https://doi.org/10.48047/AFJBS.6.14.2024.3348-3360

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Distribution and composition of marine litter along sandy beaches: A study in Goa, India

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Volume 6, Issue 14, Aug 2024

Received: 09 June 2024

Accepted: 19 July 2024

Published: 08 Aug 2024

doi: 10.48047/AFJBS.6.14.2024.3348-3360

Abstract
Beach litter, comprising a diverse mix of human-made waste, poses an escalating threat to coastal environments, particularly in tourist-infested states like Goa. As one of India's most sought-after tourist destinations, Goa attracts visitors from around the world. Its stunning coastline, spanning approximately 100 kilometers, boasts pristine beaches that contribute significantly to the state's economy. Over 40% of the population is directly or indirectly dependent on tourism, making it the backbone of Goa's economic vitality [1]. However, the challenge lies in preserving this natural beauty. To understand the distribution, composition, and sources of beach litter, a rigorous study was conducted on five major Goan beaches: Palolem, Colva, Baina, Miramar, and Calangute. Researcher employed a standardized 100-meter survey protocol established by the OSPAR Program, ensuring comparability across beaches. Over 24 months, starting in April 2022, surveys were conducted during three tourist seasons. Data collection involved identifying, counting, and measuring debris within designated transects, including plastic items, glass fragments, and fishing gear. The analysis reveals significant seasonal variations in litter accumulation and identifies key sources contributing to the problem. Our findings highlight the need for targeted waste management strategies and increased public awareness to combat the negative impacts of beach litter on the coastal ecosystem and local economies. The findings of the present study provide valuable data for formulating comprehensive policies to preserve the ecological health and natural beauty of Goa's iconic beaches.
Keywords: Beach litter, beach litter distribution, waste management, seasonal variation, environmental impact

Introduction

Marine litter, encompassing a vast array of human-made waste, has become a global crisis plaguing our oceans [2]. This ubiquitous litter originates from both land-based sources, such as littering by tourists and beachgoers, and sea based sources, including discarded fishing gears and operational waste from ships. Once in the ocean, marine litter remains at the surface, transported by currents and winds, until it ultimately sinks to the seafloor or washes ashore [3,4,5].

The presence of marine litter poses a significant threat to the health of the coastal environment. [3]. An estimated 6.4 million tonnes of litter are discarded into the ocean annually and that the annual rate of production of plastic has touched 300 million tons in 2010 itself [6]. Thus, the build-up and dispersal of marine litter is an increasingly pressing worldwide issue that impacts all marine environments [4]. Our carefree way of living has resulted in the annual discharge of around 8.8 million tonnes of plastic trash into the ocean. Consequently, there is a risk of extinction for more than 700 species of marine organisms [7]. The lack of beach cleanliness can lead to a loss of recreational potential of a beach which impacts the economy and social well-being, especially because coastal populations have become more dependent on beach areas [8]. Hence, cleaning is one of the fundamental concerns of beach managers in many destinations [9].

There are several locations in India, where studies about beach litter have been carried out, which includes the Nicobar Islands [10], Karnataka coast [11], northern Gulf of Mannar [12], selected beaches of Kerala, Karnataka and Tamil Nadu [13], some urban beaches in Mumbai [14] and Mangalore coast [15]. However, there are limited studies available on beach litter carried out in Goa.

This research focuses specifically on the beach litter that accumulates within the intertidal zone along the stunning beaches of Goa. The presence of litter detracts from the visual appeal of Goa's pristine beaches, potentially deterring tourism and impacting the livelihoods of local residents heavily reliant on this sector. Beyond the ecological damage, marine litter has severe economic repercussions for Goa's coastal communities. Tourists are drawn to clean and pristine beaches. Therefore, effective beach cleanup strategies are crucial to maintain the beauty of the beaches and ensure the safety of beachgoers. Understanding the composition and classification of beach litter in Goa is a critical step towards addressing this growing issue. Therefore, the present study is carried out with aims to analyse the types and quantities of marine litter found on Goan beaches. By studying these factors, we can gain valuable insights into the sources of the litter, allowing for targeted interventions to prevent further pollution. This study on the classification of marine litter on Goa's coast holds immense practical significance for the well-being of the region. By identifying the dominant types of litter and their sources, this research can inform effective management strategies to combat marine litter in Goa.

