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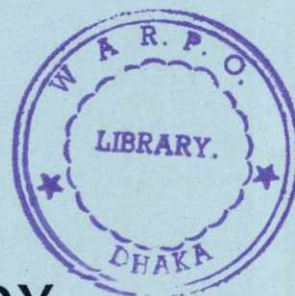
MINISTRY OF WATER RESOURCES

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MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-023

TIME SERIES ANALYSIS OF EROSION AND ACCRETION - ADDENDUM

August 1998

DHV CONSULTANTS BV

in association with

KAMPSAX INTERNATIONAL
DANISH HYDRAULIC INSTITUTE

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MINISTRY OF WATER RESOURCES
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MEGHNA ESTUARY STUDY



TECHNICAL NOTE MES-023

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Technical Note on:

TIME SERIES ANALYSIS OF EROSION AND ACCRETION - ADDENDUM

Dhaka , June 1998

Project Name : Meghna Estuary Study (MES)
Location : Meghna Estuary
Key words : LANDSAT, georeferencing,
Land cover classification
Coast contours, accretion, erosion

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TIME SERIES ANALYSIS OF EROSION AND ACCRETION IN THE MEGHNA ESTUARY

June 1998 Addendum

1. Introduction

This is an addendum to the report produced in April, 1997 and documents the second phase of the study. The April, 1997 report provides the project background and objectives, description of the study area and a discussion of related studies in the Meghna Estuary. It documents the image processing techniques and presents information on the coastal area of Bangladesh with a focus on the changes for the period 1973 to 1996. This June, 1998 addendum presents new information on the coastal area for the period 1996 to 1998 and updates the net changes, earlier reported for the period 1973 to 1996, for the period 1973 to 1998.

2. Satellite Images and Pre-Processing

This 1998 study extended the six sets of four Landsat images, comprising the satellite image time series for the period 1973 to 1996, with another set of four Landsat images. As shown in Table 1 (revised), the two scenes in the western orbit (path 137) were acquired in early March, 1998. Due to excessive cloud cover in the eastern orbit (path 136) during the desired acquisition period of January through March, 1998, images of November, 1997 were purchased for this study. The November images were out of sequence somewhat with all the other scenes used in the study, and clouds were present in some portions of the scenes; however, these scenes were the best available option and the results are believed to be sound and consistent with other analyses in the time series. Because the November images were acquired during the same dry season (early), the acquisition and discussion usually refers to the acquisition as "1998", implying the dry season of 1997 and 1998. A composite of the four new images is shown in Appendix 2.

The areas of the November image most affected by cloud were supplemented with a synthetic aperture radar (SAR) image acquired under a separate project of the Environment and GIS Support for Water Sector Planning (EGIS), the Canadian Space Agency and Radarsat International. This project is developing applications for radar images, which are not significantly affected by clouds, using RADARSAT data acquired under the Advanced Data Research Opportunity (ADRO). One of the radar images, acquired on 23 September 1997, was used to outline the land-water boundaries for some areas which were obscured by clouds in the November Landsat images. A subset of the radar image is shown in Figure 7.

3. Tide Levels for Times of Image Acquisition

Tide levels in the Bay of Bengal for the 1998 image acquisition times were collected and interpreted similarly to those for the other images in the time series. Table 2 (revised) shows that tide levels for the newly acquired images were relatively low for the eastern orbit and, in the western orbit, ranged from low in the southern portion to high in the northern areas near Chandpur. Such tide levels were not unusual relative to the other dates in the time series. As described in the April 1997 report, the information presented in Table 2 (revised) was constructed from interpretation of all the tide levels provided in Appendix 2 and gives relative

tide levels for the entire area covered by the respective satellite image. Another presentation has been prepared by MES and is presented in Table 2a. This table gives relative tide levels, according to a quantitative system for each tide gauge station at the time of satellite overpass.

As shown in Table 3 (revised) the tide levels, along with image cloud cover, were considered for determining the order of overlay of the four images to construction the satellite image mosaic.

4. Land Cover Classification Maps

The 1998 land cover was classified using digital image processing techniques similar to the other images in the time series. The land cover map, shown in Appendix 3, is reported in Table 4 (revised) with the same land cover categories as for the other dates. The exception being that the total area of "stable land" was diminished, relative to the other dates in the time series. The reduced amount was on the order of 8,000 ha, due to erosion of areas categorized as "stable land" for the 1973-96 analysis, and comprised mostly of erosion of mainland and previously stable island areas, along the main river channel. Table 5 (revised) shows the land cover classes for each of the nine subregions, with additional detail shown in Appendix 5 (revised).

5. Results

The maps showing changes in land cover for the period 1996 to 1998, and for the entire study period 1973 to 1998, are shown in Appendix 4. Other periods of study, presented in the June 1997 report, include 1973-79, 1979-84, 1984-90, 1990-1993, 1993-96. Detailed statistics for land change, for each period in the time series and for each subregion, are shown in Appendix 6. The summary statistics of land cover changes for the entire study period 1973-98, shown in Table 6v (revised), match rather closely with those presented in the original Table 6 for the period 1973-96.

Table 7 (revised) shows annual rates for the categories of change. As noted in the April 1997 report, there is a great amount of water area changing to mud flat for most periods. The converse change, of mud flat to water, is substantially less than the area of water changing to mud. The exception to this is the 1984 to 1990 period. As well, the 1996 to 1998 period shows exception since the amount of water changing to and from mud flat is almost the same, and much of the mud flat to water change is occurring in the Char Buoy area as shown in Appendix 6, and observed in the map shown in Appendix 4. Although the tide levels for this area were relatively similar for both the 1996 and 1998 acquisition times (Table 2 Revised), it could be the result of slight differences in tide levels causing substantial changes in the exposed mud flat. Also the difference could be due to only slight inconsistencies in image interpretation for the highly turbid waters of the area.

The class changes are summarized in Table 8 (revised), where erosion, accretion and net change is shown for each period and for the entire period of study, 1973 to 1998. In this analysis, the mud flat category was taken as an intertidal feature and was considered to be most related to water. Thus, for an area to be considered accreted or eroded, it had to change either to or from the "land" category. Areas that went from mud flat to or from water were not considered either eroded or accreted. This interpretation is considered more representative of the processes observed and, because the mud flat category was interpreted similarly to the water category, the effect of tide levels on the erosion and accretion mapping was minimized. The net change by period actually shows land loss up to 1984, with a period of gain during 1984 to 1990, followed by net land loss again during 1990 to 1993. There was a huge gain of land area during the 1993 to 1996. There was a net loss of land during the 1996 to 1998 period of nearly

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18,000 ha, an amount representing about half of the net accretion for the 1973 through 1996 through 1996 period. The overall land gain shown for the period of study, 1973 to 1998, remains positive, but has been reduced by half due to the net loss during the past two years. The average annual gain for the entire study period is 796 ha/year. Also notable and discussed above, with the exception of one period, there was more water changed to mud than the reverse of mud changing to water.

The changes for the total period of study, 1973 to 1998, show new land areas off the Noakhali coast and Char Bouy which is associated with an even larger area of mud flat which appears to be emerging land. There are new char areas and new areas of mud flat northwest of Sandwip Island. Other large areas of accretion include the very large char in the Lower Meghna Channels, which appears to be consolidation and extension of Char Gazaria, the extensive accreted area north of the Tetulia offtake and the filling and enlargement of the chars in the extreme southwest of the study area, including Char Rangabali, Char Montaz and Char Kukrimukri. The 1996 to 1998 erosion trend continues to be associated with widening of the main Lower Meghna and with the Shahbazpur and Hatia Channels. The north and east banks of Hatia and Bhola Islands were affected during the 1996 to 1998 period, as was the west bank of the Meghna River, just south of Chandpur. As mentioned above in Section 4, and evident in the Table 6 (revised), a substantial portion of the lands lost were due to bank erosion during 1996 to 1998 of areas previously called "stable land" in the 1973-96 analysis. The area, computed by difference in the "stable land" areas for 1996 and 1998, is a total of 7,442 ha for the period or over 3,000 ha per year.

