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Heterogeneous Microbial Oceanographic Environments: Application of GIS Technology in Deciphering of Microenvironment Scenarios off the Central West Coast of India.

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Abstract: In the vast oceanic microbial environment of 2468.83km^2, GIS modeling techniques involving sixty query steps, enabled the deciphering of Microenvironments as low as 1.19km^2 to 38.6 km^2 for the summer of 2004 and in case of summer 2005 where 84 query steps were involved to decipher Microenvironments of 10.55km^2 to 25.94km^2. Thirtythree sampling stations were established between Betul to Ankola off the central west coast of India accounting for a spatial coverage of 2468.83km^2. GIS query-modeling investigation was carried out using spatial layers of depth, optical parameters (k-Irradiance attenuation Coefficient, c-Beam attenuation coefficient), sediment size parameters (Sediment Mean Size and Sediment Sorting) and Benthic Foraminifera Suborders (Rotaliina, Textulariina, Miliolina, Lagenina). Foraminifera have been used as a surrogate parameter. However, any microbial parameter could proxy for foraminifers providing for the numerical deciphering of microenvironments. This is suggestive of the assimilation of GIS technology for a better appreciation of microbial oceanography.

Keywords: *Geographic Information System, Microbial Oceanographic Environments, Central West Coast off India.*

Introduction:

Plankton use solar energy to drive the nutrient cycles that make the planet habitable for larger organisms. We can now explore the diversity and functions of plankton using genomics, revealing the gene repertoires associated with survival in the oceans. Such studies will help us to appreciate the sensitivity of ocean systems and of the ocean's response to climate change, improving the predictive power of climate models (Bowler, et al., 2009). Fuhrman, (2009) envisages a holistic view of marine microbial communities and suggests that they are engines of globally important processes; wherein data on the structures of these communities show that they adhere to universal biological rules and some microbial systems are found to change predictably, providing one to anticipate how microbial communities and their activities will shift in a changing world. Longdill et al., 2008, have demonstrated an integrated marine approach for sustainable aquaculture management area site selection. Mapping of the oceans have become evident with the advent of GIS technology. Sotheran, et. al., (1997) have demonstrated mapping of benthic habitats using image processing techniques within a raster-based geographic information system. Shylini (2010) too has successfully used GIS modeling techniques in deciphering microenvironments off Kankon-Karwar shallow marine environment. Raghavan et al., (2011) have used GIS techniques to appreciate the spatial distribution of Chlorophyll in a Multi-parametric shallow marine environment off Karnataka-Kerala coast. GIS techniques have been used to decipher the spatial distribution of heavy metals in the Gulf of Chabahar, Oman Sea (Raghavan et al., 2010). GIS techniques were used for cartographic mapping Spring Inter Monsoon Algal Blooms in the Eastern Arabian Sea off Karwar and Kumbla Coast (Raghavan et al., (2010). Signatures of a changing world are imprinted in the heterogeneity of microbial oceanography in the context of marine informatics that is evolving contemporaneously with application of existing numerical techniques and modern technology. It becomes necessary to identify the existence of microenvironments in a larger microbial oceanic environment. Rohwer and Thurber (2009) in describing the inherent behaviour of oceanic biota (viruses) suggest that these viruses affect Bacteria, Archaea and eukaryotic organisms that contribute major components to the food web and further suggests viruses have the ability to manipulate the life histories and evolution of their hosts in remarkable ways, challenging our understanding of this almost invisible world. DeLong (2009) in reviewing the microbial oceans, suggests that microbial species dominate the oceans numerically, population dynamics, metabolic complexity, and synergistic interactions, remain largely uncharted, and the construction of predictive models that can interrelate microbial dynamics with the biogeochemical matter and energy fluxes that make up the ocean ecosystem, probably are indeed a focal point in modern oceanography. Thus, microbial oceanography indeed call for the use of Spatial techniques that include Geographic information system (any GIS packages ArcView, ArcGIS, MapInfo or any of GIS software) does indeed enable one to decipher through modeling by 'query' various intrinsic relations that generate microenvironments that exist in the microbial oceanographic environments. A geographic information system (GIS) is a computer system for capturing, storing, querying, analyzing and displaying geographically referenced data. Also called geospatial data, geographically referenced data are data that describe both the locations and characteristics of spatial features. Alva, (2002) in her studies of the shallow marine environment off Karwar, Arabian Sea, carried out a GIS query model for benthos and oceanographic parameters for the summer and post monsoon season and was able to isolate numerous benthic habitats. Urbanski, and Szymelfenig, 2003 have used GIS techniques in mapping the benthic habitats. The ability of a GIS to handle and process geographically referenced data, distinguishes GIS from other information systems (Chang, 2006). Raghavan et., al., (2000) in their in situ studies constructed extensive GIS data banks on marine fauna of the coastal and shallow marine environments of the Karwar Islands. Our ability to measure change in oceans and along coasts has increased as marine GIS has grown more complex (Dawn et., al. 2007). Raghavan et al., (2004a) have demonstrated the use of GIS techniques in modeling of SST, mercury, iron and biomass in the Lakshwadeep Sea and have isolated microenvironments. Similarly, GIS query modeling was carried for prospecting of placer deposits in the black sands of the shallow marine environment off Kerala (Sunil et al., 2003). Raghavan et al., (2006) explained the multiproxy mapping of chlorophyll-a, potential temperature, salinity and dissolved oxygen using GIS query model of the southern ocean, Antartica. Raghavan et al., (2004b) used GIS query techniques to find out potential primary productivity in the Indian Ocean. In this study a GIS query modeling technique is enforced to isolate the probable existence of microenvironments. Gold and Mostafavi, (2000), have finally driven home the need to ingest technology into marine sciences in voicing their thoughts in Towards the Global GIS. Ecological Informatics is making inroads in oceanography and an overview is well defined by Boyd, and Foody, (2011). Thus, with the advent of spatial analytical technology, deciphering of microenvironments in a microbial oceanographic system provides for a better comprehension of oceanic systems.

