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Benthic Foraminifera as Bio-Indicators of Trace Element Pollution at St. Martin's Island, Bangladesh

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ABSTRACT: Benthic Foraminifera occupied all marine environments. The practice of utilizing benthic foraminifera for monitoring the state of the marine environment has garnered widespread recognition all over the world. Changes in foraminiferal assemblage indicate the level of environmental stress. The prime concern of the present research is to evaluate the abundance and distribution of benthic foraminifera and how anthropogenic stresses affect their diversity in St. Martin's Island, Bangladesh. About 250 foraminifera specimens were collected, of which 22 species, 19 genera, and 17 families of predominantly benthic provenance were recognized. Astrorhiza holds the first position in order of relative abundance and frequency of occurrence followed by the Elphidium, Robulus, and Eponoides. The stress-tolerant and heterotrophic genera (Quinqueloculina, Elphidium, Ammonia, Trochammina) dominated the sensitive or symbiont genera (Calcarina, Operculina, Cibicides, Nummulites). Analysis of various diversity indices reveals that the northern part of the island near the boat terminal shows a lower diversity of benthic foraminifera. The southern part of the island shows moderate diversity indicating less pollution. For the investigation of the Foraminiferal shell, in addition to statistical computing, SEM (Scanning Electron Microscopy), EDX (Energy Dispersive X-ray Analysis), and XRD (X-ray Diffraction) analyses have been utilized. From the EDX analysis, it has been found that lower oxygen (O) with a weight range of (36.51-53.71%) and calcium (Ca) with a weight range of (30.44-53.38%) are the primary components of the foraminifera test. The shells also contain higher percentages of trace elements such as silicon (Si), magnesium (Mg), iron (Fe), chlorine (Cl), sodium (Na), aluminum (Al), and manganese (Mn). Anthropogenic activity is the main source of these trace elements, which clearly demonstrates the island's environmentally stressed condition. The intrusion of these elements in the benthic foraminiferal shell indicates they react to anthropogenic contaminants. These exogenous trace elements are responsible for particular morphological distortion of foraminifera shells which are also observed in St. Martin's Island. The outcomes from the current research will build a foundation for future researchers focusing on anthropogenic impact assessment and sustainable coastal management in Bangladesh.

Keywords: Benthic Foraminifera; Bio-indicators; Trace Element Pollution; St. Martin's Island

INTRODUCTION

Contamination by trace elements in the saltmarsh aquatic ecosystem has emerged as a widespread occurrence in the present era, given their non-degradable nature and harmful impact on living organisms (MacFarlane and Burchett, 2012). Coastal regions play crucial roles as breeding grounds and habitats for both commercial and recreational species, as well as areas for housing, industry, and waste disposal (Siddique and Aktar, 2012). Recently, there has been global concern about the pollution of trace elements in the marine environment due to their environmental toxicity, prevalence, and enduring nature, as highlighted in studies by Ali et al. (2018), (Proshad et al.2019), and Raknuzzaman et al., (2016a, 2016b). Trace elemental pollution in coastal areas can be assessed through various methods such as from direct measurements of contamination status of marine sediments, measurements of water and measurements of contamination status in organism. Marine shelled organisms foraminifera and ostracoda can be used as suitable bio-indicators of pollution status because of their very characteristics such as resistant to weathering from ambient water, sensitivity to the changes in water chemistry and wide diversity with depth range (Sinha et al., 2021).

Benthic foraminifera is a single-celled eukaryotic microfauna that belongs to Kingdom- Protista and Class- Granuloreticulosea. They are the dominant shelled microorganism group in present-day oceans,

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with a vast fossil record and overwhelming diversity in contemporary marine environments (Gupta, 1999). Benthic foraminifera have been proven to be an important tool for monitoring the environmental status mainly of marine and coastal settings in many scientific studies (Jayaraju et al., 2011, Natsir and Rubiman, 2010, Narayan and Pandolfi, 2010, Carnahan et al., 2009). Their tiny appearance and abundance make them more easily recoverable in statistically significant amounts than the other hard-shelled taxa like mollusks often used in pollution monitoring (Yanko et al., 1999). Rapid growth and short reproductive cycles of six to a year make their population especially susceptible to environmental change (Yanko et al., 1999).

In the 1960s, research on the impacts of pollution on benthic foraminifera and their use as proxies began (Resig, 1960; Watkins, 1961; Boltovskoy, 1965) and are considered one of the most effective bio-indicators because of their short life span, and quick response to biochemical changes in the marine environment.

Foraminifera shells are made of pure calcite. Geochemical analyses of the carbonate tests calcified by foraminifera can provide reliable insight into trace element pollution. Benthic foraminifera selectively consumes metallic ions from the surrounding water and sediments to build up their skeletons. As a result, the chemistry of their bioskeletal components can be used to identify different types of pollution in the habitat. Foraminifera can exhibit a variety of test deformations brought on by anthropogenic and biological influences, and in places where heavy metals and trace element contamination are present, these deformations become substantially more pronounced (Alve, 1991; Boltovskoy et al., 1991; Yanko et al., 1994, 1998).

Agricultural runoff, liquid hydrocarbon, unplanned urbanization, and domestic sewage are the main sources of trace elements in coastal ecosystems (Frontalini et al., 2009). Foraminifera have two ways to incorporate those trace elements into their calcite shells: either via trapping, where the trace elements appear as a distinct phase or absorbed ion, or by direct solid solution when the trace element directly replaces Ca2+ in the calcite structure (Pingitore Jr, 1986). When such components are added to the crystalline framework during calcification, it may result in a crystalline disarray that eventually causes abnormalities in tests (Pati et al., 2018). The percentage of abnormal foraminifera can rise sharply in polluted areas (Lidz, 1965), and the presence of deformed tests of benthic foraminifera is a potent in situ bioindicator of trace element pollution (Frontalini et al., 2009).