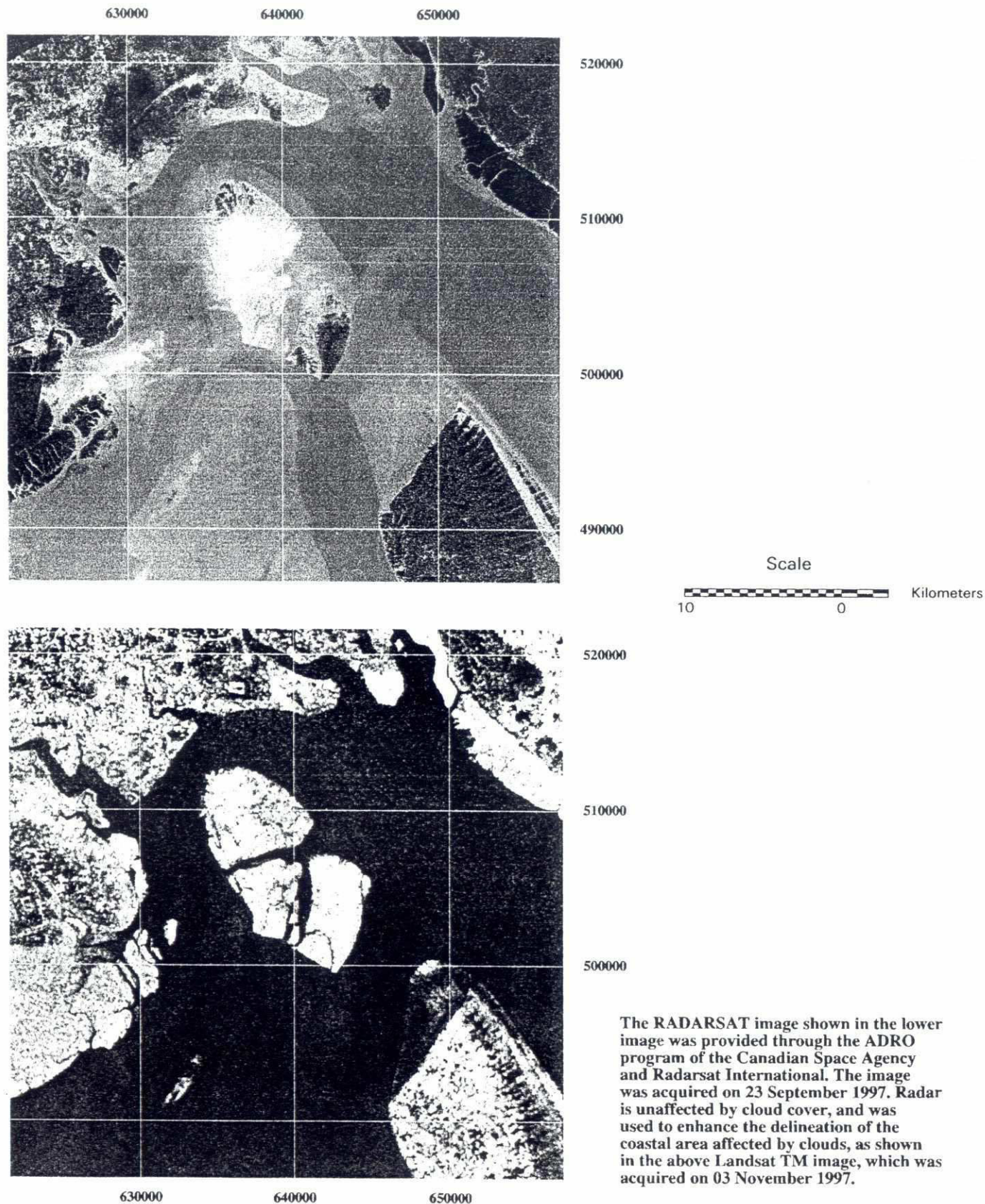


Figure 7: RADARSAT Image Used for Updated Cloud-Affected Portions of the 1998 Satellite Image

Table 1 (Revised): Characteristics of Landsat Digital Satellite Imagery

| Year | Frame | Date | Sensor | Source/Format ^{1/} | Cloud (% study area) | Other |
|------|-------|--------|--------|-----------------------------|----------------------------|------------------|
| 1973 | NW | 02 Feb | MSS | EDC/X-format | 0 | non linear warp |
| | SW | 02 Feb | MSS | EDC/X-format | 0 | non linear warp |
| 1974 | NE | 27 Jan | MSS | EDC/X-format | 0 | non linear warp |
| | SE | 09 Jan | MSS | EDC/X-format | <1 | |
| 1979 | NW | 02 Jan | MSS | EDC/EDIPS | 0 | |
| | SW | 02 Jan | MSS | EDC/EDIPS | 0 | noise |
| | NE | 24 Feb | MSS | EDC/EDIPS | 0 | noise |
| | SE | 24 Feb | MSS | EDC/EDIPS | 0 | noise |
| 1984 | NW | 19 Mar | MSS | ERIM | 0 | noise, band 4 |
| | SW | 19 Mar | MSS | ERIM | <1 | noise, band 4 |
| | NE | 25 Feb | MSS | ERIM | 0 | contrast stretch |
| | SE | 25 Feb | MSS | ERIM | 0 | contrast stretch |
| 1990 | NW | 24 Feb | TM | TRSC | 0 | |
| | SW | 24 Feb | TM | TRSC | 3 | |
| | NE | 05 Mar | TM | TRSC | 0 | |
| | SE | 05 Mar | TM | TRSC | 0 | |
| 1993 | NW | 15 Jan | TM | TRSC | 0 | |
| | SW | 15 Jan | TM | TRSC | 0 | |
| | NE | 09 Feb | TM | TRSC | 0 | |
| | SE | 09 Feb | TM | TRSC | 0 | |
| 1996 | NW | 09 Feb | TM | TRSC | 0 | |
| | SW | 09 Feb | TM | TRSC | 0 | |
| | NE | 18 Feb | TM | TRSC | 0 | |
| | SE | 18 Feb | TM | TRSC | 0 | |
| 1997 | NE | 03 Nov | TM | TRSC | 10 | |
| | SE | 03 Nov | TM | TRSC | 5 | |
| 1998 | NW | 02 Mar | TM | TRSC | 0 | |
| | SW | 02 Mar | TM | TRSC | 0 | |

^{1/} Format is BSQ or BIL unless noted



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Table 2 (Revised): Summary of Relative Tide Levels on Image Acquisition Dates^{1/}

| Year | Date | Eastern Orbit | | Western Orbit | | |
|---------|--------|----------------------|--------------------------|-------------------------|-----------------------|--------------------------------|
| | | Little Feni Noakhali | Sandwip Hatia Chittagong | Chandpur to North Bhola | Bhola North to Middle | South Bhola and Chars to South |
| 1973-74 | 02 Feb | | | No Data | No Data | No Data |
| | 27 Jan | low-mid (2) | low (2-1) | | | |
| | 09 Jan | low-mid (2) | low (1-2) | | | |
| 1979 | 02 Jan | | | high (5-4) | mid (3) | low (2-1) |
| | 24 Feb | mid (2) | mid (3) | | | |
| 1984 | 19 Mar | | | mid (4) | mid-low (3-2) | low (1) |
| | 25 Mar | mid-high (4) | high (4-5) | | | |
| 1990 | 24 Feb | | | mid (3) | low (2-1) | mid (2-4) |
| | 05 Mar | high (4-5) | high-mid (5-3) | | | |
| 1993 | 15 Jan | | | high (4-5) | high-mid (2-3) | mid (3-2) |
| | 09 Feb | low (2) | low (2-1) | | | |
| 1996 | 09 Feb | | | high (5-4) | mid (3-2) | low (1) |
| | 18 Feb | low (1) | low-mid (2) | | | |
| 1997 | 03 Nov | low (2) | low (1) | | | |
| 1998 | 02 Mar | | | high (4) | mid (3) | low (2) |

^{1/} The qualitative description and index of tide levels is a summary interpretation of tide tables provided in Appendix 1. The index range represents relative tide levels (1 to 5 corresponds to low to high) from the north to the south portion of the satellite image frame.