Study Area:

The study area is located off the central west coast of India, exposed to tropical climate. Seven shore normal transects with respective sampling stations are furnished in figure 1.

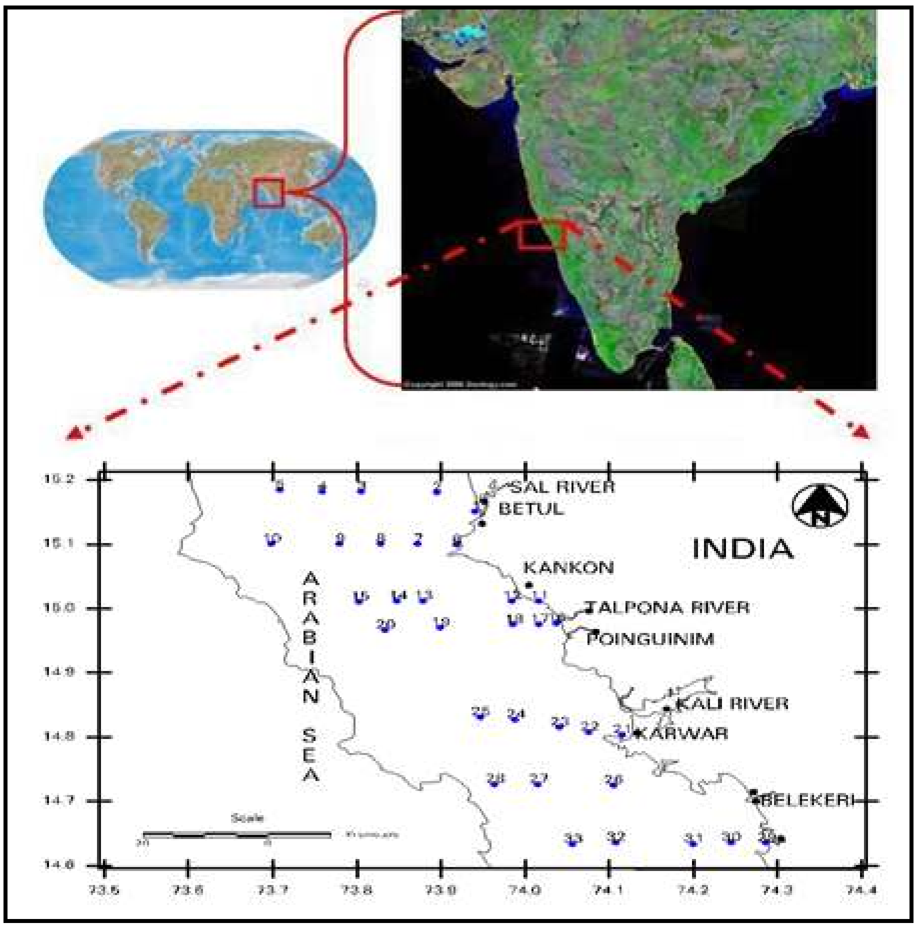

Figure 1: *Study Area of the Central West Coast of India. Seven Shore Normal Transects with Thirty Three Sampling Stations*

Material and Methods:

The sediment samples were collected from 33 sampling stations using Van Veen grab for summer 2004 and 2005. Benthic foraminifera (suborder - Rotaliina, Textulariina, Miliolina, Lagenina see. Nigam., and Khare, 1999) were identified and sediment size parameters were analysed using a size analyzer (courtesy: T. N. Prakash, CESS). The Beam attenuation Coefficient(c) (IOP) and Diffused attenuation for down welling irradiance (K_d) (AOP) are computed after Bukata (1995). The spatial distribution maps was generated for Depth, Diffused attenuation for downwelling irradiance (K_d), Beam attenuation coefficient (c), Sediment Mean size (M_z), Sediment sorting and Benthic Foraminifera (suborders Rotaliina, Textulariina, Miliolina and Lagenina) using suitable software. Each spatially distributed parameter was categorized as low, medium and high. Using ArcView 3.2 software the spatial layers were intersected and querying was enforced (see. Mitchell, 1999). A query expression is a precise definition of what is to be selected in an oceanic environment. Thus, building of a query expression is a powerful way to select features because an expression can include multiple attributes, operators, and calculations (see Shylini, 2004; Zeiler, 1999; Mitchell, 1999).

Results and Discussion:

The GIS query results (Fig.1-8) of summer season 2004 and 2005 is given in Table 1 to Table. 8. A total of sixty query steps were involved for the data of summer 2004 and eighty-four query steps were involved for the data of summer 2005. These one hundred and forty four steps establish the existence of microenvironments in the ocean.

