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Grain Size Analysis of Beach Sand in the Southern Lombok Coastal Zone

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***Abstract*— Beyond its tourist appeal, beach sand plays a significant role in various dimensions, including ecological and geological aspects. The objective of this study is to understand the composition of sand grains along the coastal zone of southern Lombok through sand grain analysis to support coastal management. Sand samples (n=60) were collected during June-July 2023 from ten different locations along the southern coast of Lombok, including both the intertidal and supratidal zones. The collected samples were dried and sieved to classify their size as Gravel, Very Coarse Sand, Coarse Sand, Medium Sand, Fine Sand, or Silt. Permutational Multivariate Analysis of Variance on transformed log-ratio data confirms that the sand composition in the intertidal zone is significantly different from the supratidal zone in all locations except Bumbang Beach, concluding the dominance of coarser materials in the intertidal zone and finer materials in the supratidal zone. The dominance of coarser materials is found in the southward-facing beaches, which are directly exposed to strong waves, while finer-grained sand is mostly found in covered coastal areas. Most of the coarser materials along Lombok's southern coastline are composed of well-rounded carbonate sand formed from a large foraminifers, mixed with coral and shell fragments. Extreme dominance of the finer grain class can be found on Selong Belanak and Ekas beaches, indicating a susceptibility to abrasion.**

Keywords— Sand, Granulometry, Southern Lombok

I. Introduction

As one of the super-priority tourism destinations designated by the Indonesian government, Lombok Island is expected to attract visitors from around the world [1]. Coupled with the development of Mandalika race circuit, which has garnered worldwide attention, marine-based tourism remains the primary attraction for travelers in the southern part of Lombok. The pristine coasts, along with their unique and beautiful sands, further enhance the allure of the beaches in this region.

In addition to its role as a tourist attraction, beach sand plays a significant role in various dimensions, including ecological and geological aspects [2]. Beach sand acts as a natural buffer, protecting coastal areas from the impacts of storms and waves by absorbing and dispersing their energy [3]. Moreover, the composition of beach sand holds valuable information regarding the geological and sediment transport history in the region [4], which can be understood through scientific approaches, one of which is sand granulometry analysis.

Sand granulometry, also known as sand grain analysis, is a method used to reveal the distribution and characteristics of particle sizes in a sample of sand or sediment, which is crucial in the study related to beach management. Analyzing the distribution and size of sand grains on a beach helps stakeholders understand how sediments are transported by waves, tides, and currents [5]. This provides essential data to track and predict shoreline shifts caused by abrasion and changing climate conditions [6].

This study aims to understand the sand grain distribution along the coastal zone of southern Lombok. By conducting a thorough analysis of the sand grains in this region, researchers can gain valuable insights into the beach's dynamics and contribute to the sustainable management and preservation of this unique coastal environment.

II. Method

A. Sand Sample Collection

Sand samples for this analysis were collected during June-July 2023 from ten different locations along the southern coast of Lombok (Figure 1). These locations were selected among several tourism destinations and are approximately 5 to 10 km apart. Three samples from both the intertidal zone (the area between low and high tidal levels, regularly covered by water during high tide) and supratidal zone (the area above high-tide line, and might be covered by water only during extreme storms) were taken from each location. Sand samples were collected using a modified 2-inch PVC pipe, reaching a depth of up to 20 cm, and then stored in plastic bags for further analysis in the laboratory.

B. Laboratory Analysis

Data on sand grain size were obtained using a sieve stack procedure, following Hoque et al. [7] with slight modifications. The collected sand samples were cleaned and washed with freshwater to eliminate any debris, organic materials and benthic organisms. Subsequently, the wet samples were sun-dried for about 2-3 days before being placed in an oven and heated to 105°C for 24 hours to ensure uniform dryness. The dried samples were then manually sieved using multiple sieves consisting of sieve numbers 10, 20, 30, 50, and 120 to determine the grain classes, which were grouped based on size using the Krumbein [8] scale. The retained sand on each sieve was weighed to the nearest 0.01 g using an analytical balance

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to classify the sand as Gravel, Very Coarse Sand, Coarse Sand, Medium Sand, Fine Sand, or Silt, respectively (Figure 2). The percentage weight of each class was determined by dividing the weight of the retained sand by the total weight of the samples.

