity varied 22-31 ppt, due to prolonged monsoon rainfall.

Table 2. Measured Sea Surface Salinity near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, Red: Dangerous)

	Collection Date	Min	Max	Average (ppt)
Secondary Data	Optimum for Coral Ecosystem	28	40	34
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	27.80	30.71	29.26
	US RV Thomas Thompson (1-10 Aug 2025)	21.68	32.61	27.37
Prior Tourism Ban	27-30 Nov 2022	35	35.4	35.2
	01-09 Dec 2022	34.4	36.1	35.25
	19-30 Apr 2024	30	34	32.42
	20-22 May 2024	32	34	33.71
	20-22 Jun 2024	28	31	29.41
During Tourism Ban	11-15 Feb 2025	30	38	35.48
	27-30 Sep 2025	24	25.81	24.91
	13-18 Oct 2025	22	26	24
	20-23 Oct 2025	27	31	29

Figure 7. Measured Sea Surface Salinity near Saint Martin's Island



3.3. Dissolved Oxygen (DO)

DO refers to seawater's oxygen concentration, essential for respiration, metabolism and calcification of coral reef (Nelson *et al.* 2019). Sufficient DO supports the productivity of reef ecosystem while depleted oxygen content

threatens coral biodiversity (Diaz *et al.* 2008). DO≥6 mg/L is considered favorable and DO≤4 mg/L can induce hypoxic stress with possible extinction of species (Vaquer-Sunyer *et al.* 2008).

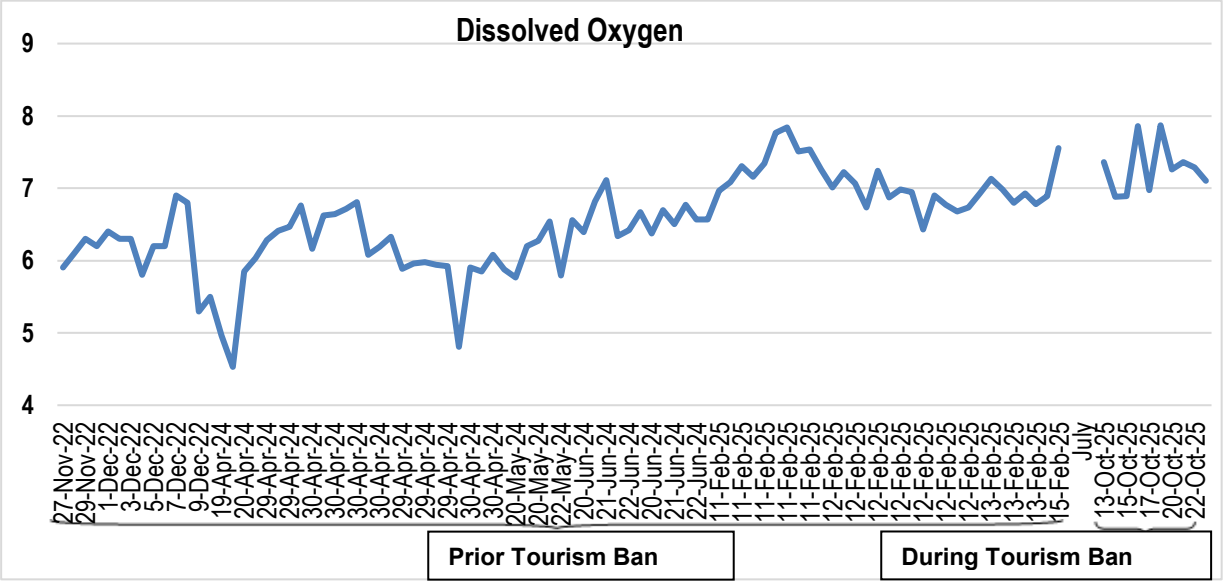
Table 3. Measured Dissolved Oxygen in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min	Max	Average (mg/l)
Secondary Data	**Optimum for Coral Ecosystem**	**6**	**8**	**7**
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	4.22 @10m depth	4.45	**4.34**
	US RV Thomas Thompson (1-10 Aug 2025)	4.46 @10m depth	4.75	**4.64**
Prior Tourism Ban	**27-30 Nov 2022**	5.9	6.3	6.1
	01-09 Dec 2022	5.3	6.9	6.1
	19-30 Apr 2024	4.53	6.81	6.02
	20-22 May 2024	5.77	6.56	6.14
	20-22 Jun 2024	6.34	6.82	6.60
During Tourism Ban	**11-15 Feb 2025**	6.43	7.84	7.07
	13-18 Oct 2025	6.82	7.87	7.35
	20-23 Oct 2025	7.02	7.36	7.2