St. Martin’s Island is a host of vast marine and land resources that have great biodiversity significance. Being a natural heritage of the country, the island attracts thousands of tourists every year which exerts a negative effect on its ecosystem. Utilizing geospatial methods, Gazi et al. (2020) studied the degradation of the coral reefs located around Saint Martin’s Island and reported that anthropogenic factors like turbidity from agricultural activities, building construction, tourism, coral harvesting, and climate change are mainly responsible for the rapid vanishing of coral reef colonies. Tajwar et al. (2022) also confirmed the presence of microplastics in sediments along and across the shore sediments of Saint Martin’s Island.

Concerning marine pollution issues several studies have been carried out on St. Martin’s Island focusing on biodegradation of coral habitats and other marine resources (Gazi et al., 2020; Nafi and Ahmed, 2017). Paleoenvironmental analysis, coral reef assessment, and microplastic contamination of the island were studied through micropaleontological (microfossils) analysis (Tajwar et al., 2022; Shemu and Saha, 2021) However, no detailed comprehensive studies have been carried out on this island focusing on pollution monitoring based on micropaleontological indicators. So, it is imperative to ascertain the impact of trace elements on the benthic habitat of this island to safeguard this exceptional marine ecosystem from marine pollution.

The study is mainly based on two manifold objectives first one is to investigate the distribution and abundance of benthic foraminiferal species in the studied location and finally to determine trace element concentration in the benthic foraminifera shells to assess the degree of contamination using foraminifera as a bio-indicator.

STUDY AREA

Saint Martin’s Island is located 9 km south of the Cox’s Bazaar-Teknaf peninsular tip of Bangladesh within the coordinates (20°34 ‘ and 20°39’N and 92°18’ and 92°21’ E) covering a total area of 12 km^2 (Fig.1) among which the island covers 5.9 km^2 and the rest are the submerging rocky platform (Tajwar et al., 2022). The island is nearly flat, having an average height of 2.5 meters above mean sea level (MSL) and a maximum height of 6.5 meters (Thomson and Islam, 2010). The island is aligned at NNW and SSE direction. This island is exposed to beach sand, shale, concretions, coquina bed, calcareous sandstone, fossiliferous conglomerate, corals, etc.

St. Martin's Island, the only coral-bearing Island in Bangladesh, is a natural wonder that draws a large number of tourists. During the months of November to April, St. Martin's Island received about 3500 tourists each day, exceeding the island's carrying capacity which affects the delicate ecosystem of the island (Tajwar et al., 2022; Nafi and Ahmed, 2017).