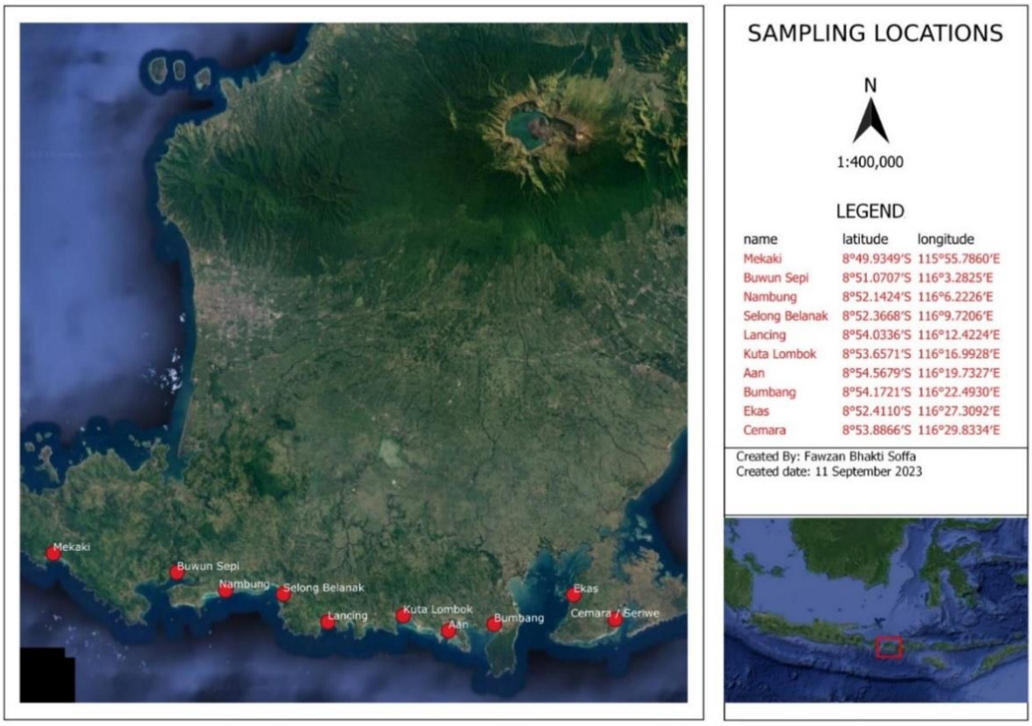

Figure. 1. Sampling locations

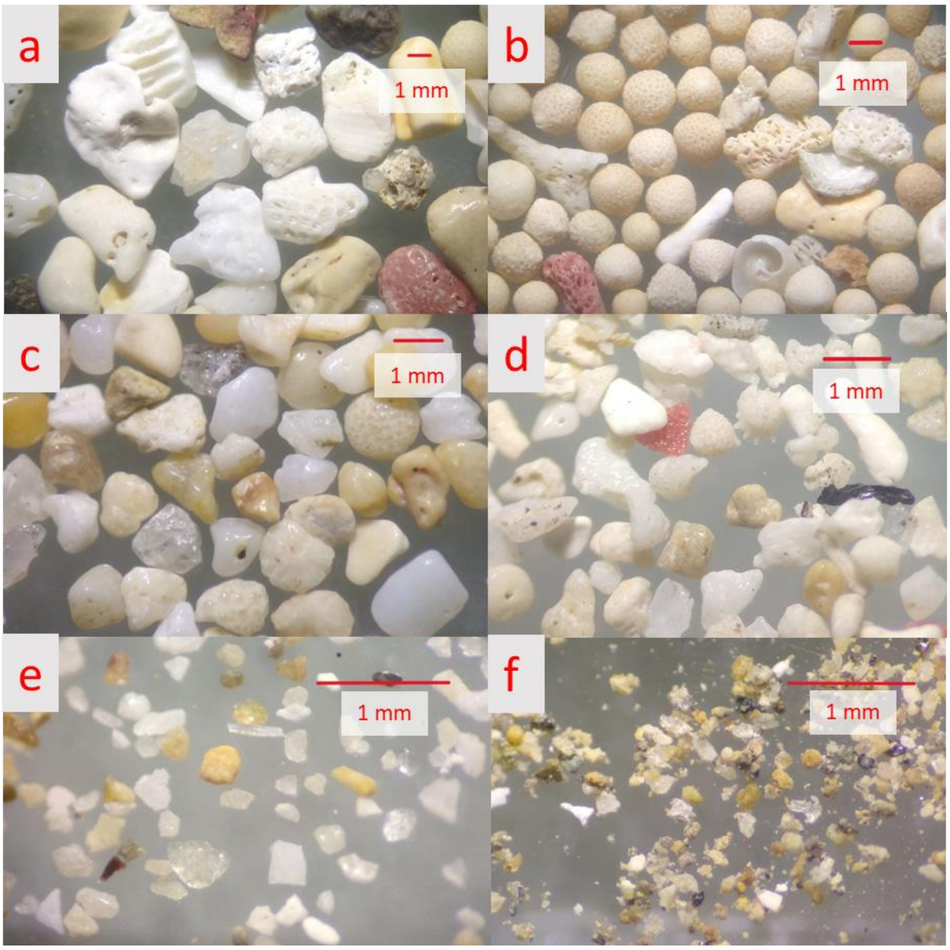

Figure. 2. a) Gravel, b) Very coarse sand, c) Coarse sand, d) Medium sand, e) Fine sand, f) Silt

C. Statistical Analysis

All analyses were performed in R, utilizing the “compositions”, “easyCODA”, and “vegan” packages. Before conducting compositional data analysis, the sand grain distribution data were transformed from compositional data to a log-ratio matrix form by performing centered log-ratio transformation (clr), resulting in a distance matrix. This conversion was necessary due to the inherent “closure constraint” present in raw compositional data, rendering it unsuitable for analysis using standard statistical methods [9]. Permutational Multivariate Analysis of Variance was implemented to determine whether there are differences in sand composition between locations [10]. The matrix data were then visualized by generating a biplot of the log ratio analysis (LRA) to examine the similarity of sand composition from each location where the samples were taken. Each class of 6 grain size (such as Gravel, Very Coarse Sand, and so on) will also be referred to as “components” further.

III. RESULTS AND DISCUSSION

The composition of sand grains from the beach sand along the southern coast of Lombok is shown in Figure 3. Statistical analysis (95% confidence level) confirms that the sand composition in the supratidal zone is significantly different to the intertidal zone in all locations except Bumbang Beach. Most of the intertidal zone sand mainly consists of coarser and heavier sand (Very Coarse and Coarse Sand), while in the supratidal zone, it comprises finer and lighter materials such as medium sand and fine sand. Domination of coarser materials can be found in Mekaki, Nambung, Lancing, Kuta, and Aan beaches, especially in their intertidal zone, while the finer sand mainly found in other locations.

Generally, the composition of grain size in beach sand shifts towards finer sediments as we move further from the intertidal zone. This tidal area is constantly subjected to high-energy forces like waves and currents, which dissolve the finer materials and leave coarser sediment behind. In contrast, the supratidal zone is most likely affected by low-energy forces like wind, which blows and accumulates lighter materials in the upper coastline [4][11]. Additionally, the presence of river runoff and other geological features such as volcanoes also significantly contribute to shaping the sand composition in the shoreline area [12]. The exception of insignificant differences in sand composition between the intertidal and supratidal zone at Bumbang Beach is likely attributed to man-made structure near the sampling location, including the construction of seawalls along the coastline and the planting of large trees at the very beginning of the supratidal zone. The dynamics of sediment transportation in the coastal environment have been reported to be disrupted by the establishment of coastal structures such as seawalls [13] and afforestation [14].