- **February:** DO ranged 6.43-7.84 mg/L, reflecting high oxygen solubility due to cool winter.
- **April:** DO deteriorated to 4.53-6.81 mg/L, due to high temperature and limited water circulation.
- **May:** With the start of monsoon rainfall, DO improved to 5.77-6.56 mg/L.
- **June:** DO stabilized at 6.34-6.82 mg/L**,** consistent with monsoon rainfall and increased mixing.
- **October 2025:** Due to minimal anthropogenic stressors during 'nine months' tourism ban', DO improved to 6.82-7.87 mg/L. This highest recorded DO reduced the risk of hypoxia and increased the pace of coral calcification.

Figure 8. Measured Dissolved Oxygen in Seawater near Saint Martin's Island



3.4. Potential of Hydrogen (pH)

pH indicates acidity (pH<7: acidic) or alkalinity (pH>7: alkaline) (Zeebe *et al.* 2001). pH governs the availability of carbonate ions, necessary for coral calcification and skeleton formation (Plaisance *et al.* 2021). 7.8≤pH≤8.5 is favorable for coral growth (Kleypas *et al.* 2006).

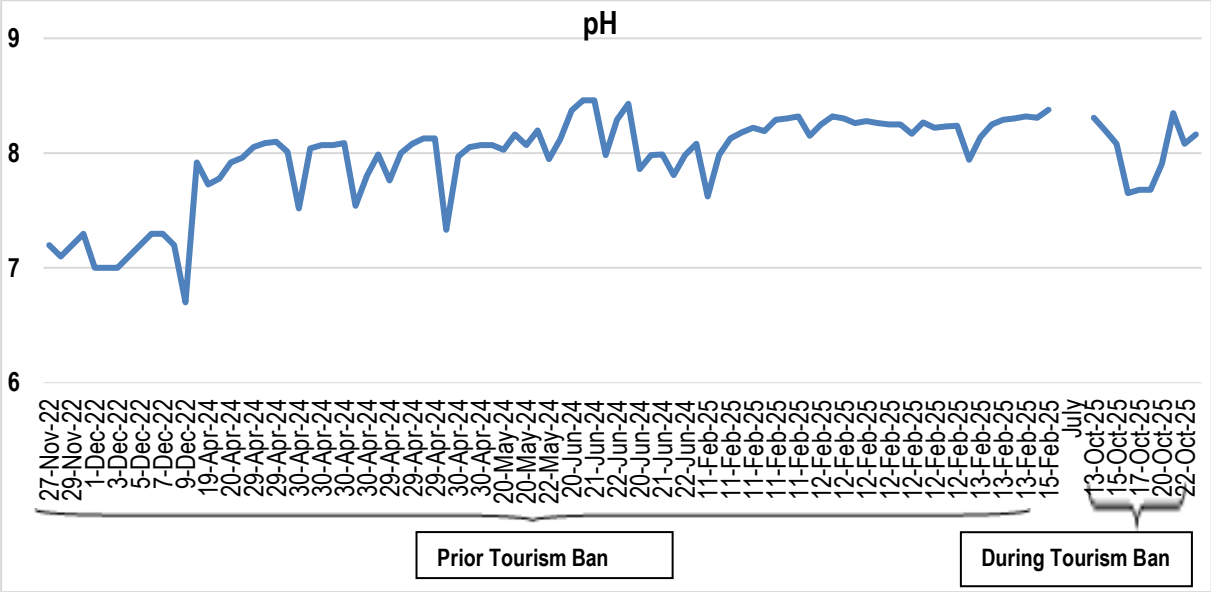
Table 4. Measured pH in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