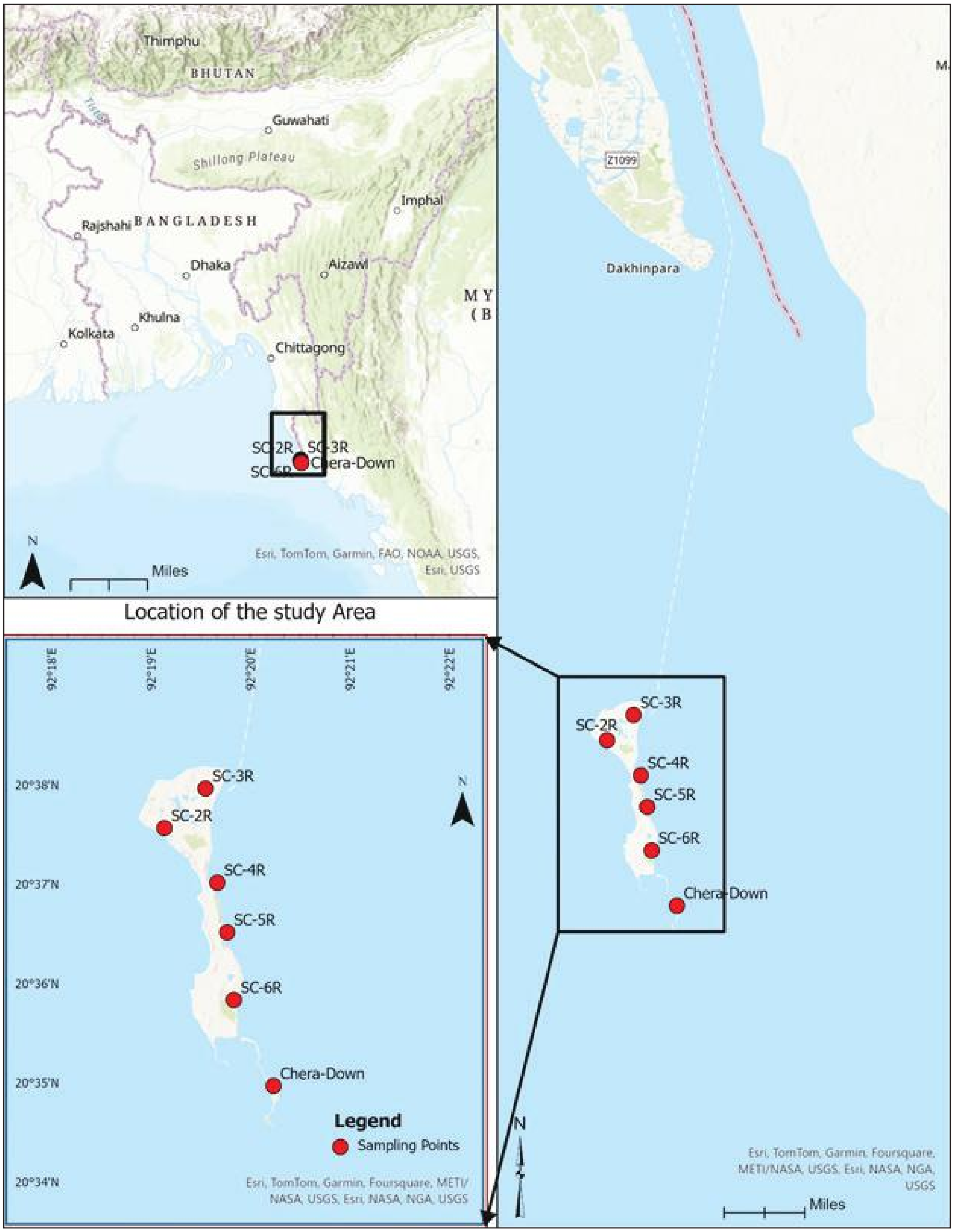

Figure 1: Location of the St. Martin's Island Area Including Sampling Points

MATERIALS AND METHODS

The study is a compilation of both field work and laboratory analysis. Fieldwork was confined to the collection of sediments samples whereas the laboratory investigation encompassed sample preparation, sieving, extraction of microforams and geochemical analysis of the recorded forams.

Field Sampling

In the current study, surficial sediment samples were collected from 7 different places on St. Martin's Island at low tide periods. Sampling locations and sampling intervals were selected using the Global Positioning System (Table 1 & Fig. 1). With the help of a hand-operated auger, the upper 20 cm of surface sediments were removed and undisturbed sediments were collected and stored in an air-tight polybag.

Table 1: Coordinates of Sampling Points

Sample ID	Latitude	Longitude
SC-2R	20.62611111	92.31888889
SC-3R	20.63277778	20.63277778
SC-4R	20.61694444	92.32777778
SC-5R	20.60861111	92.32944444
SC-6R	20.59722222	92.33055556
Chera- Down	20.58277778	92.33722222

Laboratory Analysis

Sample Preparation

The samples were first rinsed in distilled water to remove any undesirable contaminants. About 250 grams of samples were then placed in individual bikers and dried in a 1000° C oven for 30 minutes. After that, the samples were thoroughly smashed with a rubber hammer to prevent the grains from sticking together and to prepare them for sieving.

Sieving

A subsample weighing 100 gm was subjected to a sieving process using a stack of ASTM sieves with varying pore sizes. The pore sizes were as follows: 0.5 mm = 1 Φ, 0.25 mm = 2 Φ, 0.125 mm = 3 Φ, 0.063 mm = 4 Φ and <0.063mm= >4 Φ. The sieving process was conducted for 15 minutes.

Extraction of Microforams and Micrography

A stereo binocular microscope (Meiji techno EMT2) was used to examine the sediments, including a rich micro fauna diversity. After being screened, the samples were transferred to a gridded picking tray and subjected to meticulous inspection to choose various species of foraminifera. Following the collection of the specimens, the species were moved with a no. 0 brush into the assemblage slide, also known as a Champan slide (slightly moisturized with demineralized water). This investigation utilized a LEICA EZ4E stereomicroscope with a 25x zoom magnification to examine several morphological characteristics, such as the test shape, chamber number, nature of coiling, and type of aperture. A Tescan Vega 3 LMU Scanning Electron Microscope (JSM-6490LA, JEOL, Japan) was used for taking micrograph of the picked foraminifera, using a backscattered electron detector, a standard view field of 10 m, and a 20 kV accelerating voltage.

Loeblich and Tappan (1964), Foraminiferal Classification (www.foraminifera.EU), and World Modern Foraminiferal Database (www.marinespecies.org/foraminifera/) were utilized for the identification and taxonomic classification of the recorded foraminifera into the taxonomic orders.

Geochemical Analysis of Foraminifera Shells

The chemical composition of the identified foram shells have been obtained through XRD and EDX analysis.

X-ray Diffraction (XRD) of Selected Sample

To identify the chemical composition of Foraminifera shells, five samples were selected for XRD in this study. The XRD analysis was performed in the Centre for Advanced Research in Science (CARS) of the University of Dhaka using a step scanning technique on a Rigaku Ultima IV X-ray Diffractometer with CuK radiation in the range of 2=10°-70°.

Firstly, the samples were grinded to fine powder by mortar and pestle. Then the samples were placed into a sample holder. The sample holder had a depth of 0.2mm. The sample of foraminifera was placed within the Rigaku Ultima IV X-ray diffractometer. The sample was inserted into the Goniometer by sliding the sample holder into the central clip assembly. The current of the X-ray tube was 40 mA, and the voltage of the X-ray generator tube was 40 kV. The X-ray generator had a wavelength of 1.5406 Å.

Energy Dispersive X-Ray Analysis (EDX)

Eight foraminifera shells were analyzed by EDX detectors in the Bangladesh Council of Scientific and Industrial Research (BCSIR). In this research, the EDX analysis utilized the foraminiferal shell without coating. The spectrum was produced by irradiating the EDX detector in a single location. Each element captured by the EDX sensor displays distinct peak characteristics.

RESULTS AND DISCUSSION

Results

Distribution of Benthic Foraminifera

About 250 foraminifera specimens were examined in this study, with 22 species, 19 genera, and 17 families were recognized. (Table 2).