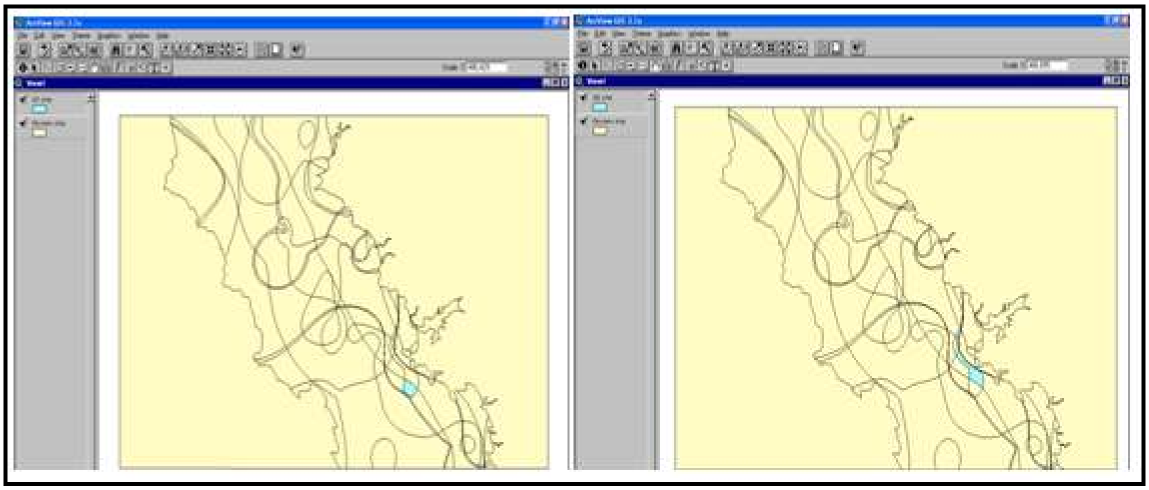

Figure 1: *Integrated Thematic Layers and Query Results of Benthic Foraminifera (Suborder- Rotalina), Sediment Size Parameters and Optical Properties of Summer 2004.*
Note: *The Shaded Areas Represent the Microenvironments.*

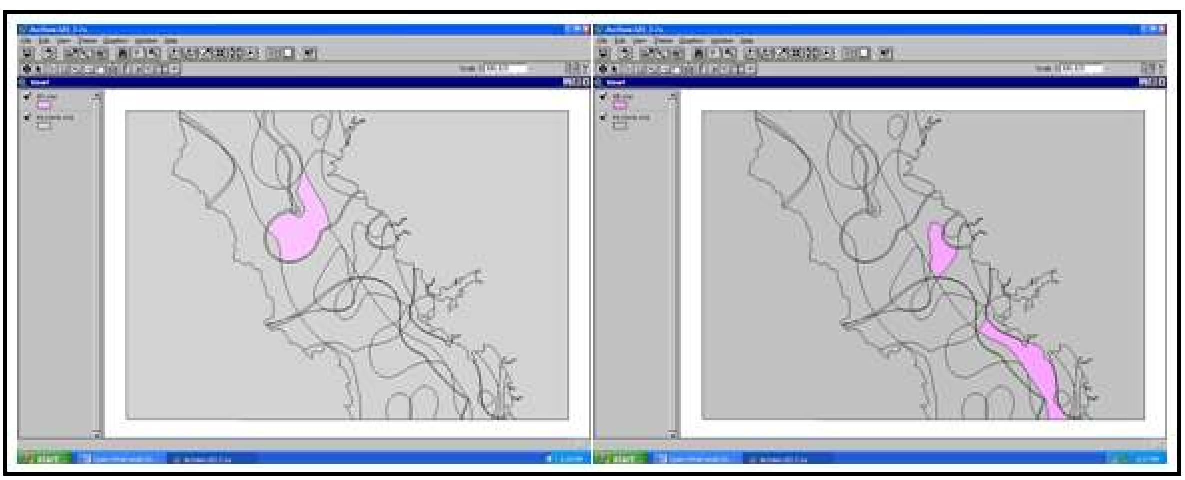

Figure2: *Integrated Thematic Layers of Benthic Foraminifera (Suborder-Textulariina), Sediment Size Parameters and Optical Properties of Summer 2004.*
Note: *The Shaded Areas Represent the Microenvironments.*