Materials and Methods

Study area

Goa is a popular tourist destination in India and is considered suitable for this study to understand beach litter and associated sources, considering varied beach activities in the state which includes tourism as major activity. Therefore, this research investigated beach litter on the coast of Goa, India (15.29° N to 74.12° E), spread over 100 kilometres. The study period spanned for over 24-months commencing April 2022, encompassing three tourist seasons. In the present study five prominent beaches were selected (Figure 1) to provide a comprehensive overview of litter accumulation along Goa's coastline. These beaches, Baina, Calangute, Colva, Miramar, and Palolem, are known as key tourist hubs attracting visitors not only from across India, but also from other countries around the globe. The characteristics of these beaches, including their geographical coordinates, and dimensions, are detailed in Table 1.

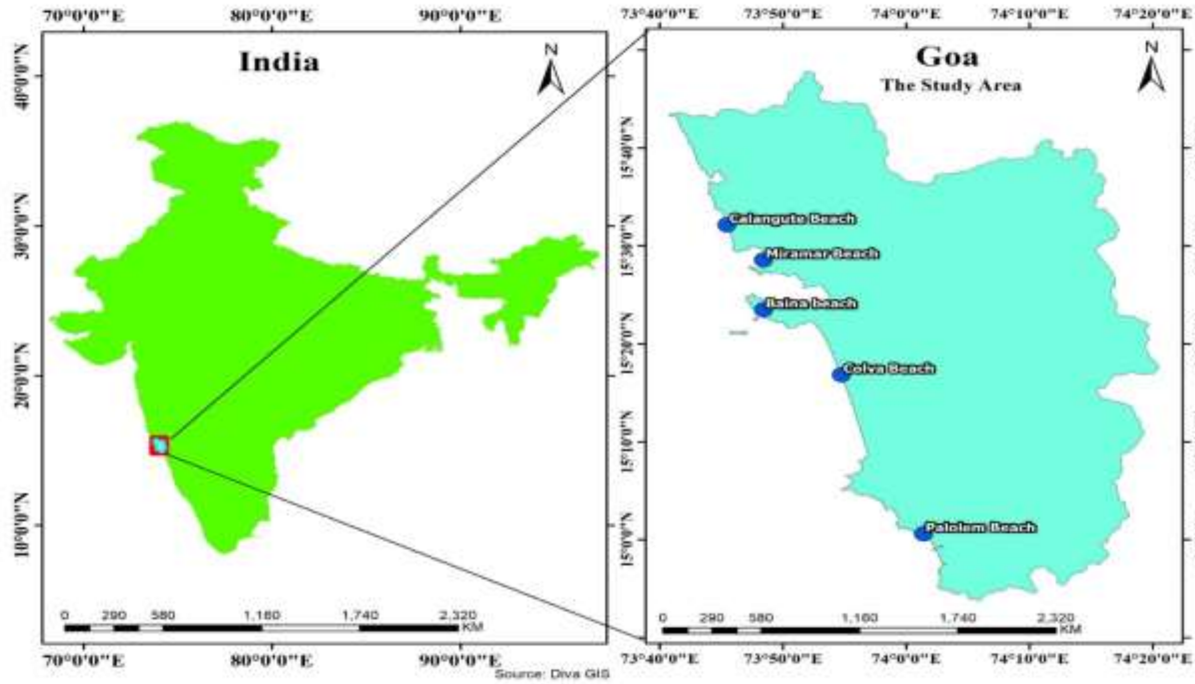

Figure 1: Study area map showing the beaches surveyed for sample collection in Goa (India)

Beach Name	Latitude	Longitude	Length (Approx.)
Miramar	15.4667° N	73.8333° E	2 km
Calangute	15.5439° N	73.7551° E	4.5 km

Table 1: Characteristics of the studied beaches

Sample collection

Beach Litter Collection Methodology

Beach litter collection was conducted in accordance with the OSPAR Program [16] which provides a standardized survey protocol for observing marine litter on the beaches. This protocol has been developed, tested, and used in fieldwork, offering two survey options: a 100-meter stretch or a 1-kilometer stretch of beach. The 100-meter survey protocol includes over 100 different items of various sizes, while the 1-kilometer survey protocol focuses on about 20 larger items (greater than 50 cm in any direction). Considering the limitation of the resources and scope of study the first option i.e. the 100-meter survey protocol was selected and used for data collection.