Table 2a: Relative Tide Levels for Gauge Stations on Satellite Image Acquisition Dates¹

| Year | Date Frame | Western orbit (137 path) | | | | | Eastern orbit (136 path) | | | | |
|------|--------------------------------|--------------------------|-------------------|-----------------|-------------------------|--------------------|------------------------------|-------------------------|--------------------|--|--|
| | | Chandpur | Char Ramdaspur | Khepu- para | Char Chenga | Sandwip | Chittagong Khal No. 10 | Chittagong Sadarghat | Cox's Bazar | | |
| 1973 | 02 Feb/ NW-SW | No Data | No Data | No Data | No Data | - | - | - | - | | |
| 1974 | 09 Jan/ SE 27 Jan/ NE | - - | - - | - - | No Data No Data | No Data No Data | No Data No Data | Low (19%) Low (08%) | No Data No Data | | |
| 1979 | 02 Jan/ NW-SW 24 Feb/ NE-SE | No Data - | No Data - | No Data - | No Data No Data | - Med (53%) | No Data | - Med (60%) | - High (90%) | | |
| 1984 | 25 Feb/ NE-SE 19 Mar/ NW-SW | - High (74%) | - Med (49%) | - Low (20%) | Med (51%) Low (04%) | High (83%) - | High (76%) - | High (84%) - | Low (21%) - | | |
| 1990 | 24 Feb/ NW-SW 05 Mar/ NE-SE | Med (63%) - | Med (62%) - | High (72%) - | Low (25%) High (88%) | - High (72%) | Med (52%) | High (73%) | Low (08%) | | |
| 1993 | 15 Jan/ NW-SW 09 Feb/ NE-SE | Low (26%) - | High (93%) - | Low (15%) - | Med (64%) Low (08%) | - Low (09%) | - Low (11%) | - Low (03%) | - Med (54%) | | |
| 1996 | 09 Feb/ NW-SW 18 Feb/ NE-SE | High (89%) - | Med (66%) - | Low (16%) - | Low (25%) Low (28%) | - Med (47%) | - Low (31%) | - Low (33%) | - High (92%) | | |
| 1997 | 03 Nov/ NE-SE | - | - | - | Low (05%) | Low (07%) | Low (14%) | Low (03%) | Med (52%) | | |
| 1998 | 02 Mar/ NW-SW | High (90%) | Med (61%) | Low (20%) | Low (21%) | - | - | - | - | | |

¹ The tidal inundation around gauge station is classified into 3 different categories: low, medium and high. The categories were defined quantitatively as follows:
a) Low: time difference between satellite pass time (09:50 hrs BST) and low water is between 0 to 33% of time difference between low water and high water.
b) Medium: difference between satellite pass time and low water is between 34% to 66% of time difference between low water and high water.
c) High: difference between satellite pass time and low water is between 67% to 100% of time difference between low water and high water.

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Table 3 (Revised): Priority for Constructing Digital Satellite Image Mosaic

| Year | Priority | | |
|---------|----------|--------|-------|
| | First | Second | Third |
| 1973-74 | NE | SE | West |
| 1979 | East | West | |
| 1984 | West | East | |
| 1990 | NE | SE, NW | SW |
| 1993 | NW | SW | East |
| 1996 | NE | SW, SE | NW |
| 1998 | SW | NW, SE | NE |

Table 4 (Revised): Land Cover Classes for the Study Area by Date

| Land Cover Category | Area (ha) | | | | | | |
|---------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| | 1973-74 | 1979 | 1984 | 1990 | 1993 | 1996 | 1998 |
| Water | 877,657 | 868,891 | 863,669 | 878,554 | 851,991 | 774,753 | 784,524 |
| Intertidal / Mud | 63,402 | 113,111 | 126,480 | 74,702 | 112,698 | 128,531 | 136,678 |
| Dense Vegetation | 32,288 | 15,598 | 37,544 | 38,138 | 44,819 | 84,654 | 50,534 |
| Upland Bare Soil | 91,911 | 69,025 | 37,099 | 74,433 | 57,088 | 76,814 | 99,443 |
| Dry Soil / Beach | 2,352 | 986 | 2,819 | 1,776 | 1,005 | 2,852 | 3,876 |
| Stable Land | <u>537,402</u> | <u>537,402</u> | <u>537,402</u> | <u>537,399</u> | <u>537,403</u> | <u>537,402</u> | <u>529,956</u> |
| Total | 1,605,012 | 1,605,012 | 1,605,012 | 1,605,002 | 1,605,003 | 1,605,006 | 1,605,010 |

Table 5 (Revised): Land Cover Classes by Subregion by Date ^{1/} (area in ha)