Collection Date	Min		Max	Average
Optimum for Coral Ecosystem	**7.8**		**8.5**	**8.2**
Prior Tourism Ban	**27-30 Nov 2022**	7.1	7.2	**7.15**
	01-09 Dec 2022	6.7	7.3	**7.0**
	19-30 Apr 2024	7.33	8.13	7.93
	20-22 May 2024	8.03	8.16	8.08
	20-22 Jun 2024	7.81	8.43	8.14
During Tourism Ban	**11-15 Feb 2025**	7.62	8.38	8.21
	13-18 Oct 2025	7.65	8.71	8.18
	20-23 Oct 2025	7.91	8.35	8.13

- **February:** pH ranged 7.62-8.38. This lower pH values may have resulted from elevated CO_2 solubility and reduced photosynthesis, causing potential ecological stress.
- **April:** During hot and dry spring, pH reduced to 7.33-8.13. Localized pollution or increased biological activity might have caused this deterioration.
- **May:** pH improved to 8.03-8.16, indicating phytoplankton's enhanced photosynthesis.
- **June:** pH ranged 7.81-8.43, indicating high biological productivity.
- **October 2025:** After nine months' tourism ban, pH remained stable within favorable range (7.65-8.71), probably due to increased photosynthesis in pollution-free clear water.

Figure 9. Measured pH in Seawater near Saint Martin's Island



3.5. TDS

TDS represents the inorganic and organic salts (calcium, sodium, magnesium, potassium, carbonate, chloride, sulfate, nitrate, etc.) present in water solution (WHO, 2016). Healthy coral reefs thrive in stable TDS (32,000-36,000 mg/L) and can tolerate 25,000-40,000 mg/L (Millero *et al.* 2006). Instable TDS can disrupt coral physiology, growth and resilience (Sealife Planet, 2022).

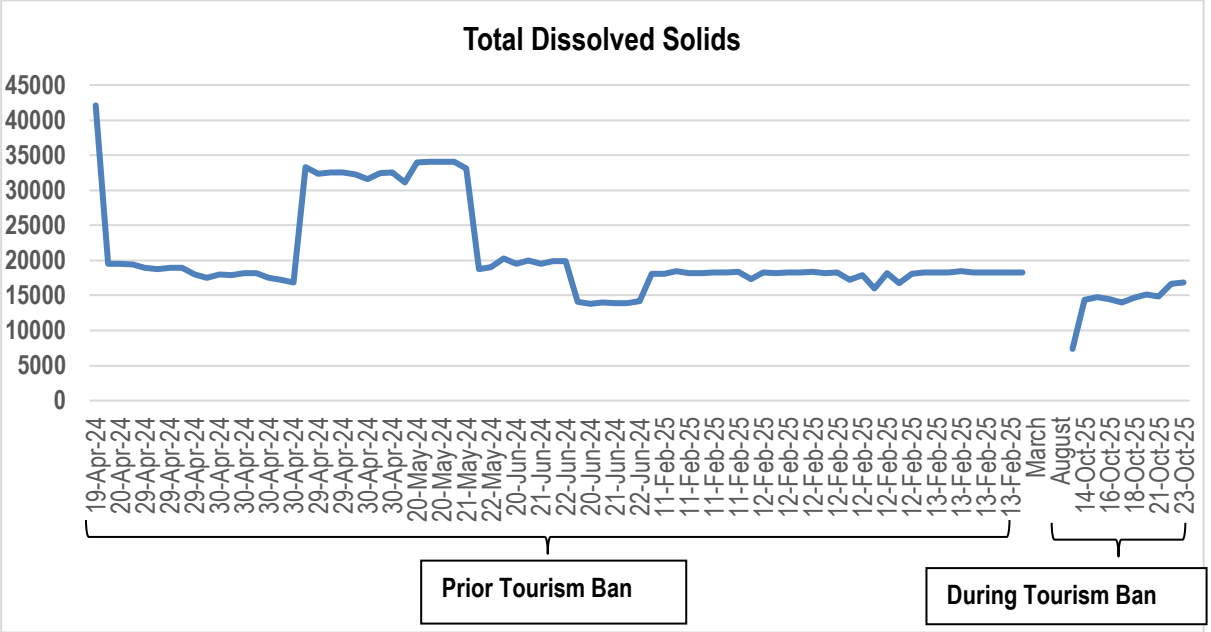
Table 5. Measured Total Dissolved Solids in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, Red: Dangerous)