To monitor beach litter, a stratified random sampling (StRS) method was employed. This method was selected for its efficiency in providing representative and accurate estimates with a reduced sample size compared to other methods. Each beach was divided into sections of at least 1 km, with two transects of 100 m per beach. Repeat sampling was conducted to establish trends.

The peak season in Goa spans from October to March, covering the periods from October 2022 to March 2023 and October 2023 to March 2024. During these months, the weather is particularly pleasant, with temperatures ranging from 20°C to 32°C and minimal rainfall. This season is ideal for beach activities, water sports, and sightseeing, as well as attending local festivals such as Christmas, New Year’s Eve, and the Goa Carnival. These events attract both domestic and international tourists, leading to crowded beaches, and bustling markets.

Data on Beach Litter was collected from the study area at low tide from April 2022 for next two years covering peak tourist seasons and non-peak seasons. The debris within these transects was identified, counted, and recorded. The position of each location was tracked using the Global Positioning System (GPS).

The collected beach litter was categorised into over 110 type items, including plastic stirrers, straws, plastic silverware, cotton swabs, plastic cling wrap, cigarette butts, plastic resealable bags, and food containers etc. All these items were broadly categorised into nine broad categories i.e. Plastic, Glass, Rubber, Paper, Fabric, Metal, Wood, Sanitary waste and Miscellaneous further analysis and understanding the litter composition.

Calculation of Beach Litter Concentration:

The concentration of marine debris (macro) per transect was determined using the formula:

$$C_i = \frac{n_i}{a_i \times b_i}$$

where C_i is the concentration of beach litter items (items/m²), n_i is the total number of marine debris items per transect, a_i is the length of the transect (100 m), and b_i is the width of the transect (2 m). This formula has been used in previous studies to assess the concentration and density of marine debris in different coastal regions [17].

Clean-Coast Index (CCI):

The Clean-Coast Index (CCI) was used to measure the cleanliness of the coast [18]. The CCI, which classifies beaches based on the amount of beach litter found on them, is expressed as follows:

$CCI = K \times Ci$

where K is a constant (20 in this study) used to make the numerical value of the CCI comprehensible. According to the scale provided for the number of litter items on the coast, beaches were classified from 'clean' to 'extremely dirty'. The values of Ci, CCI, Coast index, and visual assessment are given in Table 2. The main objectives for many researchers are to find the spatial distribution, abundance, CCI, and concentration of marine debris in various coastal regions.

Results

Marine Debris Sources

The three main categories of sources that contribute to marine debris input are land-based, sea-based, and unknown sources. According to the findings of the study, litter from land-based sources contributes the most to the total amount of debris generated. Overall, the land-based marine debris accounted for 68.5% of the items, sea-originated marine debris for 21%, and 10.5% of the marine debris could not be identified (Fig. 2). Similarly, study has been carried out on the Thondi coast, India, which has been compared in the discussion section.