| | Chandpur Reach | Barisal Reach | Middle Estuary | Bhola- Hatia | Char Buoy | Upper Tetulia | Lower Tetulia | Chitta- gong | Sandwip Island | Class Totals |
|-----------------------|-------------------|------------------|-------------------|-----------------|--------------|------------------|------------------|-----------------|-------------------|-----------------|
| 1973-74 | | | | | | | | | | |
| Water | 30717 | 20448 | 29569 | 332697 | 195631 | 15915 | 125892 | 95322 | 31465 | 877657 |
| Intertidal / Mud | 8018 | 4883 | 8083 | 7993 | 22228 | 6324 | 2208 | 2848 | 818 | 63402 |
| Dense Vegetation | 2650 | 1521 | 1963 | 15988 | 3178 | 724 | 3782 | 1764 | 716 | 32288 |
| Upland Bare Soil | 14347 | 12935 | 10221 | 9631 | 14314 | 6876 | 15640 | 2247 | 5700 | 91911 |
| Very Dry Soil/ Beach | 613 | 99 | 114 | 609 | 413 | 1 | 38 | 203 | 261 | 2352 |
| 1979 | | | | | | | | | | |
| Water | 31698 | 24724 | 31830 | 326924 | 196662 | 18836 | 109060 | 95926 | 33232 | 868891 |
| Intertidal / Mud | 8231 | 4072 | 8336 | 30576 | 26322 | 5701 | 24330 | 4743 | 802 | 113111 |
| Dense Vegetation | 7130 | 1669 | 2454 | 769 | 1109 | 721 | 865 | 108 | 772 | 15598 |
| Upland Bare Soil | 9246 | 9410 | 7327 | 8426 | 11622 | 4582 | 12909 | 1451 | 4052 | 69025 |
| Very Dry Soil/ Beach | 41 | 10 | 4 | 224 | 50 | 1 | 396 | 156 | 102 | 986 |
| 1984 | | | | | | | | | | |
| Water | 31572 | 26108 | 34052 | 326261 | 186484 | 17169 | 112314 | 94913 | 34797 | 863669 |
| Intertidal / Mud | 5993 | 4806 | 8241 | 29376 | 34113 | 9675 | 28915 | 4128 | 1233 | 126480 |
| Dense Vegetation | 9478 | 2964 | 3721 | 7197 | 5126 | 1881 | 3992 | 2714 | 471 | 37544 |
| Upland Bare Soil | 9254 | 6005 | 3936 | 3728 | 8493 | 1117 | 2024 | 445 | 2097 | 37099 |
| Very Dry Soil/ Beach | 48 | 3 | 0 | 357 | 1549 | 0 | 315 | 184 | 363 | 2819 |
| 1990 | | | | | | | | | | |
| Water | 30315 | 25375 | 34938 | 331790 | 191862 | 16224 | 115087 | 96248 | 36713 | 878554 |
| Intertidal / Mud | 7387 | 5478 | 5240 | 18027 | 23426 | 4902 | 5542 | 4151 | 548 | 74702 |
| Dense Vegetation | 3460 | 2208 | 837 | 11985 | 3701 | 3210 | 10782 | 1835 | 122 | 38138 |
| Upland Bare Soil | 14135 | 6776 | 8935 | 4820 | 16763 | 5503 | 15836 | 109 | 1556 | 74433 |
| Very Dry Soil/ Beach | 1049 | 49 | 0 | 296 | 6 | 0 | 315 | 39 | 22 | 1776 |
| 1993 | | | | | | | | | | |
| Water | 31946 | 27629 | 38989 | 323620 | 177917 | 18310 | 105238 | 94052 | 34290 | 851991 |
| Intertidal / Mud | 7441 | 4353 | 2590 | 26579 | 31772 | 4992 | 26453 | 4398 | 4120 | 112698 |
| Dense Vegetation | 4735 | 1799 | 987 | 12464 | 12465 | 920 | 8171 | 3274 | 4 | 44819 |
| Upland Bare Soil | 12091 | 6079 | 7383 | 3917 | 13542 | 5617 | 7362 | 589 | 507 | 57088 |
| Very Dry Soil/ Beach | 132 | 27 | 2 | 338 | 68 | 0 | 329 | 69 | 39 | 1005 |
| 1996 | | | | | | | | | | |
| Water | 30408 | 25900 | 36923 | 307624 | 133548 | 16760 | 103562 | 91928 | 28098 | 774753 |
| Intertidal / Mud | 6810 | 8065 | 4479 | 25276 | 58821 | 4237 | 7965 | 4909 | 7969 | 128531 |
| Dense Vegetation | 8068 | 4224 | 1534 | 22658 | 24927 | 4067 | 13437 | 4433 | 1305 | 84654 |
| Upland Bare Soil | 10392 | 1608 | 6999 | 11031 | 17318 | 4775 | 22296 | 1053 | 1343 | 76814 |
| Very Dry Soil/ Beach | 666 | 89 | 16 | 329 | 1147 | 0 | 299 | 61 | 245 | 2852 |
| 1998 | | | | | | | | | | |
| Water | 29828 | 25852 | 37570 | 303165 | 144524 | 16034 | 103539 | 93467 | 30545 | 784524 |
| Intertidal / Mud | 4312 | 4312 | 6053 | 38298 | 51389 | 6737 | 16060 | 3834 | 5683 | 136678 |
| Dense Vegetation | 3927 | 2061 | 786 | 15535 | 11147 | 964 | 12906 | 3174 | 34 | 50534 |
| Upland Bare Soil | 18937 | 8831 | 6524 | 10356 | 28300 | 6434 | 15612 | 1722 | 2727 | 99443 |
| Very Dry Soil / Beach | 522 | 108 | 390 | 519 | 1157 | 252 | 355 | 262 | 311 | 3876 |

^{1/}Details including "stable land" statistics, category percentages and totals are provided in Appendix 2

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Table 6 (Revised): Change Classes for Study Area by Period (area in ha)

| Change Classes | | 1973 to 1979 | 1979 to 1984 | 1984 to 1990 | 1990 to 1993 | 1993 to 1996 | 1996 to 1998 | 1973 to 1998 |
|----------------|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| New Class | Old Class | | | | | | | |
| Water | Water | 801,901 50% | 813,442 51% | 819,995 51% | 825,403 51% | 754,625 47% | 736,653 46% | 690,550 43% |
| Water | Mud flat | 31,295 2% | 29,077 2% | 35,365 2% | 14,054 1% | 12,888 1% | 34,757 2% | 24,800 2% |
| Mud flat | Water | 65,302 4% | 48,830 3% | 29,252 2% | 48,667 3% | 84,454 5% | 35,048 2% | 101,142 6% |
| Mud flat | Mud flat | 22,713 1% | 59,967 4% | 35,256 2% | 35,929 2% | 34,161 2% | 75,859 5% | 16,743 1% |
| Land | Land | 65,760 4% | 46,776 3% | 44,073 3% | 73,711 5% | 85,757 5% | 132,846 8% | 45,990 3% |
| Water | Land | 35,695 2% | 21,150 1% | 23,190 1% | 12,534 1% | 7,236 0% | 13,114 1% | 69,173 4% |
| Mud flat | Land | 25,096 2% | 17,682 1% | 10,193 1% | 28,102 2% | 9,916 1% | 25,771 2% | 18,794 1% |
| Land | Water | 10,454 1% | 6,619 0% | 14,419 1% | 4,476 0% | 12,912 1% | 3,109 0% | 86,010 5% |
| Land | Mud flat | 9,395 1% | 24,067 1% | 55,855 3% | 24,719 2% | 65,649 4% | 17,896 1% | 21,853 1% |
| Stable Land | Stable Land | 537,402 33% | 537,402 33% | 537,403 33% | 537,403 33% | 537,403 33% | 529,956 33% | 529,956 33% |
| Total | | 1,605,013 | 1,605,012 | 1,605,001 | 1,604,998 | 1,605,001 | 1,605,008 | 1,605,010 |

Table 7 (Revised): Annual Rates of Change for Study Area by Period (area in ha)

| Change Classes | | 1973 to 1979 | 1979 to 1984 | 1984 to 1990 | 1990 to 1993 | 1993 to 1996 | 1996 to 1998 | 1973 to 1998 |
|----------------|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| New Class | Old Class | | | | | | | |
| Water | Mud flat | 5,216 | 5,815 | 5,894 | 4,685 | 4,296 | 17,379 | 992 |
| Mud flat | Water | 10,884 | 9,766 | 4,875 | 16,222 | 28,151 | 17,524 | 4,046 |
| Water | Land | 5,949 | 4,230 | 3,865 | 4,178 | 2,412 | 6,557 | 2,767 |
| Mud flat | Land | 4,183 | 3,536 | 1,699 | 9,367 | 3,305 | 12,886 | 752 |
| Land | Water | 1,742 | 1,324 | 2,403 | 1,492 | 4,304 | 1,555 | 3,440 |
| Land | Mud flat | 1,566 | 4,813 | 9,309 | 8,240 | 21,883 | 8,948 | 874 |

Table 8 (Revised): Summary of Erosion and Accretion for Study Area^{1/} (area in ha)

| Land Cover Change | 1973 to 1979 | 1979 to 1984 | 1984 to 1990 | 1990 to 1993 | 1993 to 1996 | 1996 to 1998 | 1973 to 1998 |
|---------------------------------------|-------------------|--------------------|----------------------------|---------------------------|--------------------------|--------------------------|--------------------------|
| Erosion for Period (ha) | (60,791) | (38,832) | (33,389) | (40,636) | (17,152) | (38,885) | (87,967) |
| Accretion for Period (ha) | 19,849 | 30,686 | 70,272 | 29,195 | 78,561 | 21,005 | 107,863 |
| Net Change for Period (ha) | (40,942) | (8,146) | 37,313 | (11,441) | 61,409 | (17,880) | 19,896 |
| Annual rate of change (ha/yr) | (6,823) | (1,629) | 6,219 | (3,814) | 20,470 | (8,940) | 796 |
| Net change, water to/from mud (ha) | 34,007 | 19,753 | (6,113) | 34,613 | 71,566 | 291 | 76,342 |
| Annual rate of change (ha/yr) | 5,668 | 3,951 | (1,019) | 11,538 | 23,855 | 146 | 3,054 |
| General Tide Levels | low/mid to mid | mid to mid/high | mid/high to mid/high | mid/high to low/mid | low/mid to low/mid | low/mid to low/mid | low/mid to low/mid |

^{1/} Erosion is shown in ().