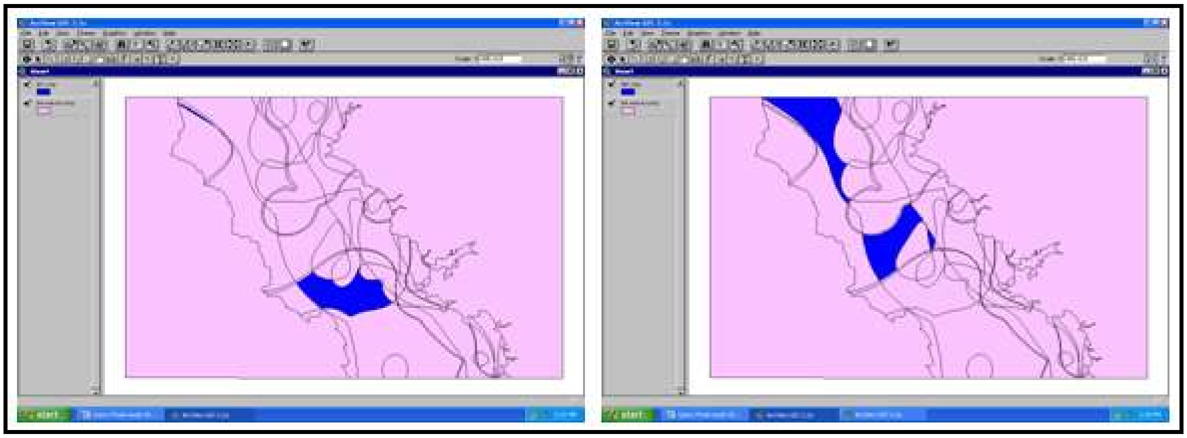

Figure 3: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Miliolina), Sediment Size Parameters and Optical Properties of Summer 2004.*
Note: *The Shaded Areas Represent the Microenvironments.*

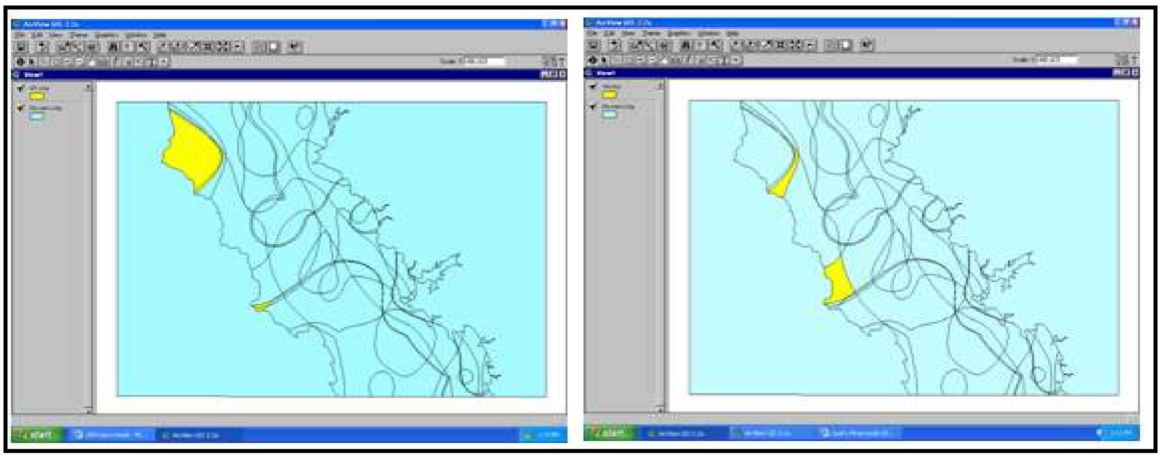

Figure 4: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Lagenina), Sediment Size Parameters and Optical Properties of Summer 2004.*
Note: *The Shaded Areas Represent the Microenvironments.*

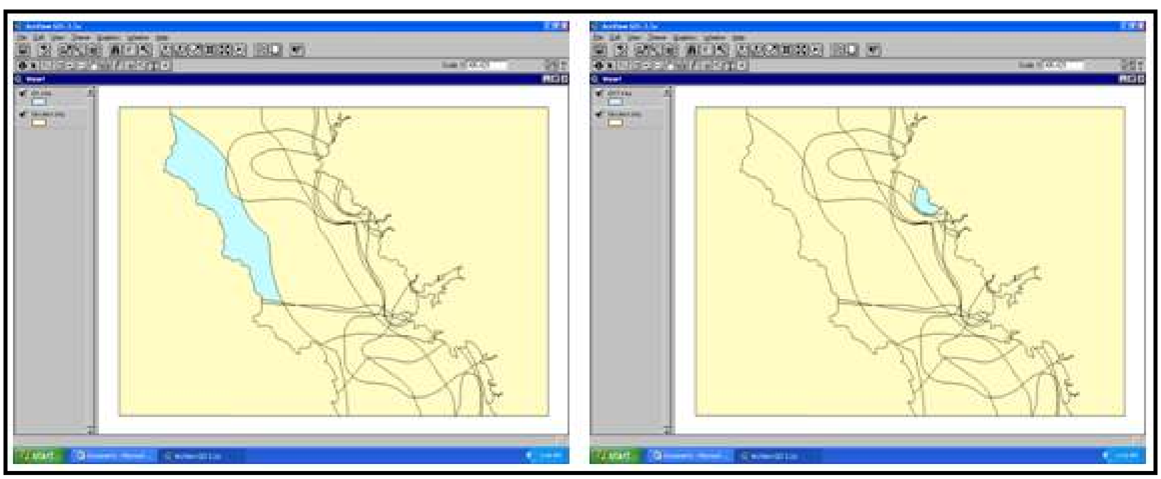

Figure 5: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Rotalina), Sediment Size Parameters and Optical Properties of Summer 2005.*
Note: *The Shaded Areas Represent the Microenvironments.*