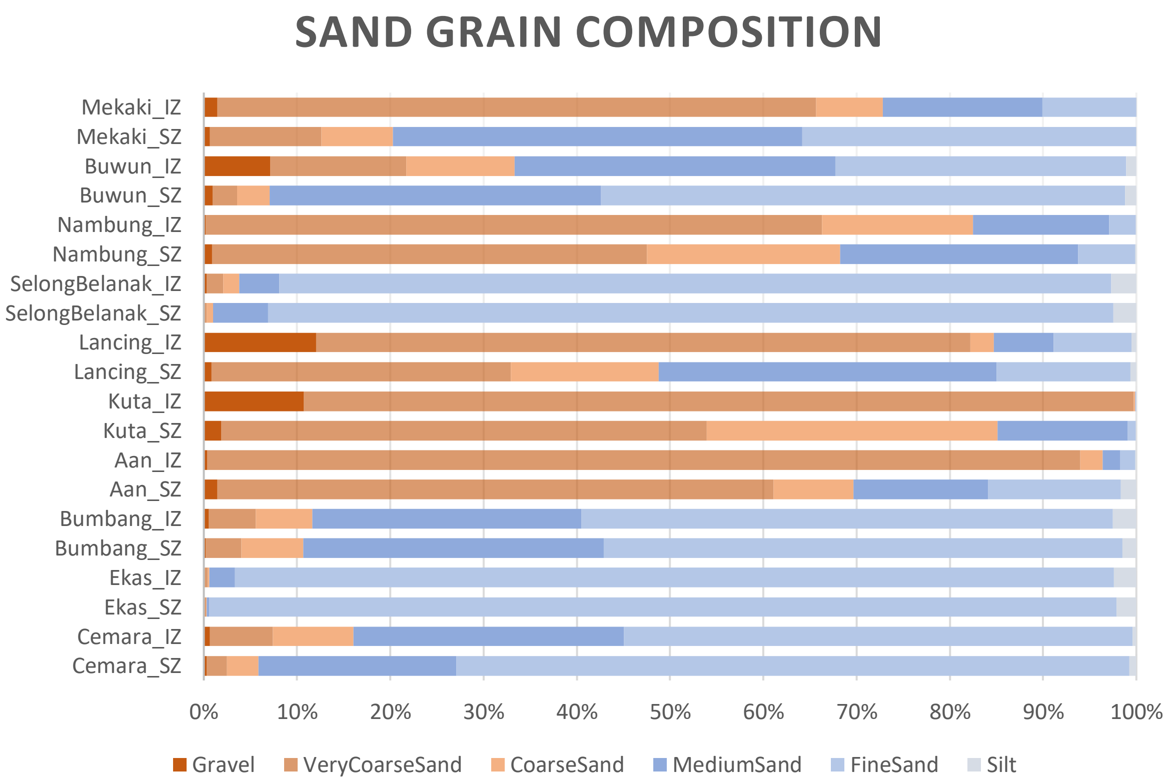

Figure. 3. Sand grain composition of the samples, IZ = Intertidal Zone and SZ = Supratidal Zone, arranged based on location from the westernmost (Mekaki) to the easternmost (Cemara).

The biplot results of the logratio analysis (LRA) of all samples from 20 different locations shown in Figure 4, explaining 97.9% of the total logratio variance from 6 components. There are no component arrows that have close position between each other, indicating that no two components have high logratio-correlation and cannot be merged to simplify the composition matrix. The area between two arrows (on a logarithmic scale) represent which components is dominant on each location data point. For instance, the location of MKI (Mekaki Intertidal) data point falls between Very Coarse Sand and Coarse Sand arrows, which means these two components are the dominant grain class for this location. Another example is Kuta Intertidal (KTI), whose data point falls in the same area as MKI but far northwest in the plot and very close to the "Very Coarse Sand" arrow. This means that the sand composition in the Kuta Intertidal area is strongly dominated by the very coarse sand and only has a few percentages for the 5 other components. In contrast, such an extreme domination of fine sand can be found in Selong Belanak (SBI and SBS) and Ekas (EKI and EKS) beaches in both intertidal and supratidal zones.

There are only two dominant groups where all data points fall into (Figure 4): the first group is dominated by Very Coarse Sand – Coarse Sand components (consisting of KTI, ANI, LCI, ANS, MKI, KTS, NBI, NBS and LCS), or the second group which is dominated by Medium Sand – Fine Sand class (consisting of BWI, MKS, CMI, BBI, BBS, BWS, CMS, SBI, SBS, EKI and EKS). Several data points are at very close positions to each other in the plot (such as CMI, CMS, BBI, BBS and BWS), indicating high similarity of sand composition between locations.

Sand grains in southern Lombok are dominated by two types of sand: calcite sand and lithic fragments, formed from larger material that eroded down to sand size, ranging from very fine sand up to very coarse sand [15]. The domination of coarser sand on the southern coast of Lombok is found in the southward-facing beaches, which are directly exposed to strong waves on a daily basis. The coarser materials along these areas are mostly composed of well-rounded carbonate sand formed from a large foraminifer, mixed with coral and shell fragments [16]. This mixture of coarse materials can also be found in the Lesser Sunda islands, encompassing Bali, the two main island of West Nusa Tenggara (Lombok and Sumbawa) and extending up to Flores [17]. However, the accumulation of the well-rounded foraminifera sand (Figure 2b) is relatively rare occurrence due to oceanographic and other climatic factors caused by periodic upwelling in the region millions of years ago [18][19].