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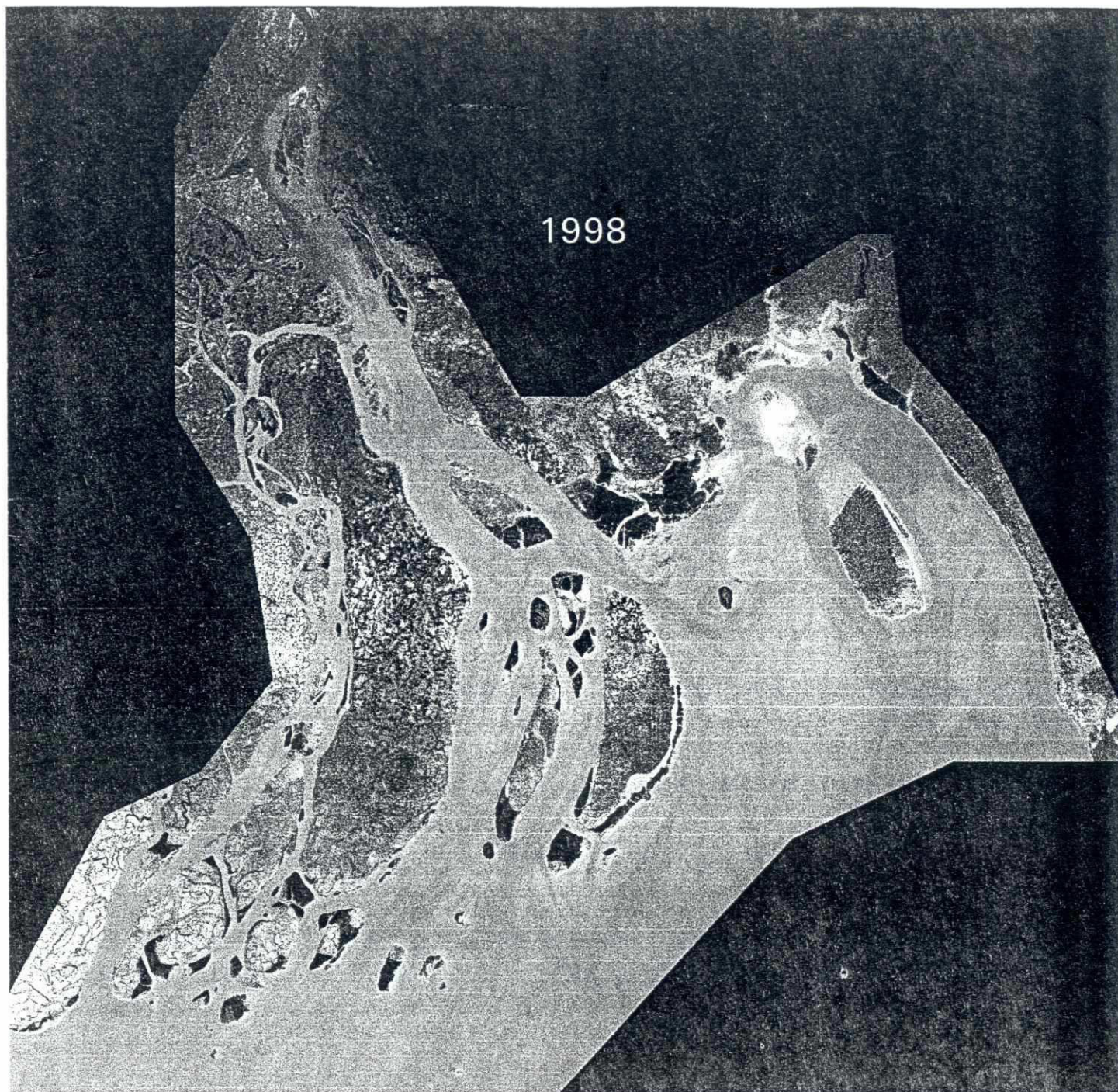
Appendix 1 (Revised): High and Low Water Levels by Station on Days of Landsat Overpasses
Used in this Study (in meters above CD).

| Date | Chandpur | | Char Ramdaspur | | Khepu-para | | Char Chenga (Hatia) | | Sandwip | | Khal No.10 Chittagong | | Sadarghat Chittagong | | Cox's Bazar | |
|------------|--------------|--------------|----------------|--------------|---------------|--------------|---------------------|--------------|---------------|--------------|-----------------------|--------------|----------------------|--------------|---------------|--------------|
| | WL | Time | WL | Time | WL | Time | WL | Time | WL | Time | WL | Time | WL | Time | WL | Time |
| 02 Feb '73 | | | | | | | | | | | | | | | | |
| 09 Jan '74 | | | | | | | | | | | | | 0.09 3.45 | 0828 0337 | | |
| 27 Jan '74 | | | | | | | | | | | | | 3.41 0.21 | 0311 1001 | | |
| 02 Jan '79 | | | | | | | | | 5.50 -0.20 | 0348 1105 | | | 3.90 0.10 | 0327 1033 | 0.15 2.810 | 0653 1309 |
| 24 Feb '79 | | | | | | | | | 0.50 4.20 | 0646 1204 | | | 0.30 3.10 | 0610 1142 | 2.60 0.30 | 0852 1455 |
| 25 Feb '84 | 1.61 1.02 | 0133 0941 | 0.50 1.30 | 0657 1133 | 1.71 0.63 | 0437 1124 | 0.96 1.67 | 0346 1000 | 3.20 1.20 | 0826 1443 | 2.51 0.96 | 0758 1418 | 2.20 0.50 | 0829 1440 | 0.93 0.00 | 0430 1048 |
| 19 Mar '84 | 2.38 1.20 | 0724 1537 | 2.80 0.10 | 0509 1341 | -0.23 2.62 | 0722 1258 | 3.27 -0.32 | 0258 0946 | -0.50 5.50 | 0959 1505 | 0.22 4.09 | 0835 1418 | 0.00 3.80 | 0929 1454 | -0.95 2.62 | 0639 1139 |
| 24 Feb '90 | 1.51 0.58 | 0637 1423 | 2.50 0.50 | 0356 1205 | 0.62 2.52 | 0527 1104 | 0.28 2.60 | 0802 1356 | 0.66 5.12 | 0805 1319 | 0.54 3.84 | 0651 1235 | 0.54 3.53 | 0739 1305 | 0.16 2.86 | 0442 1004 |
| 05 Mar '90 | 0.74 1.01 | 0823 1328 | 0.74 1.54 | 0615 1040 | 2.12 1.05 | 0407 1101 | 1.81 1.11 | 0849 1418 | 3.96 1.28 | 0746 1359 | 2.76 1.38 | 0651 1315 | 2.60 0.85 | 0747 1403 | 1.96 0.87 | 0352 0958 |
| 15 Jan '93 | 0.58 1.23 | 0721 1145 | 2.18 0.38 | 0857 1708 | 2.71 0.78 | 0351 1031 | 2.48 0.61 | 0715 1329 | 4.97 0.63 | 0611 1310 | 3.72 0.41 | 0534 1214 | 3.11 0.41 | 0609 1257 | 0.63 2.60 | 0932 1552 |
| 09 Feb '93 | 1.69 0.55 | 0803 1605 | 2.96 0.18 | 0523 1357 | 0.34 3.26 | 0739 1249 | 3.30 -0.22 | 0310 1001 | 6.23 -0.18 | 0248 1012 | 0.17 4.18 | 0858 1438 | 4.21 0.12 | 0237 0944 | 0.03 3.30 | 0650 1149 |
| 15 Jan '96 | 0.52 1.08 | 0908 1315 | 0.77 1.84 | 0618 1036 | 2.05 0.69 | 0422 1202 | 2.17 0.18 | 0908 1507 | 4.47 1.09 | 0803 1435 | 3.22 0.60 | 0709 1350 | 2.90 0.56 | 0755 1440 | 2.23 0.77 | 0431 1045 |
| 24 Jan '96 | 1.58 0.47 | 0848 1711 | 2.78 0.23 | 0609 1457 | -0.02 2.66 | 0831 1403 | 3.13 -0.04 | 0425 1101 | 5.76 0.10 | 0353 1106 | 4.32 0.10 | 0309 0954 | 3.89 0.29 | 0345 1043 | 0.29 2.97 | 0746 1301 |
| 09 Feb '96 | 1.51 0.50 | 0909 1712 | 2.48 0.41 | 0641 1502 | 0.29 2.66 | 0838 1409 | 2.81 0.26 | 0429 1109 | 5.58 0.37 | 0400 1110 | 0.26 3.93 | 0956 1536 | 3.68 0.27 | 0347 1043 | 0.12 2.92 | 0723 1302 |
| 18 Feb '96 | 1.51 0.51 | 0615 1409 | 2.63 0.28 | 0333 1203 | 0.25 2.60 | 0539 1053 | 0.05 2.72 | 0757 1331 | 0.25 5.30 | 0807 1314 | 0.40 3.87 | 0650 1236 | 0.25 3.60 | 0743 1311 | 0.16 3.02 | 0451 0953 |
| 03 Nov '97 | 2.91 1.98 | 0727 1557 | 3.15 1.05 | 0447 1349 | 0.71 3.16 | 0723 1242 | 3.52 0.64 | 0312 0950 | 5.73 0.96 | 0254 1001 | 0.70 4.18 | 0842 1417 | 0.85 3.81 | 0939 1505 | 0.78 3.10 | 0649 1200 |
| 02 Mar '98 | 1.75 0.62 | 0842 1657 | 2.88 0.21 | 0602 1450 | 0.14 2.97 | 0823 1350 | 3.16 -0.05 | 0409 1055 | 6.11 -0.23 | 0345 1104 | 4.28 0.26 | 0302 0946 | 4.05 0.15 | 0338 1033 | -0.02 3.25 | 0721 1251 |