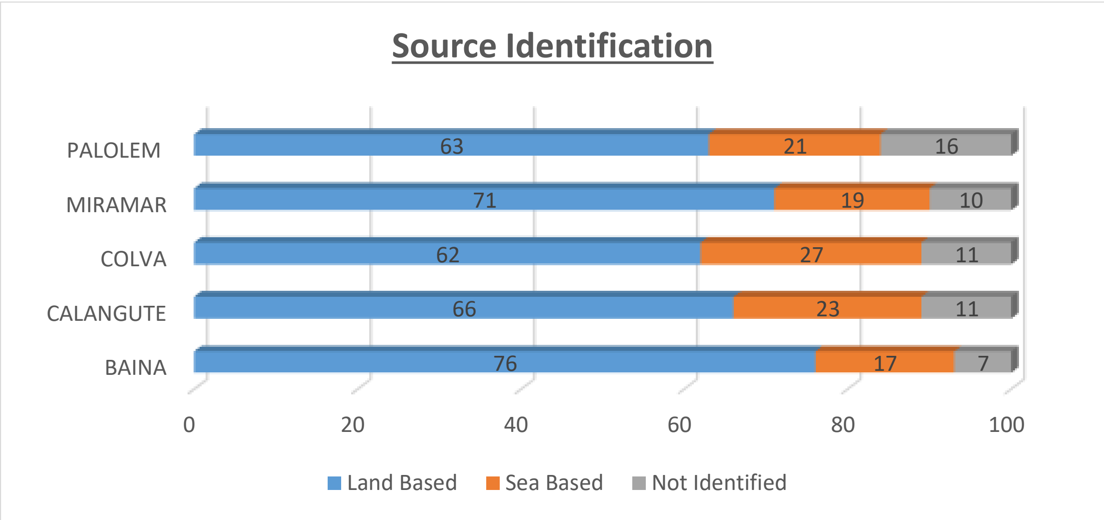

Figure 2: Shows the source identification at selected beaches of goa

Marine Debris Distribution:

Analysis of category wise composition of litter

Litter composition on five beaches (Baina, Calangute, Colva, Miramar, and Palolem) was analysed to understand the distribution and percentage of various types of litter (Figure 3). The primary categories of litter include plastic, glass, rubber, paper, fabric, metal, wood, sanitary waste, and miscellaneous items.

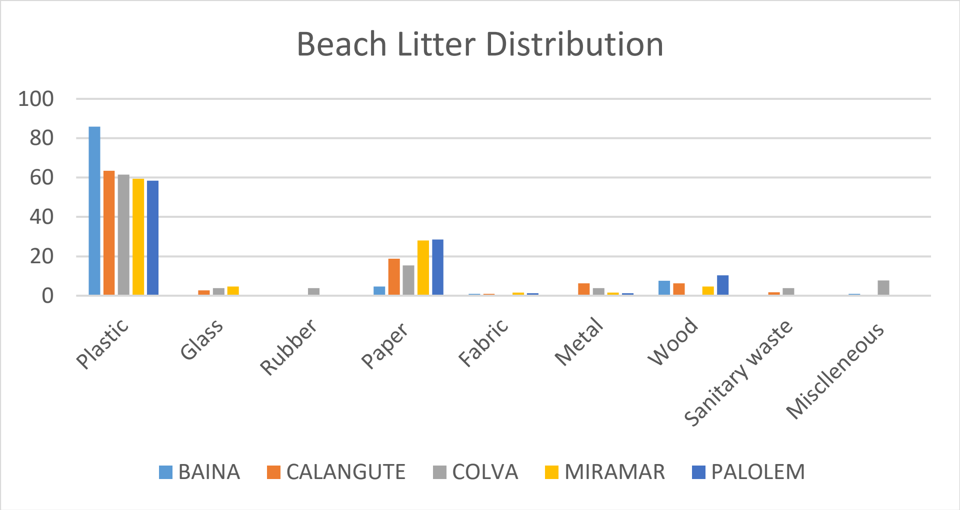

Figure 3: Shows the distribution of beach litter at five selected beaches of Goa

Plastic

Plastic is the most prevalent type of litter across all beaches. In the first dataset, Baina beach had the highest percentage of plastic litter at 76.5%, followed by Calangute (66.4%), Miramar (62.3%), Palolem (57.0%), and Colva (55.2%). The second dataset showed a slight reduction but maintained similar trends with Baina at 70.5%, Calangute (63.0%), Miramar (62.1%), Colva (61.3%), and Palolem (59.8%). The consistent high percentage of plastic litter indicates a significant environmental issue, necessitating targeted waste management and reduction strategies.

Glass

Glass litter was found in minimal quantities. In the first dataset, Calangute had the highest glass litter percentage at 2.8%, while Baina and Palolem had no glass litter. The second dataset showed similar low percentages, with Miramar having the highest at 5.4%. The consistent low percentage of glass litter suggests that it is not a major pollutant compared to plastic but still requires monitoring to prevent hazards.

Rubber

Rubber litter was negligible across all beaches. Only Colva reported 1.4% in the first dataset and 4.0% in the second dataset. Other beaches had no significant presence of rubber litter. This minimal presence indicates that rubber is not a prevalent litter type in these areas, but its impact should still be assessed periodically.