Collection Date		Min (mg/l)	Max (mg/l)	Average
Optimum for Coral Ecosystem		**25,000**	**40,000**	**32,500**
Prior Tourism Ban	**19-30 Apr 2024**	17,230	42,100	**24,080**
	20-22 May 2024	18,790	34,100	29,665
	20-22 Jun 2024	13,760	20,230	**16,995**
During Tourism Ban	**11-15 Feb 2025**	15,970	18,480	**17,225**
	13-15 Oct 2025	13,920	15,820	**14,870**
	20-22 Oct 2025	14,140	16,840	**15,490**

TDS ranged 13,760-42,100 mg/L, showing distinct seasonal variation due to freshwater influence from rainfall and Naf River discharge. Unusually low TDS adversely affected ion availability and coral calcification; while high TDS increased osmotic stress. Maintaining TDS within the tolerable range is vital for coral health and reef resilience.

Figure 10. Measured Dissolved Oxygen in Seawater near Saint Martin's Island



3.6. Turbidity

Turbidity measures water haziness, caused by suspended particles (silt, clay, organic matter, plankton, etc) and is expressed in Formazin Turbidity Units (FTU) (Fabricius *et al.* 2005).

Table 6. Measured Seawater Turbidity near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min (FTU)	Max (FTU)	Average
Optimum for Coral Ecosystem	**Ideal**	**0.3**	**0.8**	**0.5**
	Moderate	1	3	2
	Stressed	3	5	4
	Harmful	5	15	10
During Tourism Ban	**13 Oct 2025**	1.1	1.2	1.15
	14 Oct 2025	2.9	3.5	**3.2**
	15 Oct 2025	0.4	0.5	0.45
	16 Oct 2025	0.6	0.7	0.65
	17 Oct 2025	0.7	0.8	0.75
	18 Oct 2025	0.7	0.7	0.7

The optimum turbidity for coral colonies is 0.3-0.8 FTU (Fabricius *et al.* 2005). Due to unavailability of suitable instrument, turbidity value could not be measured before 'tourism ban'. However, after 'nine months' tourism ban', it was visually evident that SMI's seawater turbidity reduced and water quality improved. Except abrupt sediment re-suspension due to heavy rainfall on 13-14 October, turbidity remained within the acceptable range (0.45-0.75), suggesting ideal condition for light penetration, photosynthesis and coral-algae symbiosis.

4. Results and Discussion

Teeming with biodiversity, coral reefs are called 'The Rainforest of the Sea'. Despite covering 0.1% of ocean floor, they are home to 25% of global marine creatures (up to 2 million species). Since pre-industrial period, 50%

of global coral reefs have been lost due to 1.2°C warming of the earth. The loss may reach upto 70% and 99%, if average global temperature rises by 1.5°C and 2°C (WWF, 2025). Higher temperature and nutrient enrichment can cause hypoxic DO conditions, jeopardizing the stability of coral ecosystem (Altieri *et al.* 2015). In addition, the ever-growing global carbon emission is causing seawater to absorb more carbon dioxide and increase ocean acidification, posing a serious threat to coral calcification (FAO, 2025).

Despite initial protests from hospitality stakeholders and local communities, SMI's first-ever 'nine months' tourism ban' was successfully implemented due to Bangladesh Government's firm commitment for ecological recovery. Awareness campaigns could convince the local communities that 'tourism ban' may have reduced tourist revenue, but was necessary for island's survival and would gradually usher indirect benefits for the islanders. In the end, local communities realized that SMI's ecological recovery could potentially generate sustainable livelihood (increased fishing, agricultural output, ecotourism, etc.).

Unsustainable tourism activities had caused physiological stress for coral ecosystem through higher temperature, turbidity and lower DO, pH. The 'nine months' tourism ban' (February to October 2025) has reduced anthropogenic pressures, improved water transparency, pH, DO and contributed to SMI's gradual ecosystem recovery. However, anthropogenic drivers from natural and seasonal phenomenon could not be separated due to non-availability of data on climatic effects, Naf river discharge and localized precipitation. Furthermore, the availability of only one year data during 'tourism ban' posed a major challenge to perform further analysis to corroborate these preliminary results.