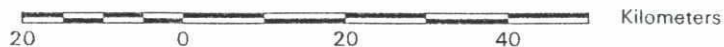


Appendix 2 (1998 Addition)
Satellite Image Mosaic Series

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Scale



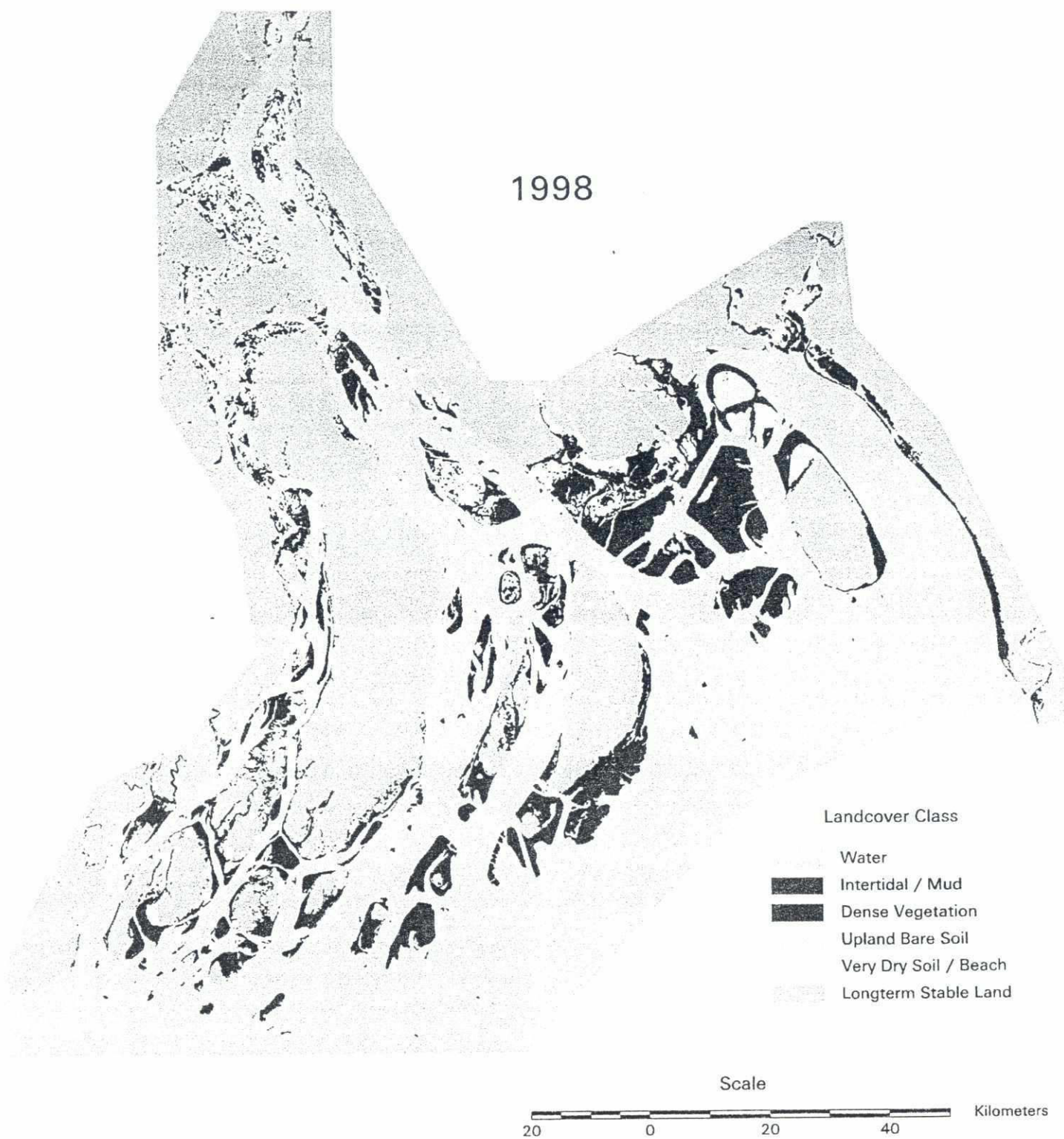
Satellite Image Mosaic

This series shows a mosaic of four digital Landsat satellite images which have been computer classified into six classes. Images were purchased by the Meghna Estuary Study with some provided by the EGIS Project. Maps printed at EGIS, Dhaka, June 1998.