Table 2: Number of Foraminiferal Genus at Different Locations

Sl. No.	Foraminiferal Genus	SC-1R	SC-2R	SC-3R	SC-4R	SC-5R	SC-6R	Chera Down
1.	Schackonia	1	0	0	1	1	1	1
2.	Agathamminoides	1	0	0	1	2	2	2
3.	Robulus	8	5	1	5	4	5	8
4.	Quinqueloculina	1	2	1	1	2	1	1
5.	Trochammina	1	1	0	2	1	1	1
6.	Calcarina	1	1	0	1	1	1	2
7.	Elphidium	10	5	1	5	5	5	9
8.	Triloculina	1	1	0	1	2	1	1
9.	Woodella	1	1	1	1	1	1	1
10.	Ammonia	1	1	0	1	1	1	1
11.	Operculina	1	0	0	1	0	1	1
12.	Carterina	1	0	1	1	1	1	1
13.	Eponoides	6	2	1	4	3	2	3
14.	Rotalidium	1	1	1	1	2	1	1
15.	Cibicides	1	2	0	1	1	1	2
16.	Nummulites	1	0	0	1	0	1	1
17.	Dentostomina	1	0	0	1	1	1	1
18.	Astorhiza	11	8	3	10	6	7	12
19.	Spiroloculina	1	0	0	1	1	1	1
Total Number of Genus		50	30	10	40	35	35	50

Astrorhizidae is the most prevalent family on St. Martin's Island which is represented by Astrorhiza (22.8%). Previous studies on St. Martin's Island confirm their higher distribution on the island at a depth range of 30 to 100m (Shemu & Saha, 2021). The most abundant families of Rotaliina are the Elphidiidae and Eponididae which are represented by Elphidium (16%) and Eponoides (8.4%) respectively. Species of this family are abundant in almost all active marine environments (Loeblich & Tappan, 1987). Other dominant families are Vaginulinidae which is represented by *Robulus* (14%). (Fig. 2)

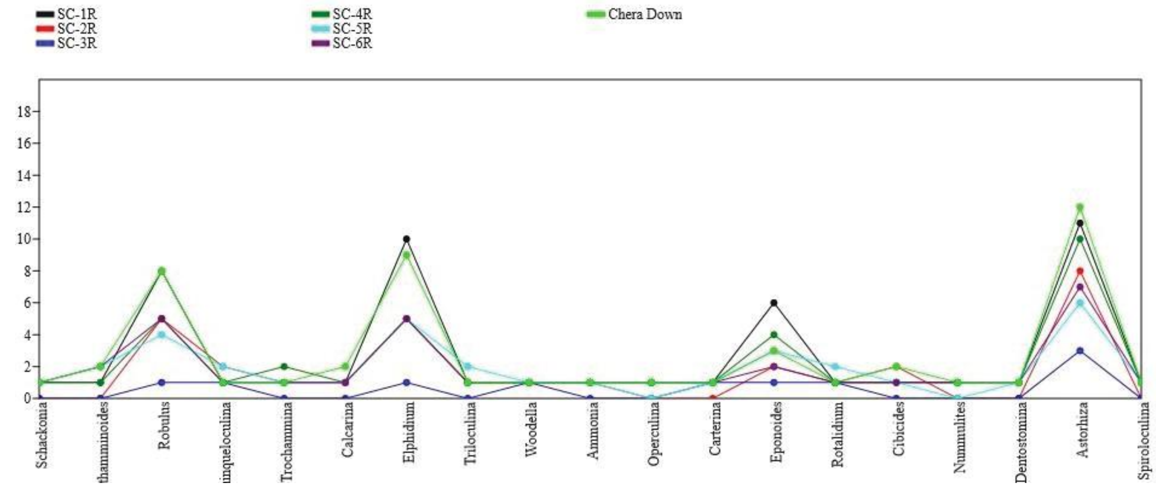

Figure 2: Absolute Abundance of Collected Benthic Foraminifera in St. Martin's Island

Morphological Abnormalities in Foraminifera Shells

Different morphological abnormalities are observed in the identified foraminifera species such as corrosion, cavity development and secondary particle inclusion, abnormal chamber arrangement, twinning, alteration of colors, and unusual coiling (Fig. 3 & Fig.4).