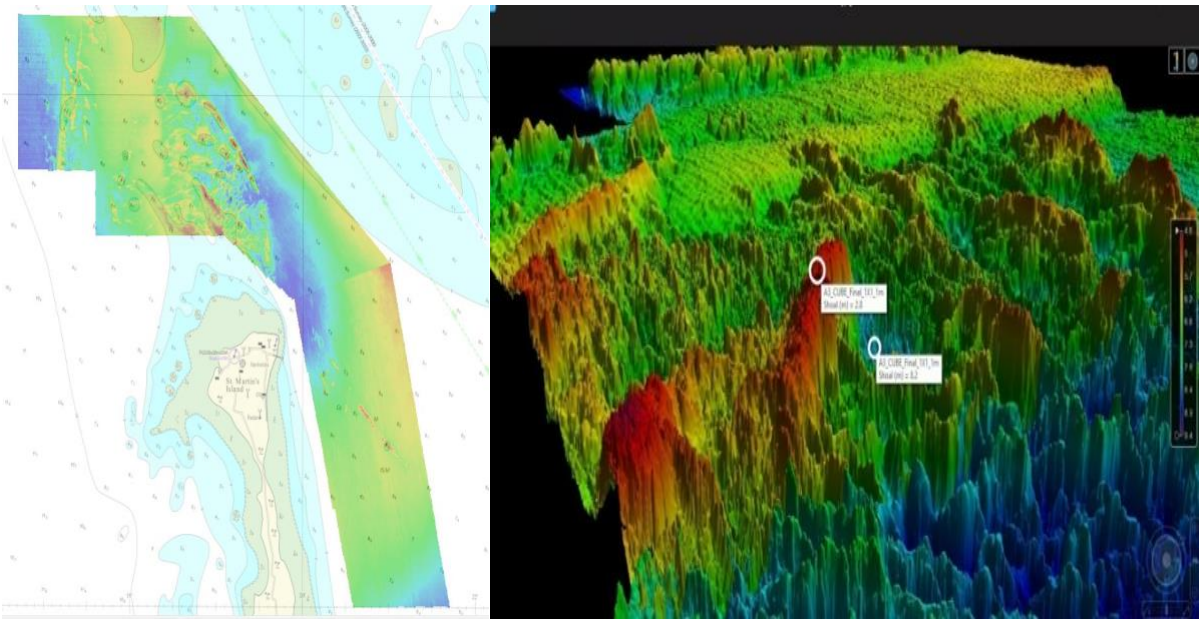
4.1. Temperature

SST measurements displayed clear monsoon-driven seasonal variation. 30°C and above values for extended period may be attributed to strong solar heating, limited cloud cover and stratification. Both global warming and local activities may have caused physiological stress to coral ecosystem, increasing the risk of algae expulsion. The warming trend of SST reduced DO, impaired plankton productivity and accelerated coral bleaching/mortality.

4.2. Salinity

Maintaining stable salinity within acceptable range is vital for sustaining coral ecosystem. Seawater salinity around SMI reflected distinct monsoonal effects. Excessively low salinity (≤28 ppt) reduced coral resilience. While tourism activities alone may have limited impact, associated pollution, sewage runoff and localized Naf freshwater discharge may have caused this variation. After 'nine months' tourism ban', salinity reduced from ≥30 to 24 ppt (later settled at 29 ppt), due to this year's exceptionally heavy rainfall and freshwater discharge.

Figure 11. Mapping Saint Martin's Coral Colonies using Multi Beam Echo Sounder



Source: Author's Construct on Bangladesh Navy Chart 3501

4.3. Dissolved Oxygen

DO around SMI showed clear seasonal variation due to varying SST and biological activity. High temperature reduced gas solubility and corresponded to low DO. After 'nine months' tourism ban', DO improved from 6.0-6.6 to 7.1-7.4 mg/L, suggesting gradual ecosystem recovery. The reduction of human-induced pollution, sewage runoff and sediment influx may have caused such variation.

4.4. pH

Before April 2024, seawater pH<7.8 reduced coral calcification and weakened reef structure. For the rest of the year, pH remained within acceptable range (7.8-8.4) with seasonal fluctuation due to freshwater influx and biological activity. The 'nine months' tourism ban' has reduced anthropogenic pressures and improved pH value from 7.0-8.14 to 8.13-8.21.