Paper

Paper litter was present in varying quantities. In the first dataset, Calangute had the highest paper litter percentage at 19.6%, followed by Palolem (27.8%). The second dataset saw Palolem with the highest at 29.9%, indicating a persistent issue with paper litter. The percentage presence of paper litter underscores the need for better waste management practices, particularly in high-tourism areas.

Fabric

Fabric litter was minimal across all beaches, with percentages generally below 1.0%. The highest recorded was 2.0% at Miramar in the second dataset. The low percentage of fabric litter indicates that it is not a significant concern compared to other litter types.

Metal

Metal litter showed a relatively low presence. Calangute had the highest percentage in the first dataset at 6.5%, with a slight decrease to 5.4% in the second dataset. The consistent yet low percentage of metal litter suggests that while it is not as pervasive as plastic, its environmental impact should not be ignored.

Wood

Wood litter varied across beaches. Palolem showed significant quantities, particularly in the second dataset at 10.3%. Other beaches had lower percentages, with Baina and Calangute showing around 7.0-8.0%. The presence of wood litter may be attributed to natural sources or discarded materials and requires continuous monitoring.

Sanitary Waste

Sanitary waste was found in small amounts, with Colva reporting the highest percentage in the second dataset at 4.0%. The presence of sanitary waste, although minimal, poses health risks and highlights the need for better public facilities and awareness.

Miscellaneous

Miscellaneous items were found in negligible quantities. Only Colva showed a significant increase to 8.0% in the second dataset. This category includes various unclassified items that could pose various environmental and health risks.

Beach Quality Index

The spatial distribution, concentration, and Clean-Coast Index (CCI) of the debris in this study are measured at ten separate locations on the five beaches in the study region and used to assess the clean beach index for all the five beaches (Figure 4). The spatial distribution of marine debris identified in the study area includes plastic bags, plastic bottles, bottle caps, lunch boxes, glass fragments, glass bottles, tires, rubber gloves, rubber shoes, newspaper, book, disposable paper cup, carton, old clothes, towels, fishing nets, electrical wiring, cans, paint buckets etc. all these items were broadly categorised into nine broad categories i.e. Plastic, Glass, Rubber, Paper, Fabric, Metal, Wood, Sanitary waste and Miscellaneous as described earlier.

The beach quality of the study area was determined by using three indexes, based on the density and character of the litter, which are Clean Coast index (CCI), General Index (GI) and Hazardous Items Index (HII). CCI calculated to assess the cleanliness state of the studied beach from plastic debris accumulation. Based on the number of plastic debris, the values of the CCI scale represent the beach cleanliness state as follows: (i) 0-2: very clean, (ii) 2-5: clean, (iii) 5-10: moderately clean, (iv) 10-20: dirty, and (v) >20: extremely dirty. The application and principle of the GI is analogous to the CCI. However, it considers every type of marine debris irrespective of plastic litters. HII applied to assess the abundance of potentially hazardous waste in the beach environment. For example, sharp metal and glass items that can potentially inflict injury to beach users, and toxic waste (medical waste, sanitary waste, and cigarettes) may induce physiological harm.