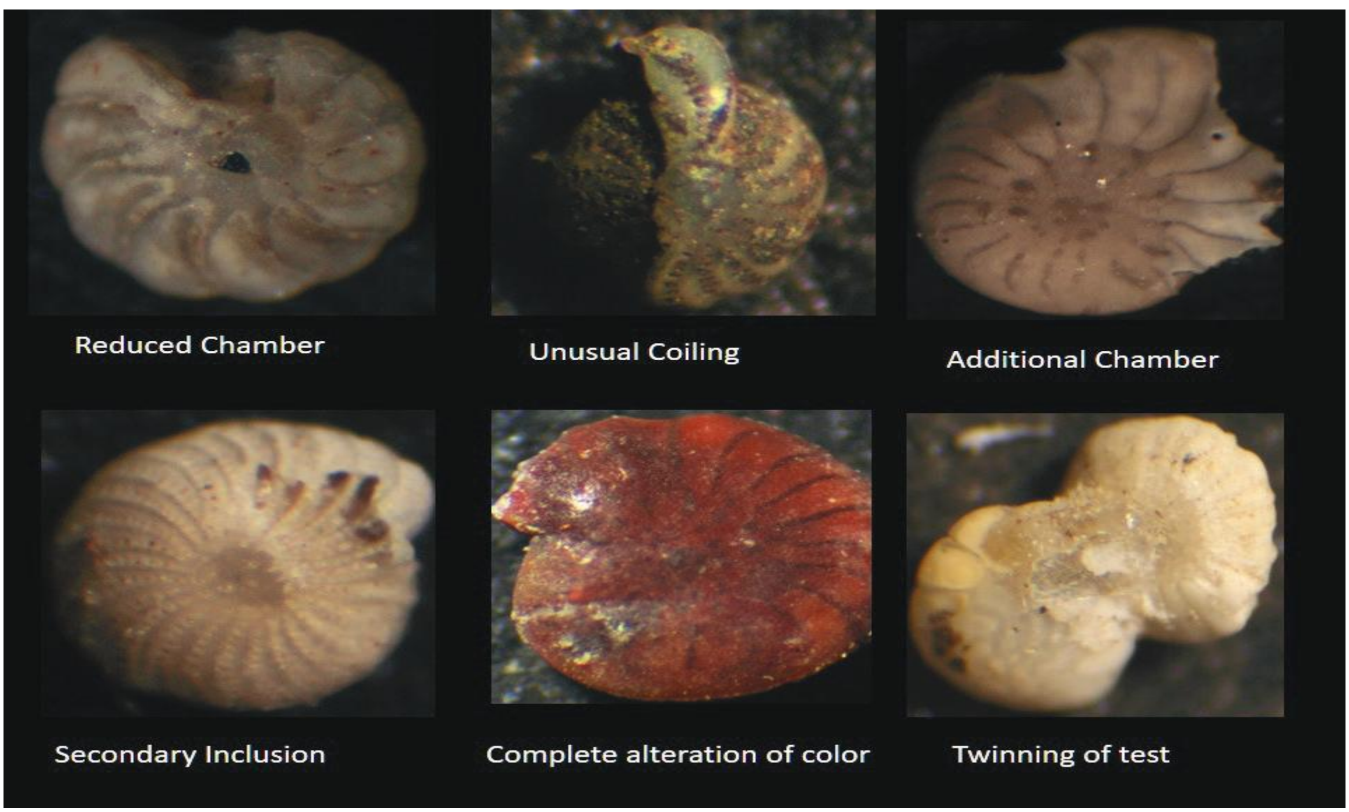

Figure 3: Different Morphological Abnormalities of Foraminifera Shell

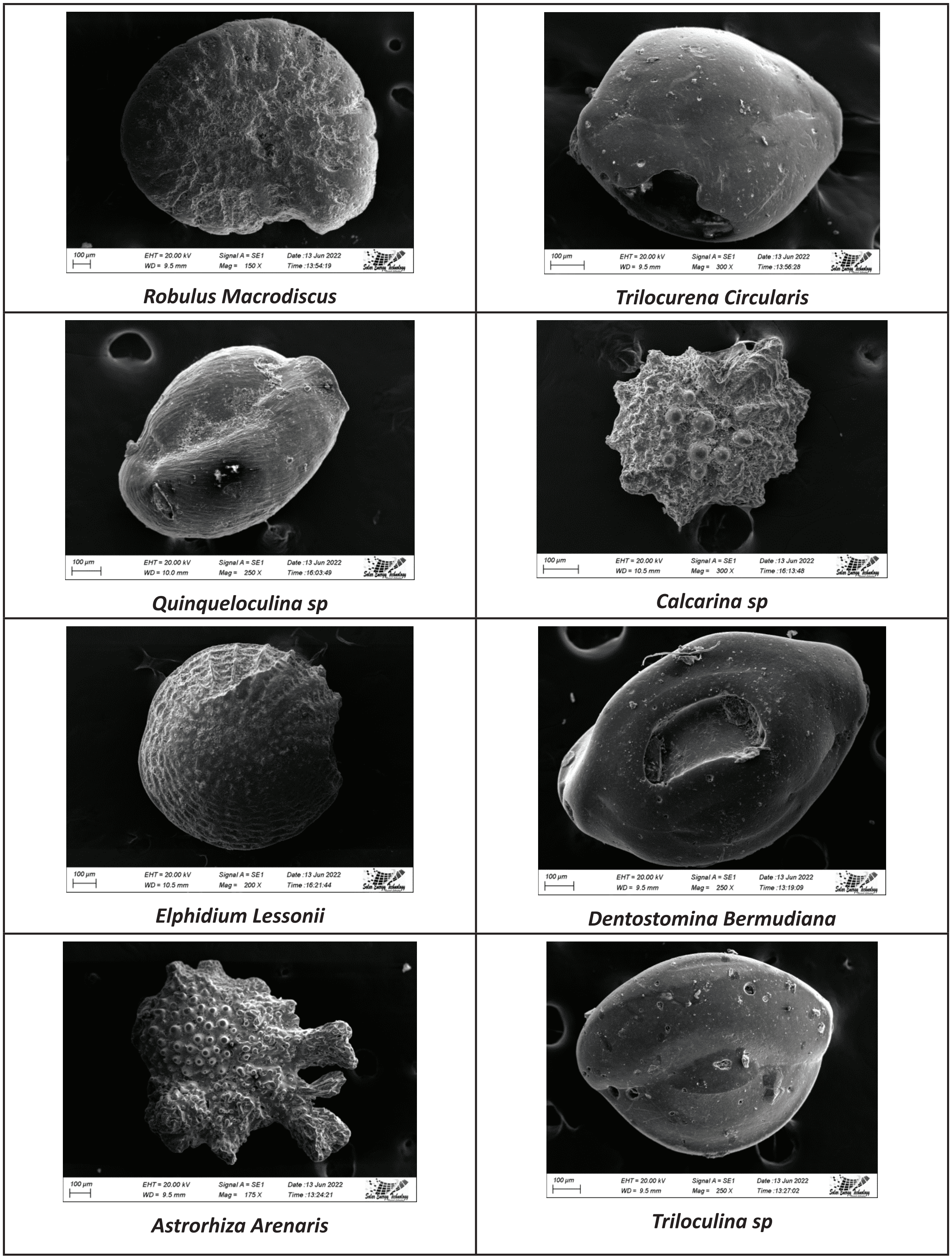

Figure 4: SEM Photographs Show Corrosion, Cavity Development, and Abnormal Chamber Arrangement in Foraminifera Species

Establishment of Foraminifera Diversity Indices

Anthropogenic and ecological variables have a direct impact on the diversity of benthic foraminifera. Values of Species dominance (D), Simpson's index of diversity 1-D, Shannon- Wiener diversity index (H), and species evenness suggest that St. Martin's Island exhibits a high degree of heterogeneity (Table 3).