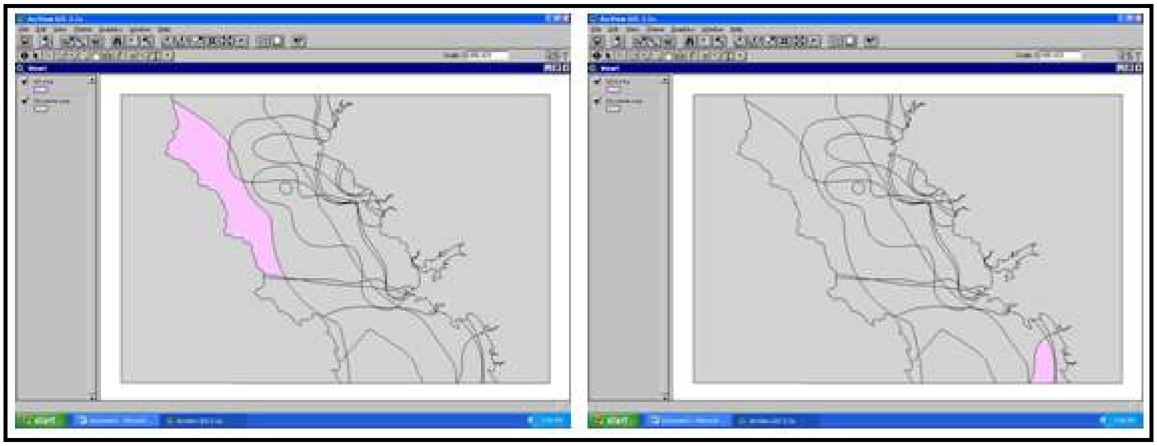

Figure 6: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Textulariina), Sediment Size Parameters and Optical Properties of Summer 2005.*
Note: *The Shaded Areas Represent the Microenvironments.*

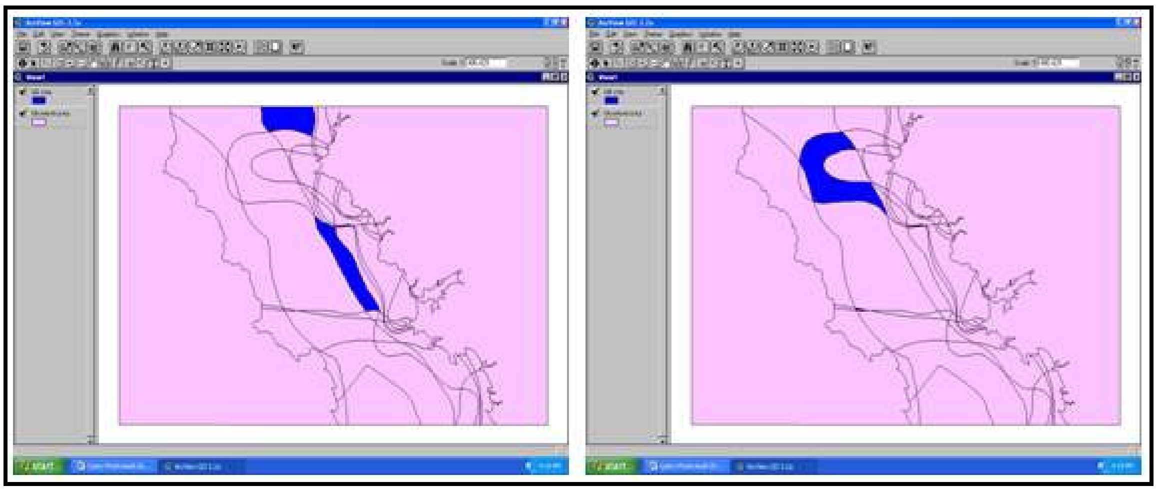

Figure 7: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Miliolina), Sediment Size Parameters and Optical Properties of Summer 2005.*
Note: *The Shaded Areas Represent the Microenvironments.*

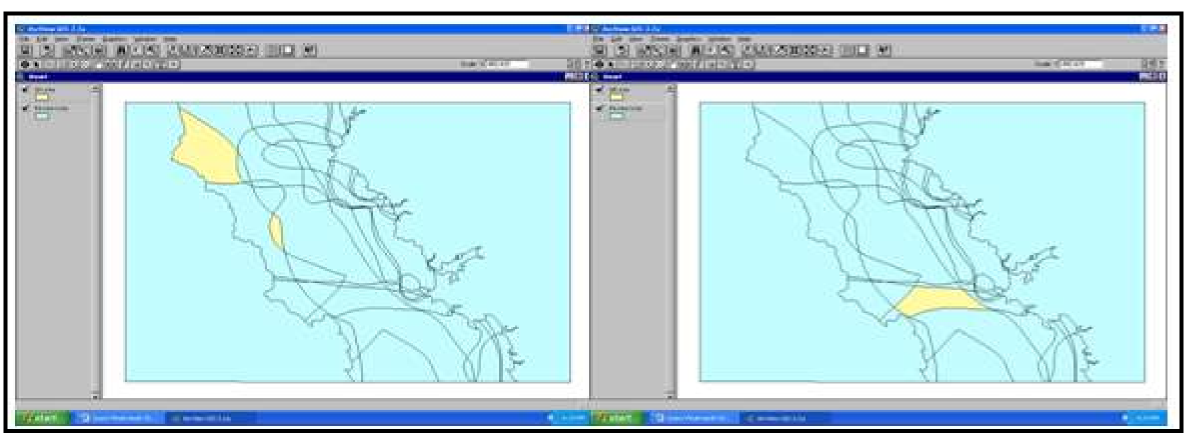

Figure 8: *Integrated Thematic Layers of Benthic Foraminifera (Suborder- Lagenina), Sediment Size Parameters and Optical Properties of Summer 2005.*
Note: *The Shaded Areas Represent the Microenvironments.*

Thus, the study of the sea-bed with an area of 2468.83km^2 provides results for two consecutive summers depicting microenvironments, enveloping areas as small as 1.19km^2 to 38.6 km^2 (summer 2004) and 10.55km^2 to 25.94km^2 for the summer of 2005. This study demonstrates the use of GIS technology to isolate microenvironments using various spatial layers including benthic foraminifers in a unique microbial environment.