m

Appendix 3 (1998 Addition)
Land Cover Classification Series





Land Cover Classification

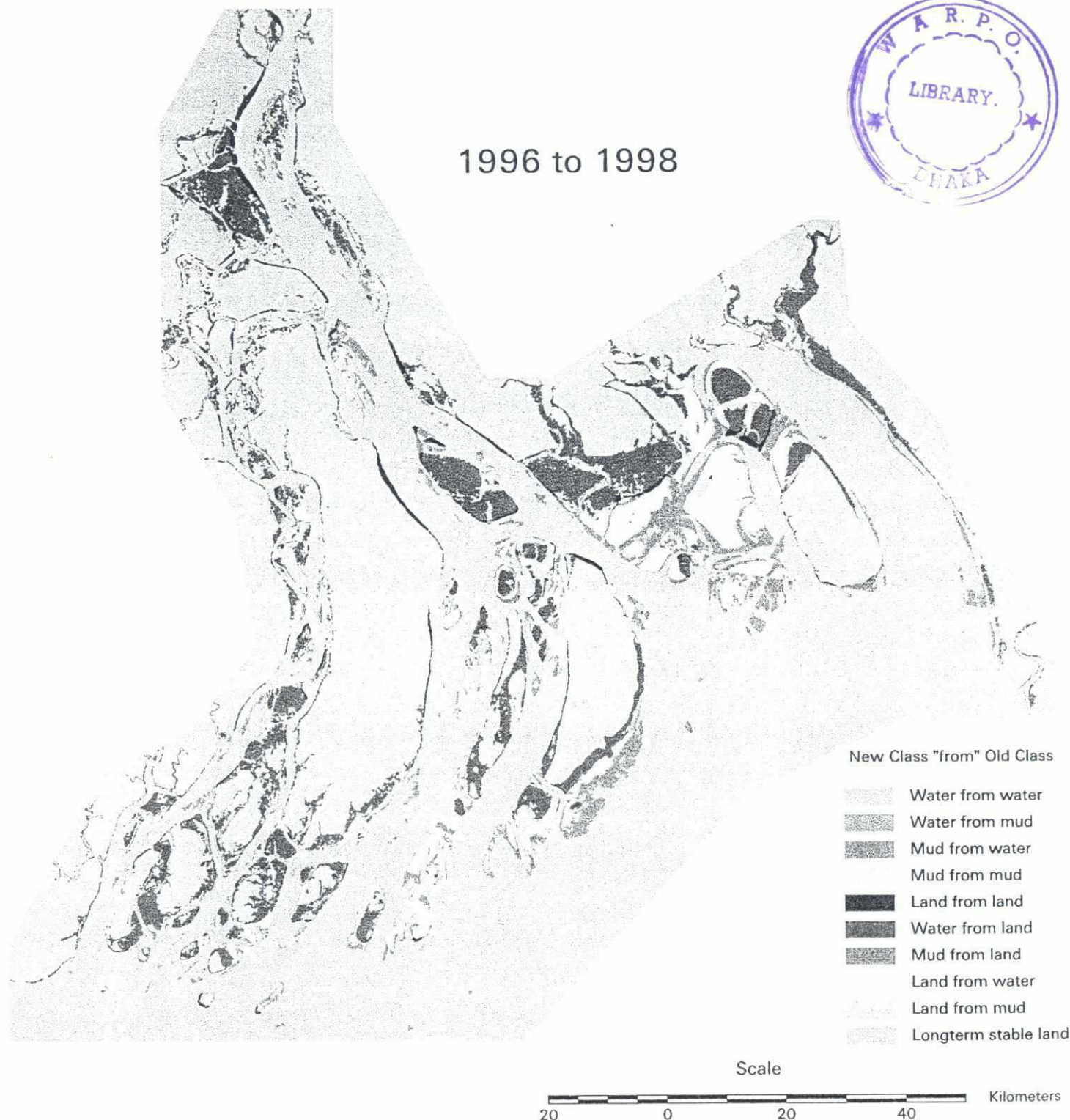
This series shows a mosaic of four digital Landsat satellite images which have been computer classified into six classes. Images were purchased by the Meghna Estuary Study with some provided by the EGIS Project. Maps printed at EGIS, Dhaka, June 1998.

Appendix 4 (1996 to 1998 and 1973-74 to 1998 Additions)

Change Map Series



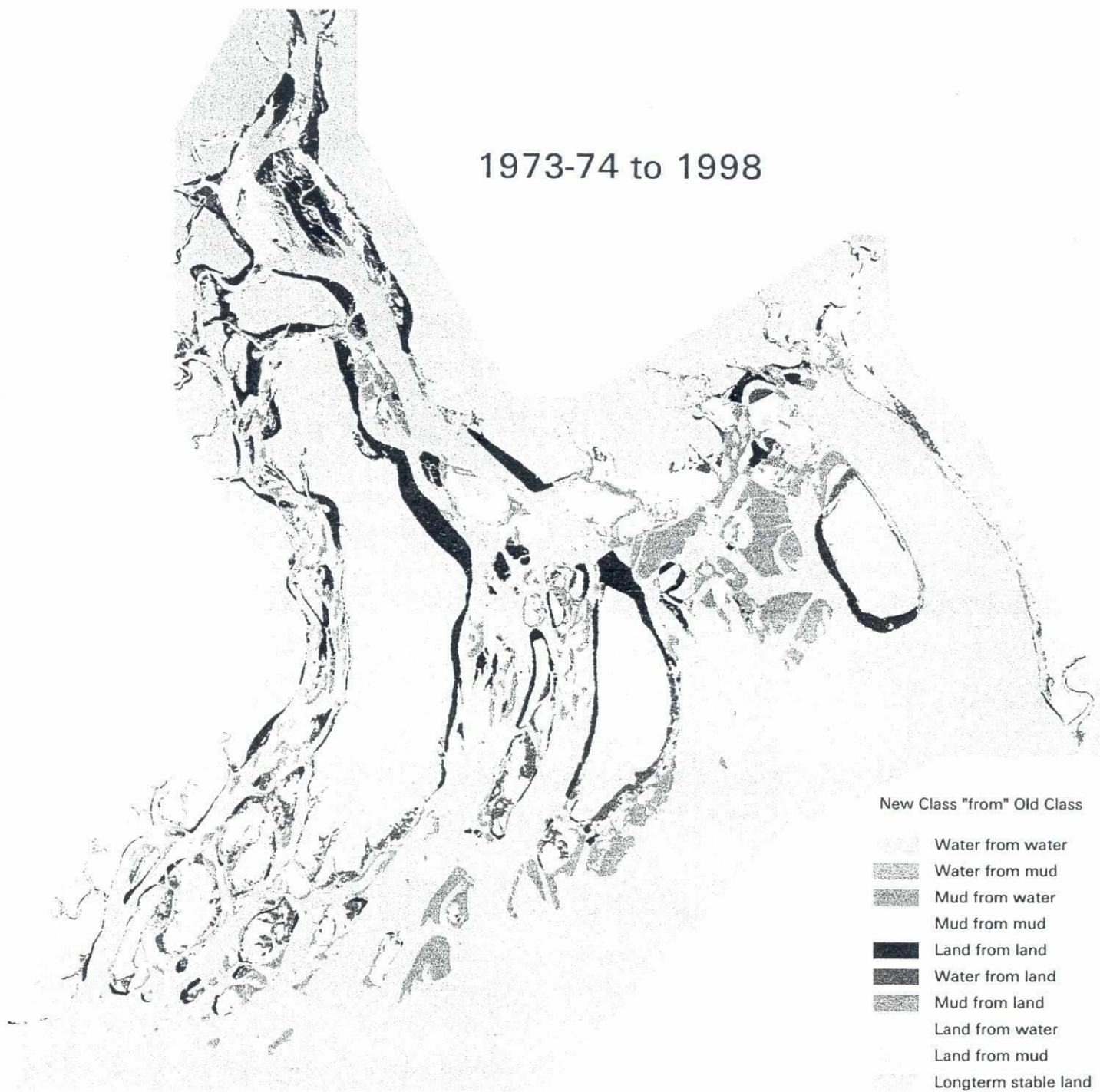
1996 to 1998



Change Map

This series shows changes in land cover determined by comparison of two mosaics, each comprised of four digital Landsat satellite images. Images were purchased by the Meghna Estuary Study with some provided by the EGIS Project. Maps printed at EGIS, Dhaka, June 1998.