Table 3: Diversity Indices Data of Collected Benthic Foraminifera in St. Martin Island

Parameters	SC-1R	SC-2R	SC-3R	SC-4R	SC-5R	SC-6R	Chera Down
Taxa_S	19	12	8	19	17	19	19
Individuals	50	30	10	40	35	35	50
Dominance_D	0.1344	0.1467	0.16	0.115	0.09061	0.09878	0.1288
Simpson_1-D	0.8656	0.8533	0.84	0.885	0.9094	0.9012	0.8712
Shannon Wiener Diversity Index_H	2.376	2.172	1.973	2.538	2.607	2.627	2.438
Evenness_e^H/S	0.5665	0.731	0.899	0.6657	0.7977	0.7281	0.6028
Foraminifera Stress Index (FSI)	1.18	0.999	1	1.45	0.999	1.6	1.72

The Simpson's diversity index of SC-5R shows the highest foraminiferal species diversity (0.9094), and SC-3R shows the lowest diversity (0.84) (Fig. 6). According to the result of the Shannon–Wiener diversity index (H), the values range between 1.973 and 2.627 where the highest diversity of benthic foraminifera was observed at the station SC-6R (2.627), followed by SC-5R (2.607) and the lowest values is in SC-3R (1.973) (Fig. 5).

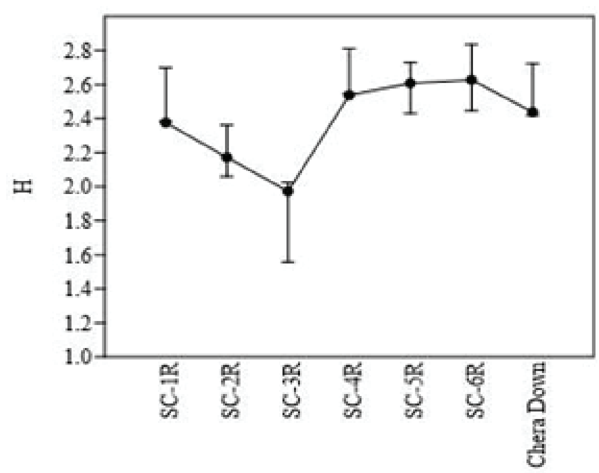

Figure 5: Shannon –Weiner Diversity Index

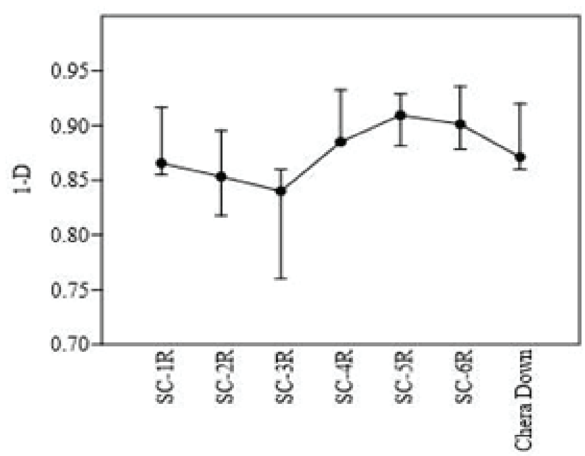

Figure 6: Simpson Diversity Index 1-D

The Foraminifera Stress Index (FSI) values of the studied locations vary from 0.999 to 1.72. SC-2R and SC-5R indicate deplorable environmental conditions (0.999), and the other sampling sites indicate polluted environmental conditions (Dimiza et al., 2016).

Chemical Analysis of Foraminifera Shells

XRD studies showed that all samples are primarily made up of calcite ($CaCO_3$) (Fig. 7). The XRD examination of calcite reveals that the mineral has a dispersed reflection pattern. The values of 2ɵ= 29.4° and 29.8° have been used to isolate calcite. Besides, some other minerals like quartz and aragonite are also present. Reflections recognize quartz at 26.7°, and aragonite reflects at 26.2°.