Table 1: *Results of the Integrated and Queried Thematic Layers of Benthic Foraminifera (Suborder- Rotaliina), Sediment Size Parameters, Optical Properties and Depth of Summer 2004 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	**DEPTH (m)**	**K_d (m-1)**	**C (m^{-1})**	**Mean Size (Ø)**	**Sorting (Ø)**	**Rotaliina**	**Area (Sq.Km)**	**% of Area**
1	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	>46 (High)	6.85	0.27
2	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	>46 (High)	13.21	0.53
3	<20 (Low)	>0.51 (High)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	>46 (High)	1.19	0.04
4	20-40 (Medium)	>0.51 (High)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	31-46 (Medium)	6.49	0.26
5	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	31-46 (Medium)	122.59	4.96
6	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	31-46 (Medium)	40.26	1.63
7	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	<31 (Low)	32.66	1.32
8	>40 (High)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	<31 (Low)	145.28	5.88
9	20-40 (medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	<31 (Low)	183.21	7.42
10	20-40 (medium)	>0.51 (High)	>4.0 (High)	5-7.5 (Medium)	<1.8 (Low)	<31 (Low)	106.42	4.31
11	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	31-46 (Medium)	165.74	6.71
12	<20 (Low)	>0.51 (High)	>4.0 (High)	5-7.5 (Medium)	<1.8 (Low)	<31 (Low)	62.87	2.54
13	20-40 (Medium)	<0.33 (Low)	<2.6 (Low)	5-7.5 (Medium)	1.8-3.2 (Medium)	31-46 (Medium)	80.19	3.24
14	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	<31 (Low)	94.78	3.83

Table 2: *Results of the Integrated and Queried Thematic Layers of Benthic Foraminifera (Suborder–Textulariina), Sediment Size Parameters, Optical Properties and Depth of Summer 2004 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	**DEPTH (m)**	**K_d (m^{-1})**	**(m^{-1})**	**Mean Size (Ø)**	**Sorting (Ø)**	**Textulariina**	**Area (Sq.Km)**	**% of Area**
1	20-40 Medium	>0.51 High	>4.0 High	5-7.5 Medium	<1.8 Low	<2.3 Low	132.04	5.34
2	20-40 Medium	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	<1.8 Low	<2.3 Low	306.61	12.41
3	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	<1.8 Low	2.3-3.8 Medium	131.29	5.31
4	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	1.8-3.2 Medium	2.3-3.8 Medium	212.12	8.59
5	<20 Low	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	1.8-3.2 Medium	<2.3 Low	155	6.27
6	>40 High	<0.33 Low	<2.6 Low	5-7.5 Medium	<1.8 Low	<2.3 Low	136.84	5.54
7	<20 Low	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	<1.8 Low	<2.3 Low	73.11	2.96
8	>40 High	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	<1.8 Low	<2.3 Low	203.79	8.25
9	<20 Low	>0.51 High	>4.0 High	5-7.5 Medium	<1.8 Low	<2.3 Low	70.48	2.85
10	<20 Low	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	1.8-3.2 Medium	2.3-3.8 Medium	57.17	2.31
11	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	1.8-3.2 Medium	>3.8 High	38.6	1.56

Table 3: *Results of the Integrated and Queried Thematic Layers of Benthic Foraminifera (Suborder- Miliolina), Sediment Size Parameters, Optical Properties and Depth of SUMMER 2004 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	DEPTH (m)	K_d (m^{-1})	C (m^{-1})	Mean Size	Sorting	Miliolina	Area (Sq.Km)	% of Area
1	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	<1.8 Low	<6 Low	138.31	5.6
2	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	1.8-3.2 Medium	<6 Low	337.39	13.66
3	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	>3.2 High	<6 Low	11.04	0.44
4	<20 Low	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	1.8-3.2 Medium	<6 Low	44.18	1.78
5	<20 Low	>0.51 High	>4.0 High	5-7.5 Medium	<1.8 Low	6-12 Medium	64.39	2.6
6	20-40 Medium	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	<1.8 Low	<6 Low	259.69	10.51
7	>40 High	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	<1.8 Low	<6 Low	207.76	8.41
8	<20 Low	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	1.8-3.2 Medium	6-12 Medium	88.55	3.58
9	<20 Low	>0.51 High	>4.0 High	<5 Low	<1.8 Low	6-12 Medium	46.52	1.88
10	<20 Low	>0.51 High	>4.0 High	5-7.5 Medium	1.8-3.2 Medium	6-12 Medium	70.1	2.83
11	20-40 Medium	>0.51 High	>4.0 High	5-7.5 Medium	1.8-3.2 Medium	6-12 Medium	11.54	0.46
12	<20 Low	>0.51 High	>4.0 High	<5 Low	1.8-3.2 Medium	>12 High	28.7	1.16
13	<20 Low	>0.51 High	>4.0 High	<5 Low	1.8-3.2 Medium	6-12 Medium	63.54	2.57
14	20-40 Medium	<0.33 Low	<2.6 Low	5-7.5 Medium	<1.8 Low	<6 Low	140.54	5.69
15	20-40 Medium	>0.51 High	>4.0 High	5-7.5 Medium	<1.8 Low	6-12 Medium	68.01	2.75
16	20-40 Medium	0.33-0.51 Medium	2.6-4.0 Medium	5-7.5 Medium	1.8-3.2 Medium	<6 Low	122.81	4.97
17	<20 Low	<0.33 Low	<2.6 Low	5-7.5 Medium	<1.8 Low	6-12 Medium	25.65	1.03
18	20-40 Medium	>0.51 High	>4.0 High	5-7.5 Medium	<1.8 Low	<6 Low	76.17	3.08
19	20-40 Medium	0.33-0.51 Medium	2.6-4.0 Medium	>7.5 High	<1.8 Low	<6 Low	44.96	1.82