4.5. Total Dissolved Solids

TDS around SMI fluctuated widely due to seasonal change, rainfall dilution and Naf river discharge. After 'nine months' tourism ban', the reduction of TDS reflected improved water quality. However, unusually low TDS (during 13-14 October's heavy rainfall) have adversely affected ion availability and coral calcification, being ultimately detrimental to ecological recovery.

4.6. Turbidity

The 'nine months' tourism ban' caused considerable reduction in sediment suspension (or turbidity) and improved water clarity. Though turbidity value could not be measured before tourism ban due to unavailability of suitable instrument, the improvement of SMI's seawater quality was visually evident. Enhanced light penetration is supporting benthic/algae productivity and the overall health of coral ecosystem.

Table 7. Chronological Assessment of Average Ecosystem Parameters in Saint Martin MPA

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

Date	Temp (°C)	Salinity (ppt)	DO (mg/L)	pH	TDS (mg/L)	Turbidity (FTU)	Remarks
27-30 Nov 2022	28.9	35.2	6.1	**7.15**	-	-	Stable, mild Acidic
1-9 Dec 2022	27.9	35.25	6.1	**7.0**	-	-	Stable, Acidic
19-30 Apr 2024	**31.41**	32.42	6.02	7.93	**24,080**	-	Highest Temp, low TDS & pH **(Coral stressed)**
20-22 May 2024	**30.64**	33.71	6.14	8.08	29,665	-	High Temp **(Coral stressed)**
20-22 Jun 2024	**30.15**	29.41	6.60	8.14	**16,995**	-	High Temp, low TDS **(Coral stressed)**
11-15 Feb 2025	27.69	35.48	7.07	8.00	**17,225**	-	Favorable, low TDS
27-30 Sep 2025	28.81	**24.91**	-	-	-	-	Lowest salinity
13-18 Oct 2025	29.86	**24.0**	7.15	8.18	**14,870**	1.15	High temperature, low salinity, lowest TDS
20-22 Oct 2025	29.84	29.0	7.36	8.13	**15,490**	-	High temperature, low salinity, low TDS

To evaluate the impact of 'tourism ban' on SMI's water quality and coral ecosystem, single-factor ANOVA was used to compare pre-ban and during-ban temporal groups and quantified the following values:

Table 8. Statistical Analysis of Ecosystem Parameters in Saint Martin MPA

Parameter	P	F	F crit	Remarks
Temp (°C)	0.1	1.69	2.5	Alternative hypothesis rejected (P>0.05) Statistically insignificant (F<F crit)
Salinity (ppt)	0.00001	14.63	2.51	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)
DO (mg/L)	0.04	2.83	2.65	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)

Parameter	P	F	F crit	Remarks
pH	0.001	6.32	2.65	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)
TDS (mg/L)	0.14	2.05	3.09	Alternative hypothesis rejected (P>0.05) Statistically insignificant (F<F crit)

Salinity (P=0.00001), pH (P=0.001) and DO (P=0.04) showed statistically significant improvements and thus, null hypothesis (H_0) was rejected. However, temperature (P=0.1) and TDS (P=0.14) were found statistically insignificant, indicating the influence of complex broader issues (global warming, ocean acidification, monsoon, etc.), rather than localized management interventions.

Conclusions

SMI is the only island in Bangladesh that sustains unique coral ecosystem, teeming with biodiversity. Since 2004, uncontrolled tourism along with unsustainable practices beyond island's hosting capacity has severely degraded coral ecosystem and is threatening its very existence. As a result, in January 2022, Bangladesh Government declared Saint Martin MPA and in October 2024, regulated tourists arrival on SMI through pre-registration (November to January, maximum 2,000 tourists/day). While many commended such endeavors to protect the threatened biodiversity, hospitality professionals have organized nationwide protests to lift this tourism ban (Dailystar, 2025). Through awareness campaigns on the necessity of tourism restrictions for island's survival and islanders' long-term benefits, SMI's first-ever 'nine months' tourism ban' was successfully implemented from February to October 2025.

Regular monitoring of bio-geochemical parameters is highly desirable for ensuring healthy coral ecosystem. The enforcement of strict tourism regulations provided unique opportunity to measure ecosystem parameters before and during 'tourism ban' to assess ecological recovery. Due to the limited accessibility, in-situ data (T, S, pH, DO, TDS, turbidity) have been collected primarily from SMI's eastern portion and during winter season. Nevertheless, these restricted samplings have generated an approximate representation and facilitated the broader oceanographic understanding of the entire Saint Martin MPA.