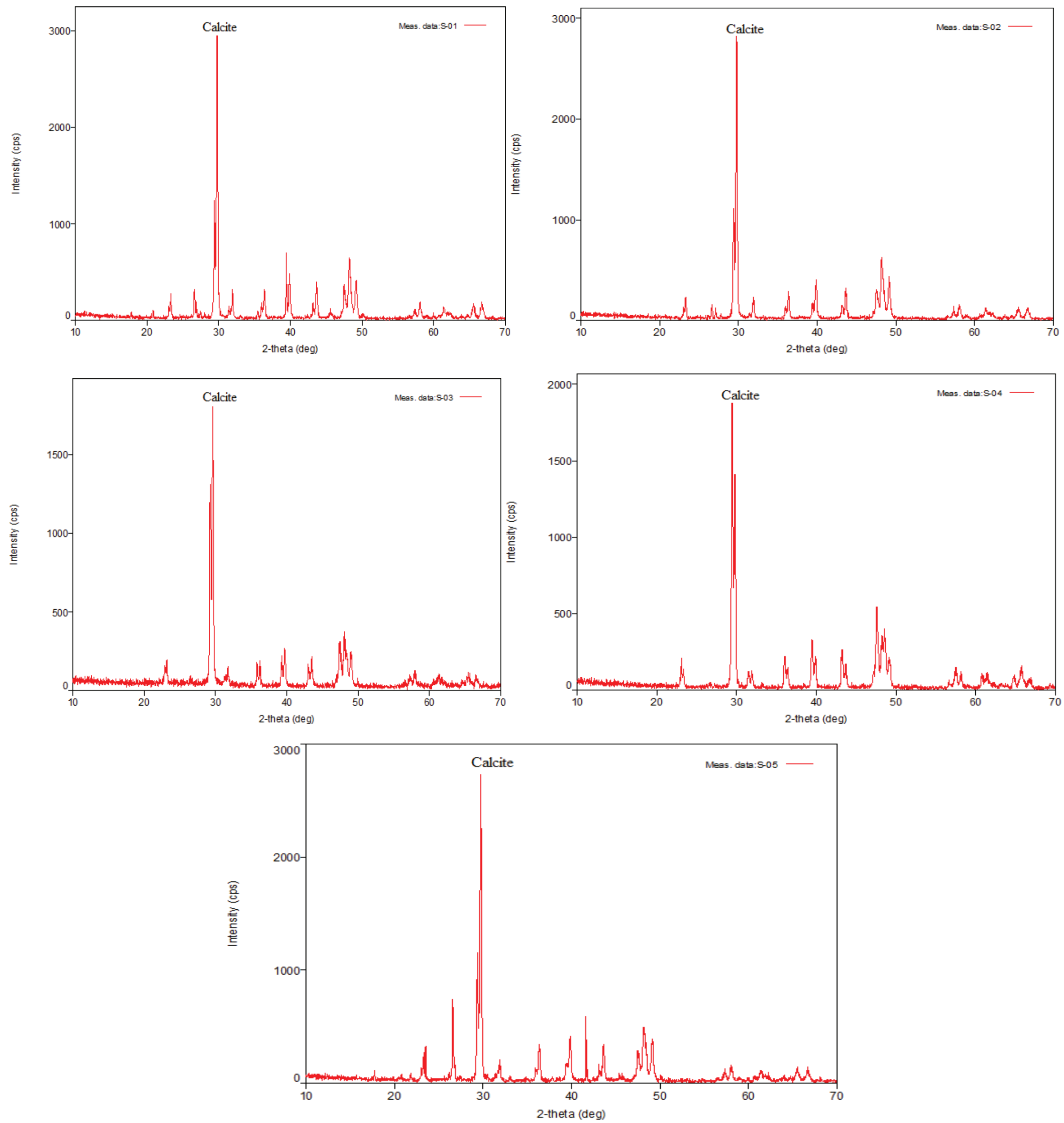

Figure 7: XRD Pattern of Foraminifera Samples

The EDX study shows a lower O content (36.51-53.71) than the usual foraminiferal test, indicating an abnormality. The C content is also lower (7.54-9.19) than the regular test. The presence of trace elements such as Si (1.68-4.62%), Mg (2.77-3.36%), Cl (1.54% in Astrorhiza Arenaris), Na (3.37% in Astrorhiza Arenaris), Al (1.08-2.63%) are also observed in the samples which are in higher percentages than the regular test. Higher percentages of heavy metals such as Fe (2.00-3.08%), Mn (1.66- 4.04%), and Au (4.62%) are also observed (Table 4 & Fig. 8).

Table 4: Weight (%) of Different Elements of Foraminifera Shells by EDX Study

Foraminifera Species	C	O	Mg	Al	Si	Ca	Mn	Fe	Na	Cl
Robulus Macrodiscus (RM)	7.95	48.93	-	-	2.73	34.21	4.04	2.50	-	-
Trilocurena circularis (TC)	8.52	43.76	3.36	-	-	34.99	1.66	3.08	-	-
Quinqueloculina sp (QS)	9.11	51.08	2.77	2.59	4.02	30.44	-	-	-	-
Calcarina sp. (CS)	-	53.71	2.61	3.56	7.33	32.79	-	-	-	-
Elphidium Lessonii (EL)	9.19	49.49	-	2.63	4.62	32.07	-	2.00	-	-
Dentostomina Bermudiana (DB)	8.63	46.95	1.97	1.08	2.10	37.49	-	2.86	-	-
Astrorhiza Arenaris (AA)	7.54	48.61	3.28	1.08	1.68	32.90	-	-	3.37	1.54
Triloculina sp (TS)		36.51	2.44			53.38			4.06	3.61