1973-74 to 1998



New Class "from" Old Class

- Water from water
- Water from mud
- Mud from water
- Mud from mud
- Land from land
- Water from land
- Mud from land
- Land from water
- Land from mud
- Longterm stable land

Scale



Change Map

This series shows changes in land cover determined by comparison of two mosaics, each comprised of four digital Landsat satellite images. Images were purchased by the Meghna Estuary Study with some provided by the EGIS Project. Maps printed at EGIS, Dhaka, June 1998.

Appendix 5 (1998 Addition)

Land Cover Categories by Subregion by Date

1998 Land Cover Categories by Subregion^{1/}

| | Chandpur Reach | Barisal Reach | Middle Estuary | Bhola- Hatia | Char Buoy | Upper Tetulia | Lower Tetulia | Chitta- gong | Sandwip Island | Class Totals |
|-----------------------|-------------------|------------------|-------------------|-----------------|---------------|------------------|------------------|-----------------|-------------------|-----------------|
| Water | 29828 25% | 25852 31% | 37570 42% | 303165 67% | 144524 45% | 16034 17% | 103539 41% | 93467 67% | 30545 52% | 784524 49% |
| Intertidal / Mud | 4312 4% | 4312 5% | 6053 7% | 38298 9% | 51389 16% | 6737 7% | 16060 6% | 3834 3% | 5683 10% | 136678 9% |
| Dense Vegetation | 3927 3% | 2061 2% | 786 1% | 15535 3% | 11147 3% | 964 1% | 12906 5% | 3174 2% | 34 0% | 50534 3% |
| Upland Bare Soil | 18937 16% | 8831 10% | 6524 7% | 10356 2% | 28300 9% | 6434 7% | 15612 6% | 1722 1% | 2727 5% | 99443 6% |
| Very Dry Soil / Beach | 522 0% | 108 0% | 390 0% | 519 0% | 1157 0% | 252 0% | 355 0% | 262 0% | 311 1% | 3876 0% |
| Stable Land | 60810 51% | 43449 51% | 37767 42% | 82304 18% | 83596 26% | 63570 68% | 101813 41% | 37197 27% | 19450 33% | 529956 33% |
| Area Totals | 118337 7% | 84613 5% | 89091 6% | 450176 28% | 320112 20% | 93990 6% | 250286 16% | 139655 9% | 58751 4% | 1605010 100% |

^{1/}Area in ha; total percentages sum with totals, other percentages sum in columns

Appendix 6 (1996 to 1998 and 1973-74 to 1998 Additions)

Land Cover Changes by Subregion by Date

Land Cover Changes 1996 to 1998^{1/}

| 1998 Class | 1996 Class | Chandpur Reach | Barisal Reach | Middle Estuary | Bhola- Hatia | Char Buoy | Upper Tetulia | Lower Tetulia | Chitta- gong | Sandwip Island | Class Totals |
|---------------|---------------|-------------------|------------------|-------------------|-----------------|---------------|------------------|------------------|-----------------|-------------------|-----------------|
| Water | Water | 26242 22% | 23254 27% | 34142 38% | 294592 65% | 125372 39% | 14852 16% | 99430 40% | 91309 65% | 27459 47% | 736653 46% |
| Water | Mud | 717 1% | 1061 1% | 1327 1% | 6711 1% | 17063 5% | 409 0% | 2431 1% | 2084 1% | 2951 5% | 34757 2% |
| Mud | Water | 2587 2% | 2036 2% | 2726 3% | 13001 3% | 8223 3% | 1441 2% | 3874 2% | 521 0% | 639 1% | 35048 2% |
| Mud | Mud | 726 1% | 1495 2% | 2463 3% | 18227 4% | 38388 12% | 2499 3% | 5191 2% | 2526 2% | 4343 7% | 75859 5% |
| Land | Land | 16441 14% | 4884 6% | 6958 8% | 26041 6% | 37221 12% | 5854 6% | 28273 11% | 4762 3% | 2411 4% | 132846 8% |
| Water | Land | 2869 2% | 1536 2% | 2100 2% | 1861 0% | 2092 1% | 771 1% | 1676 1% | 74 0% | 134 0% | 13114 1% |
| Mud | Land | 998 1% | 781 1% | 864 1% | 7070 2% | 4778 1% | 2797 3% | 6995 3% | 787 1% | 701 1% | 25771 2% |
| Land | Water | 1579 1% | 610 1% | 55 0% | 31 0% | 10 0% | 468 0% | 258 0% | 98 0% | 0 0% | 3109 0% |
| Land | Mud | 5366 5% | 5506 7% | 688 1% | 338 0% | 3369 1% | 1328 1% | 342 0% | 297 0% | 661 1% | 17896 1% |
| Stable Land | Stable Land | 60810 51% | 43449 51% | 37767 42% | 82304 18% | 83596 26% | 63570 68% | 101813 41% | 37197 27% | 19450 33% | 529956 33% |
| Area Totals | | 118337 7% | 84613 5% | 89091 6% | 450176 28% | 320114 20% | 93988 6% | 250283 16% | 139655 9% | 58751 4% | 1605008 100% |

^{1/}Area in ha, total percentages sum with totals, other percentages sum in columns

Land Cover Changes 1973 to 1998^{1/}

| 1998 Class | 1973 Class | Chandpur Reach | Barisal Reach | Middle Estuary | Bhola- Hatia | Char Buoy | Upper Tetulia | Lower Tetulia | Chittagong | Sandwip Island | Class Totals |
|---------------|---------------|-------------------|------------------|-------------------|-----------------|---------------|------------------|------------------|--------------|-------------------|-----------------|
| Water | Water | 14055 12% | 13570 16% | 21893 25% | 288038 64% | 128743 40% | 8775 9% | 96665 39% | 92829 66% | 25982 44% | 690550 43% |
| Water | Mud | 4482 4% | 2209 3% | 3752 4% | 3650 1% | 7140 2% | 2093 2% | 938 0% | 254 0% | 284 0% | 24800 2% |
| Mud | Water | 1808 2% | 1799 2% | 3425 4% | 32510 7% | 38006 12% | 4255 5% | 13931 6% | 1385 1% | 4023 7% | 101142 6% |
| Mud | Mud | 567 0% | 743 1% | 1687 2% | 2233 0% | 7982 2% | 1637 2% | 309 0% | 1152 1% | 432 1% | 16743 1% |
| Land | Land | 5565 5% | 3993 5% | 805 1% | 12151 3% | 4568 1% | 2170 2% | 12616 5% | 2607 2% | 1514 3% | 45990 3% |
| Water | Land | 11291 10% | 10072 12% | 11925 13% | 11477 3% | 8641 3% | 5167 5% | 5937 2% | 384 0% | 4280 7% | 69173 4% |
| Mud | Land | 1936 2% | 1769 2% | 942 1% | 3555 1% | 5401 2% | 845 1% | 1820 1% | 1297 1% | 1229 2% | 18794 1% |
| Land | Water | 14852 13% | 5079 6% | 4252 5% | 12149 3% | 28931 9% | 2885 3% | 15296 6% | 1107 1% | 1459 2% | 86010 5% |
| Land | Mud | 2969 3% | 1928 2% | 2644 3% | 2110 0% | 7104 2% | 2594 3% | 962 0% | 1443 1% | 100 0% | 21853 1% |
| Stable Land | Stable Land | 60810 51% | 43449 51% | 37767 42% | 82304 18% | 83596 26% | 63570 68% | 101813 41% | 37197 27% | 19450 33% | 529956 33% |
| Area Totals | | 118337 7% | 84613 5% | 89091 6% | 450176 28% | 320112 20% | 93990 6% | 250286 16% | 139655 9% | 58751 4% | 1605010 100% |

^{1/}Area in ha; total percentages sum with totals, other percentages sum in columns

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