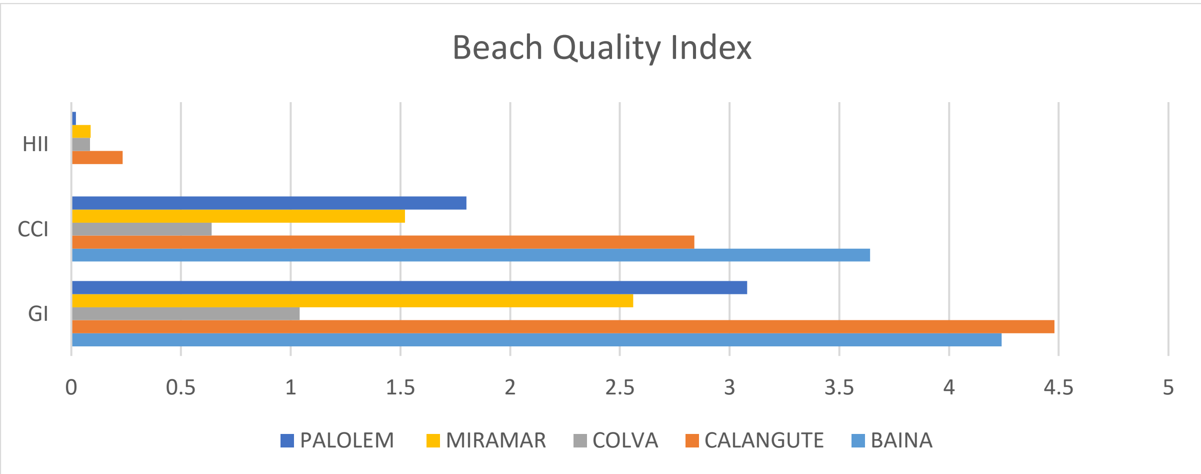

Figure 4: Shows the beach quality index of Selected beaches of Goa

Discussion:

The present study highlights the significant issue of beach litter in Goa, focusing on five major beaches: Palolem, Colva, Baina, Miramar, and Calangute. The findings of the present study revealed that the litter from land-based sources makes up the largest portion of the debris produced overall. According to the findings of the study, in total, 21% of the objects were marine debris that originated at sea, 10.5% of which could not be identified, and 68.5% of the items were marine debris that was land-based (Fig. 2). Comparably, study conducted on the Thondi coast in India [19] found that 16.41% of the marine debris could not be recognized, land-based marine debris made up 62.45% of the items, and marine debris that originated at sea accounted for 21.14%. The primary source of marine debris in both studies is land-based activities. The debris originated from land is state of Goa is found to be 62.45%, which in line with the findings of similar studies in India and other places, where land-based sources primarily tourism [20] and other domestic activities contribute significantly to the beach litter.

According to the MoES report, the Odisha coast had the lowest quantity of beach debris (0.31 g/m^2), while the Goa coast had the highest (205.75 g/m^2).

In the present study Plastic bags, plastic bottles, bottle caps, lunch boxes, glass fragments, tires, rubber gloves, rubber shoes, newspaper, book, disposable paper cup, carton, used clothing, towels, fishing nets, electrical wiring, cans, paint buckets, and other items are among the marine debris that has been identified in the study area and categorised as per previous studies [21, 23]. Plastic waste is the primary pollutant on the studied beaches which also aligns with the existing studies [20,22,24]. The predominant types of litter included plastic bags, sachets, PET bottles, and other domestic and anthropogenic discards. A similar study on the west coast of Qatar [25] brings out that major cause of litter present on the coast is tourism, which aligns with the outcome of the study. Litter levels fluctuate seasonally, peaking during the post-monsoon period when increased tourist activity and rainfall contribute to debris accumulation. However, the overall beach cleanliness is relatively good, as measured by the Clean-Coast Index.

Conclusion

This study highlights the significant issue of beach litter in Goa, focusing on five major beaches: Palolem, Colva, Baina, Miramar, and Calangute. The findings reveal that plastic waste is the most prevalent type of litter, with notable seasonal variations, particularly during the post-monsoon season when litter accumulation increases due to heightened tourist activity and runoff. Despite these challenges, the general standard of the beaches remains relatively clean, as indicated by the Clean-Coast Index (CCI). However, there is still room for improvement to ensure the beaches are maintained at a high standard year-round.

To address the issue of beach litter, several recommendations are proposed. Firstly, improving waste collection and recycling infrastructure is crucial. This includes installing more waste bins and ensuring regular collection, particularly during peak tourist seasons. Stricter enforcement of anti-littering laws is also necessary to deter improper waste disposal, with fines and penalties promoting responsible behaviour among both tourists and locals. Additionally, public awareness campaigns should be launched to educate the public about the environmental impact of littering. Signage on beaches and educational workshops can encourage proper waste disposal practices.

Engaging local communities in beach cleanup initiatives is another important strategy. Volunteer programs and partnerships with businesses and NGOs can provide additional support for these efforts. Continuous monitoring of beach litter using standardized methods is essential to track progress and identify emerging trends. Further research into the sources and pathways of marine litter can inform more targeted interventions.

By implementing these recommendations, the cleanliness of Goa's beaches can be maintained, protecting the coastal environment and supporting the local economy. This study provides a foundation for future research and policy development aimed at reducing marine litter in coastal regions.

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