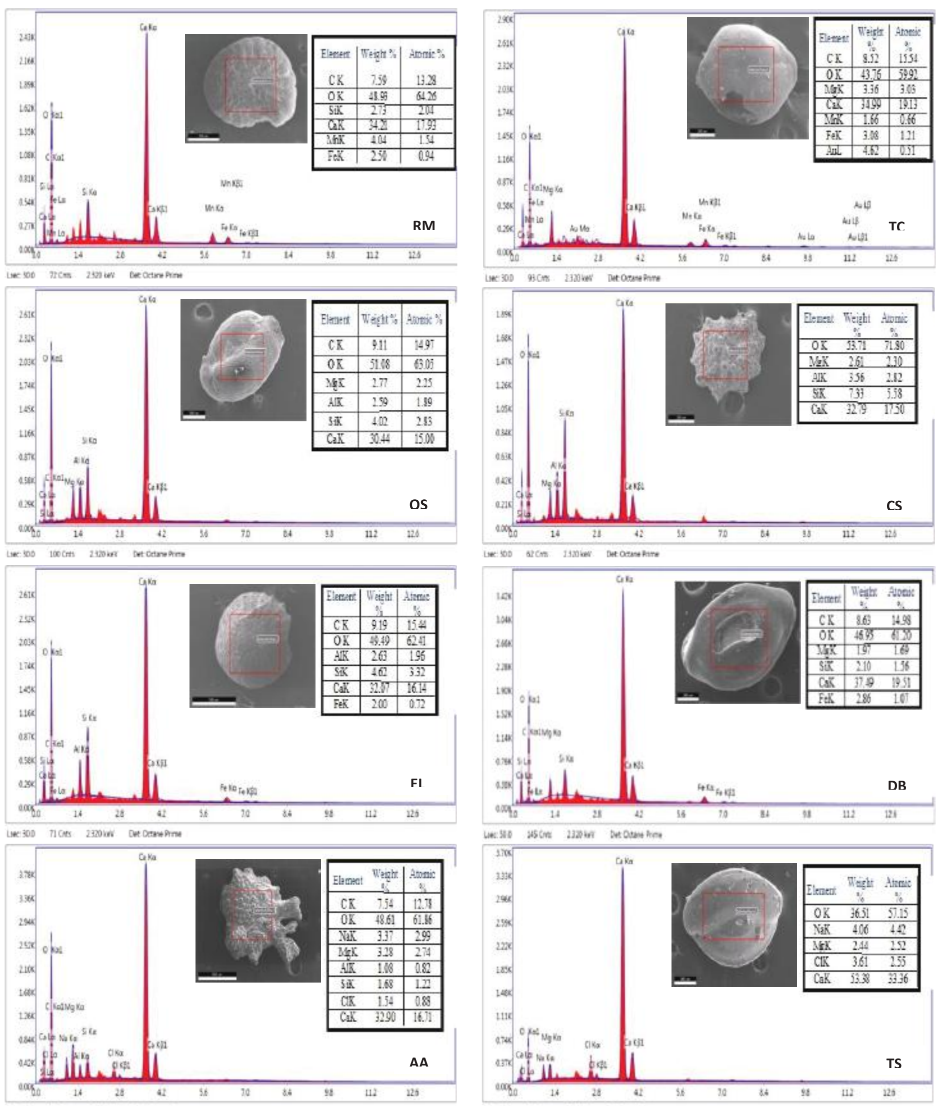

Figure 8: Energy Dispersal X-ray Analyses of the Qualitative Elemental Composition of Foraminifera Species

Discussion

St. Martin's Island is a host of vast marine and land resources that have great biodiversity and economic significance. The island's rapid loss of biodiversity and environmental degradation have recently drawn the attention of scholars and lawmakers. In addition, the study area exhibits a significant presence of foraminifers, which enables the collection of statistically significant sample sizes in a rapid and cost-effective manner. This makes foraminifera an ideal candidate for inclusion in comprehensive bio-monitoring programs over other bio-indicators. This study is an approach to monitor the diversity of benthic foraminifera in the study area and the chemistry of foram shells to assess the degree of trace elemental pollution in the island using foraminifera as a bioindicator.

Several diversity indices were computed to ascertain the abundance and distribution pattern of benthic foraminifera, and XRD and EDX studies were performed to ascertain the chemical composition of foraminifera shells.

The disorder and uncertainty of specific species are described by the Shannon-Weiner index. The degree of diversity increases with the degree of uncertainty (Ortiz-Burgos S., 2016). Sampling sites SC-4R, SC-5R, and SC-6R show higher diversity which is located at the central and southern parts of the island. Whereas, sampling site SC-3R shows lower diversity of Foraminifera. Sampling site SC-3R is located in the northern part of the island locally named Uttar Para where a large number of hotels and resorts are present. This site is also adjacent to the only port of the island where hundreds of fishing boats and tourists ship anchor every day. Lower Foraminiferal diversity in SC-3R indicates the anthropogenic impact on the benthic environment.

Calcite is the main component of foraminifera tests under optimum climatic conditions, and primary elements, Oxygen, and Carbon, have typical weight ranges of 53.2 to 58.79% and 10.07 to 12.07%, respectively (Lakshmanna et al., 2022). Lower Oxygen and Carbon in every sample indicate stressed environmental conditions. Ideally, trace elements like Mg, Sr, Ba, and Cd make up around 1% of the foraminifera tests (Pati and Patra, 2012). This study reveals that trace elements and heavy metals like Mg, Al, Fe, Mn, Na, and Cl are present in larger concentrations than under ideal circumstances which leads to different morphological abnormalities (Fig. 7). Foraminifera response differently depending upon the nature of pollutant few studies thus far have addressed the relationship between modes of deformities and pollutant (Bhalla and Nigam, 1986; Alve, 1991). Trace metal levels are higher in forms with corrosion, cavity formation, broken peripheries, and decreased overall growth (Pati & Patra, 2018). The lowest response of benthic foraminifera to pollution is shown by twinning and reduced chamber size forms, which are primarily found in areas that receive drainage water from aquaculture and agriculture runoff (Frontalini et al., 2009).

Higher concentrations of Fe and Mn in Foraminifera shells can be the contribution of construction material shipment in the sea and terrigenous materials (Youssef, 2015). Therefore, unplanned construction of hotels and resorts and their sewage can be the major sources of trace element contamination in Foraminifera shells which are largely affecting their diversity.

CONCLUSION

Benthic foraminifera are a reliable bioindicator of the natural environment and anthropogenic influences. They are widely used for monitoring the environmental health of coastal and marginal marine environments. These assemblages have demonstrated their value as sensitive and cost-effective marker instruments of environmental stress in natural and anthropogenically stressed areas. This study was an attempt to evaluate the marine pollution conditions of St. Martin's Island, the only area in the country with a coral ecosystem that is facing a tremendous threat from anthropogenic effects. Spatial variation of diversity indices towards environmentally stressed zones, deviation of shell composition from the standard value, and the morphological abnormality of recorded forams as a whole justify that the studied community of foraminifera bears the imprints of trace element pollution in the inner shelf zone at a very localized scale and the anthropogenic impacts have a major role in this variability. This study will create an effective baseline database regarding the diversity and abundance of microforms, the geochemistry of the hard shell of foraminifera, and the relationship of the environmental and ecological factors with the growth mechanism of foraminifera, and natural clues to marine pollution in Bangladesh.

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DECLARATION OF INTEREST

There are no conflicts of interest listed by the authors. This article's writing and content are solely the writers' responsibility.

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