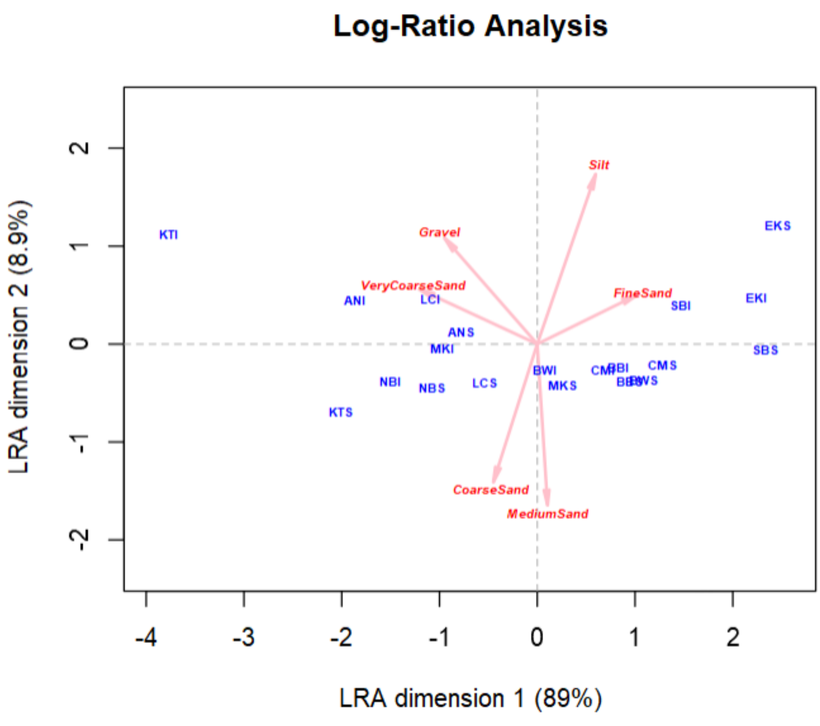

Figure. 4. Logratio Analysis plot of the 6 sand grain size classes from 20 sampling locations. The arrows explain the directions of each component, and the position of each locations indicates which dominant components that represents by 2 nearest component arrows. (*MKI = Mekaki Intertidal, MKS = Mekaki Supratidal, BWI = Buwun Intertidal, BWS = Buwun Supratidal, NBI = Nambung Intertidal, NBS = Nambung Supratidal, SBI = Selong Belanak Intertidal, SBS = Selong Belanak Supratidal, LCI= Lancing Intertidal, LCS = Lancing Supratidal, KTI = Kuta Intertidal, KTS = Kuta Supratidal, ANI = Aan Intertidal, ANS = Aan Supratidal, BBI = Bumbang Intertidal, BBS = Bumbang Supratidal, EKI = Ekas Intertidal, EKS = Ekas Supratidal, CMI = Cemara Intertidal and CMS = Cemara Supratidal*).

Much finer-grained sand mostly found in covered coastal area, as observed in Buwun, Selong Belanak, Bumbang, Ekas, and Cemara beaches in this study. The beaches in these sampling locations mostly face westward, and are either covered by land masses or islands, which are not directly impacted by high-energy waves. Oceanic waves are the primary driving forces shaping the morphology of shorelines [20], and the presence of other land masses obstructs and disperses wave momentum, consequently affecting sediment transfer in coastal area by accumulating finer materials [21][22].

In terms of geological aspects, the analysis of grain size distribution along coastlines can help us understand the physical profiles of sediments and can be used as a simple tool to evaluate trends in coastal abrasion [4][23]. Eight out of ten sampling locations have a relatively wide range of grain sizes, indicating higher sediment stability against wave action. On the other hand, beaches with a narrow range of grain sizes, such as Selong Belanak and Ekas, which are extremely dominated by finer sand grains, are more susceptible to erosion because they can be more easily transported by waves and currents and may not be able to effectively dissipate wave energy [24]. However, it is important to note that this conclusion cannot be solely based on sand grain analysis. A comprehensive, continuous and long-term monitoring effort is needed for a better understanding to support these findings.

IV. Conclusion

In the southern coastline of Lombok, the distribution of sand grains is characterized by two dominant groups: coarser sand domination and finer sand domination. Coarser materials prevail in the intertidal zone, while finer materials are predominant in the supratidal zone. Most of the sampled locations exhibit a wide range of grain sizes, providing greater resistance against abrasion. However, some areas consist of only a narrow range of grain sizes, making them more susceptible to abrasion. To ensure sustainable coastal management, it is imperative to establish more comprehensive and continuous monitoring efforts in this area.

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