The study revealed distinct environmental benefits of regulated tourism due to decreased anthropogenic stressors. The analysis of temperature and salinity demonstrated significant monsoon-driven variability and freshwater discharge from Naf River. The assessment of DO and pH demonstrated considerable improvement (DO improved from 6.0-6.6 to 7.1-7.4 mg/L and pH improved from 7.0-8.14 to 8.13-8.21). ANOVA test for salinity, pH and DO found the impact of 'tourism ban' on SMI's ecological recovery as statistically significant. However, whether this amelioration can be attributed primarily to 'tourism ban' or a combination of correlated factors could not be verified, due to the lack of longer-term complementary, pertinent dataset on climate and hydro-meteorology.

The valuable insights of this pioneering study to evaluate the impact of 'nine months' tourism ban' on SMI's coral ecosystem recovery may promote coral resilience, environmental preservation and contribute to the blue economic development. This analysis may be regarded as a microcosmic example of the interplay between human activities and marine environment in the entire Bay of Bengal. Therefore, the continuation of 'tourism ban' and measurement of ecosystem parameters should be pursued in the upcoming years. Based upon the findings of this study, the followings are recommended for the preservation of SMI's marine environment and coral ecosystem:

- **Regulated Tourism**: Bangladesh Government may continue with Saint Martin's on-going tourism restrictions for another two years to allow natural regeneration of coral colonies and healing of coral ecosystem. Upon achieving the desired ecological recovery, regulated eco-tourism may be promoted.
- **Awareness Campaign**: Bangladesh's Department of Environment & Forest may conduct awareness campaigns for both locals and tourists on the benefits of environmental preservation to reduce pollution and usher ecological recovery.
- **Underwater Survey**: Bangladesh Oceanographic Research Institute may conduct a detailed underwater survey to ascertain the location and health of coral colonies.
- **Coral Regeneration**: Efforts may be taken to minimize anthropogenic stressors like pollution, sedimentation along with global warming, ocean acidification to facilitate coral regeneration.
- **Coral Gardening**: With international support, Bangladesh's Department of Environment may conduct feasibility study and cost-benefit analysis on climate-resilient coral gardening around SMI.

- **Mangrove Plantation**: To protect the shorelines and minimize water turbidity, Bangladesh's Department of Forest may scientifically conduct mangrove plantation and other nature-based environment-friendly solutions.
- **Community Engagement**: To protect marine ecosystems, the involvement of local government and communities in environmental preservation may be prioritized.
- **Ecotourism**: To support local economies without degrading environmental health, Bangladesh's Department of Tourism may conduct a detailed study through Subject-Matter-Experts to promote ecotourism.
- **National/Regional Collaboration**: Collaboration among various stakeholders (national, regional, global) may facilitate research, funding and knowledge sharing for environmental preservation. Beside these local actions, global actions such as limiting global warming and minimizing marine pollution, ocean acidification are highly desirable for the sustainable livelihood of future generations.

Declarations

Credit Authorship Contribution Statement

Rezaur Rahman: Conceptualization, Methodology, Data collection & analysis, Writing
K. M. Azam Choudhury: Supervision, Visualization, Validation, Editing
Mirza Golam Kibria: Data collection and analysis, Writing
Tonia Astrid Capuano: Supervision, Editing

Competing Interests: The authors have no competing interests (financial/non-financial) to declare that are directly/indirectly relevant to the content of this article.

Funding Declaration: No funding was received for conducting this study or assisting in the preparation of this manuscript.

Ethics and Consent to Participate Declarations**:** The submitted work is based on collected in-situ data and original research conducted by the authors. Efforts were made to adhere to all ethical aspects during this research and while preparing this manuscript. Data were acquired, processed and the results were presented honestly and without fabrication, falsification or inappropriate manipulation. No data were used in this research that may require consent from any individual or organization. The article has not been published and is not currently under consideration for publication anywhere else. We give our full consent for the publication of this article to be published in your esteemed Journal.

Data Availability: The ecosystem parameters collected by the researchers from 2022 to 2025, are under the custody of the corresponding author and can be made available upon request.

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