Table 4: *Results of the Integrated and the Queried Thematic Layers of Benthic Foraminifera (Suborder- Laginina), Sediment Size Parameters, Optical Properties and Depth of Summer 2004 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	**DEPTH (m)**	**Kd (m-1)**	**C (m-1)**	**Mean Size**	**Sorting**	**Lagenina**	**Area (Sq.Km)**	**% of Area**
1	20-40 (Medium)	<0.33 (Low)	<2.6 (Low)	5-7.5 (Medium)	1.8-3.2 (Medium)	5-10 (Medium)	241.93	9.79
2	>40 (High)	<0.33 (Low)	<2.6 (Low)	5-7.5 (Medium)	<1.8 (Low)	>10 (High)	137.66	5.57
3	>40 (High)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	5-10 (Medium)	143.05	5.79
4	20-40 (Medium)	<0.33 (Low)	<2.6 (Low)	5-7.5 (Medium)	<1.8 (Low)	5-10 (Medium)	152.44	6.17
5	20-40 (Medium)	<0.33 (Low)	<2.6 (Low)	5-7.5 (Medium)	1.8-3.2 (Medium)	>10 (High)	91.73	3.71
6	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	<5 (Low)	84.45	3.42
7	20-40 (Medium)	>0.51 (High)	>4.0 (High)	5-7.5 (Medium)	<1.8 (Low)	5-10 (Medium)	88.13	3.56
8	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	5-10 (Medium)	109.43	4.43
9	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	1.8-3.2 (Medium)	5-10 (Medium)	132.75	5.37
10	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	<5 (Low)	67.95	2.75
11	20-40 (Medium)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	>10 (High)	127.31	5.15
12	>40 (High)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	>10 (High)	62.56	2.53
13	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	<5 (Low)	32.69	1.32
14	<20 (Low)	>0.51 (High)	>4.0 (High)	<5 (Low)	<1.8 (Low)	<5 (Low)	46.39	1.87
15	<20 (Low)	0.33-0.51 (Medium)	2.6-4.0 (Medium)	5-7.5 (Medium)	<1.8 (Low)	5-10 (Medium)	43.65	1.76
16	<20 (Low)	>0.51 (High)	>4.0 (High)	<5 (Low)	1.8-3.2 (Medium)	<5 (Low)	85.9	3.47

Table 5: *Results of the Integrated and the Queried Thematic Layers of Benthic Foraminifera (Suborder- Lagenina), Sediment Size Parameters, Optical Properties and Depth of Summer 2005 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	**DEPTH (m)**	**Kd (m-1)**	**C (m-1)**	**Mean Size**	**Sorting**	**Rotaliina**	**Area (Sq.Km)**	**% of Area**
1	>40 High	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<34 Low	348.4	14.11
2	20-40 Medium	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<34 Low	508.81	20.6
3	<20 Low	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<34 Low	175.31	7.1
4	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<34 Low	150.34	6.08
5	>40 High	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<34 Low	72.36	2.93
6	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<34 Low	85.13	3.44
7	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<34 Low	108.07	4.37
8	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	<34 Low	65.17	2.63
9	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	34-53 Medium	123.05	4.98
10	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	34-53 Medium	33.08	1.33
11	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	>53 High	62.48	2.53
12	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	34-53 Medium	33.29	1.34
13	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	34-53 Medium	51.42	2.08
14	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	>53 High	23.87	0.96
15	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	34-53 Medium	80.49	3.26
16	<20 Low	>0.65 High	>5.5 High	>5.5 High	<1.3 Low	<34 Low	20.72	0.83
17	<20 Low	0.35-0.65 Medium	3-5.5 Medium	>5.5 High	<1.3 Low	<34 Low	21.25	0.86
18	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<34 Low	47.35	1.91
19	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	<34 Low	36.31	1.47
20	<20 Low	0.35-0.65 Medium	3-5.5 Medium	>5.5 High	<1.3 Low	<34 Low	21.33	0.86
21	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	>53 High	24.89	1
22	<20 Low	0.35-0.65 Medium	>5.5 High	>5.5 High	>1.9 High	34-53 Medium	18.19	0.73
23	<20 Low	0.35-0.65 Medium	>5.5 High	>5.5 High	1.3-1.9 Medium	34-53 Medium	10.55	0.42

Table 6: *Results of the Integrated and the Queried Thematic Layers of Benthic Foraminifera (Suborder- Textulariina), Sediment Size Parameters, Optical Properties and Depth of Summer 2005 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	**DEPTH (m)**	**K_d (m^{-1})**	**C (m^{-1})**	**Mean Size**	**Sorting**	**Textulariina**	**Area (Sq. Km)**	**% of Area**
1	>40 High	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<3.3 Low	343.89	13.92
2	20-40 Medium	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<3.3 Low	357.32	14.47
3	<20 Low	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<3.3 Low	71.87	2.91
4	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	<3.3 Low	40.72	1.64
5	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<3.3 Low	46.84	1.89
6	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<3.3 Low	119.79	4.85
7	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	<1.3 Low	<3.3 Low	53.72	2.17
8	20-40 Medium	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	3.3-6.1 Medium	148.28	6
9	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<3.3 Low	99.26	4.02
10	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<3.3 Low	152.21	6.16
11	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<3.3 Low	44.83	1.81
12	<20 Low	0.35-0.65 Medium	>5.5 High	>5.5 High	>1.9 High	<3.3 Low	28.24	1.14
13	<20 Low	0.35-0.65 Medium	>5.5 High	>5.5 High	1.3-1.9 Medium	<3.3 Low	10.55	0.42
14	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	3.3-6.1 Medium	99.88	4.04
15	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	<3.3 Low	40.59	1.64
16	<20 Low	0.35-0.65 Medium	3-5.5 Medium	3.5-5.5 Medium	<1.3 Low	<3.3 Low	32.15	1.3
17	<20 Low	0.35-0.65 Medium	3-5.5 Medium	>5.5 High	<1.3 Low	<3.3 Low	21.32	0.86
18	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<3.3 Low	21.72	0.87
19	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	3.3-6.1 Medium	29.52	1.19

Table 7: *Results of the Integrated and the Queried Thematic Layers of Benthic Foraminifera (Suborder- Miliolina), Sediment Size Parameters, Optical Properties and Depth of Summer 2005 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	DEPTH (m)	Kd (m=1)	C (m=1)	Mean Size	Sorting	Miliolina	Area (Sq. Km)	% of Area
1	>40 High	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<7 Low	134.14	5.43
2	20-40 Medium	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<7 Low	507.42	20.55
3	<20 Low	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<7 Low	138.84	5.62
4	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	<7 Low	22.11	0.89
5	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<7 Low	149.11	6.03
6	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	<1.3 Low	<7 Low	54.23	2.19
7	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<7 Low	110.04	4.45
8	>40 High	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	<7 Low	73.08	2.96
9	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	<7 Low	226.85	9.18
10	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<7 Low	152.71	6.18
11	>40 High	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<7 Low	14.40	0.58
12	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<7 Low	31.23	1.26
13	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	7-13 Medium	65.05	2.63
14	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	>13 High	41.62	1.68
15	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	7-13 Medium	77.64	3.14
16	<20 Low	>0.65 High	> 5.5 High	>5.5 High	<1.3 Low	7-13 Medium	20.70	0.83
17	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	<1.3 Low	7-13 Medium	36.72	1.48
18	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<7 Low	37.21	1.50
19	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	7-13 Medium	77.34	3.13
20	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	7-13 Medium	26.56	1.07
21	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	7-13 Medium	28.37	1.14
22	>40 High	<0.35 Low	<3.0 Low	3.5-5.5 Medium	<1.3 Low	<7 Low	15.60	0.63
23	>40 High	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	<7 Low	23.51	0.95

Table 8: *Results of the Integrated and Queried Thematic Layers of Benthic Foraminifera (Suborder- Lagenina), Sediment Size Parameters, Optical Properties and Depth of Summer 2005 Depicting Area and % Area.*

Integrated Thematic Layers								
Sl No	DEPTH (m)	Kd (m-1)	C (m-1)	Mean Size	Sorting	Lagenina	Area (Sq.Km)	% of Area
1	>40 High	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	9-18 Medium	180.84	7.32
2	>40 High	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	>18 High	167.04	6.76
3	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	9-18 Medium	153.6	6.22
4	20-40 Medium	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	9-18 Medium	241.21	9.77
5	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	9-18 Medium	90.66	3.67
6	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	9-18 Medium	57.71	2.33
7	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	1.3-1.9 Medium	<9 Low	25.94	1.05
8	<20 Low	<0.35 Low	<3.0 Low	>5.5 High	>1.9 High	<9 Low	44.7	1.81
9	<20 Low	0.35-0.65 Low	>5.5 High	>5.5 High	>1.9 High	<9 Low	28.04	1.13
10	20-40 Medium	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	9-18 Medium	377.24	15.28
11	>40 High	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	>18 High	61.36	2.48
12	20-40 Medium	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	>18 High	31.13	1.26
13	<20 Low	<0.35 Low	<3.0 Low	3.5-5.5 Medium	1.3-1.9 Medium	9-18 Medium	29.19	1.18
14	<20 Low	0.35-0.65 Medium	3-5.5 Medium	<3.5 Low	<1.3 Low	<9 Low	127.1	5.14
15	<20 Low	<0.35 Low	<3.0 Low	<3.5 Low	<1.3 Low	<9 Low	116.5	4.71

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